Assessment of Flood Control Capabilities for Alternative Reservoir Storage Allocations

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Abstract

Multiple-purpose reservoir system operations are based on the conflicting objections of maximizing storage contents to assure high water supply reliability and maximizing empty storage space to mitigate flood risk. Reallocation of storage capacity between conservation and flood control purposes provides a strategy for optimizing limited available storage capacity in response to growing demands and changing objectives. A modeling and analysis methodology is presented in the article for assessing alternative reservoir storage allocations. Flood control capabilities are evaluated in terms of the probabilities of overtopping the storage capacities of the reservoirs in the system. Water supply capabilities are quantified in terms of reliability metrics. Flood control analysis capabilities are implemented in a modeling system originally created for detailed assessments of water supply capabilities. The methodology is applied to a system of eight multiple-purpose reservoirs in the Dallas and Fort Worth metropolitan area in the Trinity River Basin of Texas in the United States. The generalized modeling system and analysis methods are applicable to reservoir systems located anywhere including systems that may be very complex.

Key words: *storage reallocation, reservoir system modeling, flood frequency analysis, water supply reliability*

1. Introduction

Dams and appurtenant structures are required to control highly fluctuating river flows to reduce downstream flooding and develop reliable water supplies. Conservation purposes include agricultural, municipal, and industrial water supply, hydroelectric energy generation, recreation, and maintenance of environmental flows. Flood control and conservation purposes may be served by the same reservoir by designating separate operating pools defined by a top of conservation pool elevation that is the bottom of the flood control pool. Reservoir operations are based on maintaining conservation pools as full as feasible while supplying water demands and maintaining flood control pools as empty as feasible to mitigate flood risk. Storage reallocations are implemented by raising or lowering the designated top of conservation pool either permanently or as a function of season or other changing conditions.

Population and economic growth results in intensifying demands on limited stream flow and reservoir storage capacity. Construction of new reservoir projects is severely constrained

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by economic, financial, environmental, and institutional considerations. Reallocation of storage capacity and related modifications in the operations of existing reservoirs are growing in importance as a water management strategy.

The generalized Water Rights Analysis Package (WRAP) river/reservoir modeling system contributes significantly to water management in Texas and has also been applied in several other countries. WRAP has been extensively applied in Texas in regional and statewide planning studies and administration of a water right permit system that focus on water supply and other conservation storage purposes without consideration of flood control. Capabilities for modeling reservoir flood control operations were recently added to the modeling system.

A strategy for combining flood frequency analysis methods with WRAP capabilities for simulating reservoir operations is presented in this paper. The risks of exceeding flood control storage capacities and reliabilities of supplying water demands are assessed for alternative storage allocation plans. The modeling and analysis methodology is applied in a storage reallocation study for a system of eight multiple-purpose reservoirs operated by the U.S. Army Corps of Engineers (USACE) to control floods and supply water for the Dallas and Fort Worth metropolitan area.

Storage levels in the eight reservoirs depend upon