Causey Dam, Utah
1,000-Year Rainfall-Runoff Report

Dam Safety Office

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Contents

Page

Background

A research proposal to develop the 1,000-year thunderstorm (local) hydrograph for Causey Dam was submitted and approved by Dam Safety for fiscal year 2002. The study purpose was to use rainfall-runoff modeling procedures to compute both peak discharge and volume amounts. These results were then compared with previous frequency peak estimates at Causey Dam that used peak streamflow discharge estimates and paleoflood information from the Ogden River drainage basin. The study used the National Weather Service (NWS) draft precipitation values for the southwest region that include the 1,000-year return period. Rainfall-runoff modeling was done using these precipitation values to develop the 1,000-year thunderstorm hydrograph for Causey Dam. The thunderstorm event was chosen to eliminate snowfall as a variable in the computation.

A further note is warranted as to the selection of Causey Dam as the study site. The Southwest Region is the only location where draft NWS precipitation values, including methods to develop values out to the 1,000-year return period, have been developed. Causey Dam is one of the few unregulated locations in this region that has frequency data comprised of both paleoflood and streamgage information available to make a comparison.

The current Flood Frequency Analysis done for the CFR process use streamflow and paleoflood data to estimate peak discharges of flood events out to the 10,000-year return period. Site specific streamflow data is usually used to define the frequency estimate out to 100-years. Regional streamflow data is used to estimate the envelope curve values, assumed to span a return period of 100-500 years. Paleoflood data provides a peak estimate range with a return period range that generally occurs somewhere between the interval of 1,000-10,000-years. The median peak discharge estimate is extrapolated to a 10,000-year return period. However, this method provides only peak discharge estimates. No estimate of volume or hydrograph to route through the structure is developed.

The 1,000-year hydrograph, developed using rainfall-runoff modeling, can be routed through the dam to determine structural response. In addition, this hydrograph can be used as the basis to develop hydrographs of return periods in the 5,000-10,000-year range.

Structural Information and Basin Description

Causey Dam is located on the South Fork Ogden River, approximately 10 miles upstream (East) from Huntsville, Utah. The dam was completed in 1966 and is one of three Reclamation storage reservoirs of the Weber Basin Project. The other two are Pineview Dam, located on the Ogden River just downstream from Huntsville, and Deer Creek Dam on the Provo River, approximately 11 miles upstream from the city of Provo.

The drainage area above Causey Dam is 81 mi^2 and varies in elevation from 5,700 feet at the dam to over 9,000 feet at the northern edge of the basin. The lower portion of the basin is vegetated by sage brush, grass and scrub oak with the upper portion being more densely covered with scrub oak, aspen and scattered conifers. The channel itself supports a dense growth of cottonwoods and willows.

Causey Dam is an earthfill dam with an uncontrolled concrete overflow spillway. The following is a summary of the dam and reservoir properties:

Top of Dam El.	5704 feet
Spillway Crest El.	5692 feet
Design W. S. El.	5698.1 feet
Structural Height	218 feet
Spillway Capacity	7,570 ft^3/s at El. 5698.1
Total Reservoir Capacity	7,870 acre-feet at El. 5698.1

Previous Studies

The most recent transmittal of the probable maximum flood (PMF) for Causey Dam (USBR, 1988) provided peak and volume information for a May rain-on-snow PMF and thunderstorm PMF. The previous 1983 thunderstorm PMF included a 100-year antecedent rainfall event. Current methodology no longer uses an antecedent event in the determination of a thunderstorm PMF. Removal of the antecedent event had no effect on the peak discharge and slightly reduced the total thunderstorm PMF volume. The 1988 thunderstorm PMF for Causey Dam has a peak discharge of 93,100 ft^3/s and a 1-day volume of 24,500 acre-feet.

A paleoflood study was done for Causey and Pineview Dams (Ostenaa et al., 1997) to provide flood frequency information at larger return periods. The frequency curve from that study is the basis of comparison to the results of this study.

A hydrologic loading report was done for Pineview and Causey Dams (England/Ostenaa, 1998) for use in the risk assessment process. The frequency curve for Causey Dam was taken directly from the paleoflood study.

The following sections summarize pertinent data from the previous studies.

Streamgage Data

The 1997 paleoflood study compiled peak flow data at three USGS gages in the Ogden River basin. The closest gage to Causey Dam is on the South Fork Ogden River near Huntsville, Utah

(No. 10137500). This is approximately 5 miles downstream from the dam and has a drainage area of 137 mi^2. The period of record is from 1921-present, with flows having been regulated by Causey Dam since 1966 and perhaps to some extent for the four years prior to 1966 during construction. The largest annual peak discharge measured at the gage was 1,890 ft^3/s, which occurred May 3, 1952.

Envelope Curve

An envelope curve composed of 147 stations in the Wasatch Range was compiled for the paleoflood report and is included in Appendix A. The paleoflood report presented values in metric units. Values from the paleoflood report are given here in both metric and English units. An envelope curve plots historical peak flow values against drainage area size for stream gages within the region to give an estimate of the maximum discharge potential expected in a region. No probability is given to the envelope curve, although the expected return period would be greater than the average length of record of the gage stations used to develop the curve. The regional data were plotted with an error range of ± 25% to account for potential uncertainty in the peak discharge estimates. The envelope curve value corresponding to the Causey Dam drainage size of 81.0 mi^2 (210 km^2) is approximately 6,700 ft^3/s (190 m^3/s). The majority of the record peaks occurred during the May-June snowmelt runoff period.

Paleoflood Results

The South Fork Ogden River downstream from Causey Dam is a narrow valley with several late Quaternary geomorphic surfaces. The surfaces were from two ranges in age- from a few hundred years (latest Holocene) and from 15,000 to more than 100,000 years (mid- to late Pleistocene). Two sites and one reach located approximately 4 miles downstream from the dam were studied, and samples were taken for radiocarbon dating. Two samples taken from the lower part of the B horizon at South Fork Camp Ground were dated from 2780-2500 years B.P. (before present) and 2340-2010 years B.P. A sample taken in the Bw horizon at Hobble Camp Ground was dated from 1630-1980 years B.P. These ages provided a minimum estimate for the last overtopping. Soil contains organic components from different ages which receive continual new input of carbon that becomes mixed throughout the profile. Thus, the radiocarbon data ranges are for the minimum age estimates. Six samples in the Holocene surfaces were dated at the Botts Campground Site, resulting in an age of about 400 years B.P. These were used to estimate the date of the last partial overtopping of the lower Holocene surfaces.

Aerial photographs taken after the May 3, 1952 peak discharge of 1,890 ft^3/s show small areas of fresh erosion and signs of deposition on the lowest parts of the Holocene surfaces. This provides a minimum limit for the discharge required to inundate larger areas of the Holocene surfaces.

A step backwater model was used to estimate the discharges required to overtop various locations of the Holocene formation. The discharge estimates along with the radio carbon dating resulted in the selection of two paleoflood ranges. The lower Holocene bound (Holocene 1 on the frequency curve, Appendix A) has an estimated discharge of 2,500 ft^3/s with a range of 2,100-3,000 ft^3/s at an age estimate of 400 years B.P. The main areas of the Holocene surfaces (Holocene 2) has an estimated discharge of 4,100 ft^3/s with a range of 3,200-4,400 ft^3/s) at an age estimate of about 2,500 years B.P.

Flood Frequency Analysis

The flood frequency curve in the paleoflood study was developed using Bayesian methods and maximum likelihood techniques to combine the streamflow data and paleoflood estimates. The resulting curve is included in Appendix A and provided this range of estimates:

Table 1
Causey Dam, Utah
1,000-Year Flood Frequency Estimates
(Directly from 1997 Paleoflood Study, Ostenaa et al.)

	Peak Discharge (m^3/s)	Peak Discharge (ft^3/s)
97.5 Percentile	112	3,960
Best Estimate	71	2,500
2.5 Percentile	54	1,900

Rainfall-Runoff Procedure

The following paragraphs describe the method and input data used to develop the 1,000-yr local flood hydrograph.

Precipitation

NOAA Atlas 2 is being revised for the southwestern region of the United States and is expected to be published in Fiscal Year 2003 as NOAA Atlas 14, Volume 1. Precipitation values to determine point rainfall will be provided for return periods extending to 1,000 years. NOAA Atlas 2 was published in 1973 and provides data for return periods only out to 100-years with a method provided to extend the values to 500-years.

The Causey Dam basin is located in Division 6 on the NWS Semiarid Divisional Map. If precipitation values were to be developed using the existing NOAA Atlas 2, values would be interpolated from isopluvial lines (lines marking equal total precipitation) on existing state maps. These maps have not been developed yet for NOAA Atlas 14, Volume 1, so data had to be interpolated for Causey Dam using available data from stations in the vicinity. Data from 12 surrounding stations were gathered to compare station characteristics to the Causey Dam location. The characteristics that were analyzed were elevation, years of record, the 100-year, 24 hour precipitation value from NOAA Atlas 2, basin topography and the site location region. After careful analysis of the surrounding stations, it was decided that Hardware Ranch was the best representative of Causey Dam. Hardware Ranch is located in the same NWS Semiarid Region (Region 6) as Causey Dam, the 100-year, 24 hour precipitation value was very similar to what would be computed for the Causey Dam site and the basin topography and layout were almost identical. However, the Hardware Ranch draft values were not used directly in this study. The values computed from NOAA Atlas 2 for Causey Dam (using the isopluvials) and the published Hardware Ranch values were compared and found to be slightly different, so the NOAA 14 draft values used for this study were adjusted to reflect the same difference. The adjustment to the draft Hardware Ranch revised precipitation frequency value was done using the ratio of the 100-year, 24 hour precipitation frequency value from NOAA Atlas 2 for Causey Dam (3.4 inches) over Hardware Ranch (3.2 inches). The ratio was computed to be 1.06, meaning the Causey Dam estimates were 6 per cent greater than the Hardware Ranch data. The draft point precipitation for Hardware Ranch from NOAA Atlas 14 was multiplied by this ratio to determine the final values for Causey Dam.

The annual maximum series, which is used to calculate the point precipitation frequency for the southwest region, was missing the 1- and 6-hour values for Hardware Ranch. A curve fitting program was used to calculate these values at Hardware Ranch from several of the surrounding station data, including Echo, Evanston, Logan Woodruff, Ogden and Huntsville.

The last step to calculate the 1,000-year rainfall value was to use the depth-area ratios found in NOAA Technical Memorandum NWS Hydro-40 (NWS,1984) to obtain aerially reduced basin average 1,000-year precipitation values. Geographically fixed depth-area ratios are estimated for the southwestern part of the country. While the study relies on a methodology for computing depth-area ratios from a dense network of data, modifications of the approach were necessary to extend the results to data sparse regions. Available data indicate that reductions of point rainfall in the semi-arid southwest are greater than the previously published nationwide average depth-area curves from NOAA Atlas 2. Figure 14 from Technical Memorandum 40 best represented the Causey dam basin in topography and moisture flow patterns. The area reduction factors were taken from this chart and applied to the 1- and 6-hour computed rainfall values. The 1- and 6-hour values were 2.28 inches and 3.33 inches, respectively. The area reduction factors reduced the values to 51 percent of the 1-hour value and 62 percent of the 6-hour value. The resulting aerial reduced values are given in the following table:

Table 2
Causey Dam, Utah
1,000-Year Precipitation
DRAFT NOAA Atlas 14, Volume 1

Duration	Total Rainfall (inches)
1-hour	1.16
6-hour	2.07

The values derived from this draft NOAA Atlas 14 are both 1,000-year return period values. Using this method, the 1,000-year rainfall event will result in all time durations (1-hr, 2-hr, 3-hr, etc.) having a 1,000-year return period. Choosing all durational precipitation values from the same event will accumulate to result in an event that has a less frequent return period (NOAA, 1981). The NWS developed a technique (NOAA, 1981) that allows the time distribution to vary such that one time duration is fixed at the desired return period, 1,000-years in this case, and the other durations are reduced to achieve a more natural storm distribution. The rational for this reduction is that as a storm sequence increases in duration, it is less likely that all precipitation values will be from the same event.

To apply this method, the 6-hour value of 2.07 inches was selected as the independent (fixed) value. Selecting the 6-hr value as the independent value will serve to preserve the volume of the rainfall. The 1-hr, 2-hr and 3-hr precipitation values were computed from the 6-hr amount by applying the ratios found on the 6-hr Great Basin chart (NOAA, 1981). The Great Basin Region applies to areas of Utah located west of the Wasatch Range divide. The ratios were selected from the chart representing the highest intensity storms (Quartile 1), which is consistent with a rare storm such as the 1,000-year event. Finally, the choice of ratios can vary depending on the assumed accumulated probability that the dependent value (1-, 2-, and 3-hr cumulative precipitation) will be of the same frequency as the independent value (6-hr cumulative precipitation). A higher accumulated probability would result in the derived durations (1-hr, 2-hr and 3-hr values) closely approaching the 1,000-yr values. Since the purpose of this study was to develop an annual exceedance probability neutral storm, an accumulated probability of fifty percent was chosen.

The following table summarizes the ratios used for this study and the resulting cumulative dependent precipitation values:

Table 3
Causey Dam, Utah
Durational Precipitation Values Derived from NOAA Technical Report NWS 27

Duration	Ratio (short duration/long duration)	Cumulative precipitation (inches)
1-hr	.48	0.99
2-hr	.705	1.46
3-hr	.84	1.74
6-hr	Independent	2.07

A curve fitting program was used to determine the 15-minute incremental time step values used in the hydrologic model. The precipitation distribution used for this study places the maximum precipitation value at the initial time step, with successively smaller values following. This distribution is thought to best represent a thunderstorm event.

Soil Characteristics and Constant Infiltration Rates

Soil characteristics for the basin were determined using the Utah General Soil Map (SCS, 1973). The Causey Dam basin consists of Lithic Haploxerolls-Typic Haploxerolls Association soils. The soils tend to be cobbly silt loams and coarse sandy loams. The soils are well to excessively drained, with moderate to moderately rapid permeability.

The former Soil Conservation Service, now the Natural Resource Conservation Service, developed a category system that groups soils into one of four soils groups relative to their ultimate infiltration rates. The Causey Dam basin soils belong in the Group B soils category. The ultimate infiltration rate for this group varies from 0.15 to 0.3 inches per hour (Cudworth, 1989). Previous studies for Causey Dam have used an ultimate infiltration rate of 0.3 inches per hour, which is the value selected for this study.

Antecedent Moisture and Initial Infiltration Rates

To derive the local storm PMF no antecedent event is included in the hydrograph for areas of the country west of the 103rd Meridian (Cudworth, 1989). However, an assumption is made that a sufficiently large event has happened prior to the PMF event so that all initial infiltration losses have been met. This study is for a lesser event where it is reasonable to assume that a previous storm event has occurred and satisfied some of the initial infiltration losses. However, there can be a large range in the magnitude of the antecedent event. It is possible that very little rainfall has occurred prior to the 1,000-yr event computed in this study, resulting in dry conditions and very little antecedent soil moisture. Under this scenario, a large initial infiltration abstraction, as high as 0.8 inches, could be applied to make up for this moisture deficit. The opposite scenario would occur if significant rainfall events have occurred in the days prior to the study storm. The soil could be fully saturated, resulting in no initial infiltration abstraction.

A range of initial infiltration rates was used in this study to correspond with a range of reasonable antecedent moisture conditions. The low end of the range was selected as 0.4 inches of initial moisture deficit and assumes there has been antecedent storms to satisfy a moderate portion of the initial moisture. The upper value selected was 0.7 inches of initial loss, corresponding to a drier antecedent condition.

Basin Characteristics

Basin characteristics were modified from the 1982 and 1983 PMF studies to apply to the 1,000-year event and are summarized here.

The constant infiltration loss rate used was 0.3 inches per hour. This is a moderate infiltration rate applicable to fairly well draining soils and is applied after the initial loss has been satisfied.

The dimensionless unit graph used to compute the runoff hydrograph for the most recent thunderstorm PMF (USBR, 1988) was developed for Buckhorn Creek near Masonville, Colorado. This unitgraph is for a small basin located east of the Front Range near Loveland, Colorado. Previous studies (USBR, 1982) had used the Uinta unitgraph, developed for a basin in the Uinta Mountains near Neola, Utah. The Uinta basin is a mountainous basin with a mature growth of shrub and coniferous trees, similar to the Causey Dam basin. This study used the Uinta unitgraph because it better represents the study area. The Uinta graph has a smaller peak ordinate than the Buckhorn graph (24 versus 28.33) which results in a slightly smaller peak discharge.

The lag time was determined using the equation:

$$Lag = C * (\frac{L * Lca}{\sqrt{s}})^{0.33}$$

Where:

L = Length of the longest watercourse, in miles, from the reservoir to the boundary of the drainage area.

Lca = Length along the longest watercourse from the point of collection (the reservoir in this case) to a point opposite the centroid of the basin, in miles.

s = Overall slope in feet/mile of the longest watercourse.

C = Coefficient representing the hydrologic efficiency of the basin during severe flooding. The value is a function of numerous drainage basin parameters which include slope, ground cover, soil type, and geology.

The first four characteristics were determined for three subbasins within Causey Dam basin, Wheat Grass, Left Fork South Fork and Right Fork South Fork. The basin outline for Causey Dam, showing these subbasins, is included in Appendix A. The subbasin parameters are also given in Appendix A. The combined area weighted basin factor was 1.81.

The *C* value used for the thunderstorm event modeled in this study was 2.8. Therefore, the lag time was determined to be:

$$\begin{aligned} Lag &= 2.8 * (1.81)^{0.33} \\ &= 3.41 \text{ hours} \end{aligned}$$

A unit duration of 15 minutes was used to provide adequate definition of the peak of the flood hydrograph. The FORTRAN computer program FHAR was used to perform the hydrograph computations.

1,000-Year Rainfall-Runoff Results

The 1,000-year thunderstorm peak discharge and volume results are summarized in the following table. The FHAR computer outputs, showing the storm distribution, loss rates and hydrographs, are included in Appendix B.

Table 4
Causey Dam, Utah
1,000-Year Thunderstorm Rainfall-Runoff Results

Initial Loss Rate (inches)	Peak Discharge (ft^3/s)	Volume (acre-feet)	Peak Discharge (m^3/s)
0.4	6,930	2,500	196
0.5	6,130	2,200	174
0.6	5,300	1,880	150
0.7	4,480	1,590	127

The flood frequency estimates from the 1997 paleoflood study vary from 1,900-3,960 ft^3/s with a best estimate of 2,500 ft^3/s for the 1,000-year peak discharge estimate. The envelope curve value from the 1997 paleoflood for a drainage area corresponding to Causey Dam's 81 mi^2 is approximately 6,710 ft^3/s. Both the flood frequency curve and the envelope curve are included in Appendix A.

Conclusions

The 1,000-year local rainfall-runoff peak discharges, using draft NWS precipitation values, are 1.8-2.8 times larger than the best estimate developed from the frequency curve. The range depends on the antecedent moisture condition assumptions. The peak discharge estimates are less than the envelope curve for all but the most conservative initial loss assumption.

At this time, no general conclusion can be drawn regarding the disparity between the peak discharge estimates obtained from the paleoflood study and the rainfall-runoff model. This study provided results for one location using one model approach. The peak and volume of the hydrograph determined by rainfall-runoff modeling are highly influenced by the model parameters used. These include the dimensionless unit graph, the initial and constant infiltration rates, and the spacial and temporal distribution of the rainfall. If either infiltration rate is increased, the peak and volume will decrease. Changing the rainfall distribution will also affect the peak and volume. Therefore, it is possible to match the paleoflood peak discharge estimate by varying the basin parameters until a match is achieved. However, the model parameters are physical characteristics of the basin and will vary only slightly with changes in rainfall intensity for any specific basin. The best way to establish the range of values appropriate for an individual basin would be to calibrate the model using actual rainfall and runoff values measured in the basin, for a range of storms. This level of effort was beyond the staff days budgeted for this study but would be appropriate for a higher level study. Finally, this approach will have to be applied to other basins, as more precipitation data is published by the NWS, before trends on paleoflood peaks and model peaks can be determined.

Recommendations

The precipitation values used in this study were draft values provided by the NWS prior to the completion and publication of NOAA Atlas 14. A comparison of the final precipitation values with those used in this study should be made upon publication of NOAA Atlas 14, anticipated in 2003.

For Causey Dam, the 1,000-year thunderstorm peak discharge from rainfall-runoff modeling resulted in higher peak discharges than the paleoflood peak estimate. However, this may not be true for other basins. This modeling technique should be applied to other basins upon future availability of NWS precipitation values. Peak discharge values should be compared with available frequency and paleoflood data for the basin.

In addition, a higher level model study could be done, with the model parameters calibrated to actual historic rainfall-runoff events within the basin. Also, other methods to develop a neutral temporal and spacial rainfall distributions should be investigated.

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References

Cudworth, A.G.; Flood Hydrology Manual; Bureau of Reclamation, Denver, CO; 1989

Davidson, Paul J.; Probable Maximum Flood for Causey Dam; Bureau of Reclamation, Upper Colorado Regional Office; August 15, 1988

England, John F. Jr. and Ostenaa, Dean A.; Pineview and Causey Dams Hydrologic Loadings for Risk Analysis; Bureau of Reclamation, Denver Technical Center; December 1998

National Weather Service; NOAA Atlas 2 - Precipitation-Frequency Atlas of the Western United States, Volume VI - Utah; 1973

National Weather Service; NOAA Atlas 14 - Precipitation-Frequency Atlas for the Semiarid Southwestern United States, Volume I; (work in progress)

National Weather Service; Interduration Precipitation Relations for Storms – Western United States NOAA Technical Report NWS 27; September 1981

National Weather Service; NOAA Technical Memorandum NWS Hydro-40, Depth-Area Ratios in the Semi-Arid Southwest United States; August 1984

Ostenaa, D., Levish, D., O'Connell, D., Cohen, E.; Paleoflood Study for Causey and Pineview Dams, Weber Basin and Ogden River Projects, Utah; Bureau of Reclamation, Denver Technical Service Center; Seismotectonic Report 96-6; April 1997

Soil Conservation Service; Utah General Soil Map; September 1973

USBR; Inflow Design Flood for Causey Dam, Weber Basin Project, Utah, Memorandum from Randall Peterson Upper Colorado Regional Office to Chief Water Resources Branch; November 24, 1982

USBR; Probable Maximum Flood Study for Causey Dam, Weber Basin Project, Utah, Memorandum from Chief Division of Planning Technical Services to Regional Director Upper Colorado Region; January 20, 1983

USBR; Probable Maximum Flood Study for Causey Dam, Weber Basin Project, Utah, Memorandum from Chief Earth Sciences Division Technical Services to Regional Director Upper Colorado Region; October 25, 1988

Mission Statement

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.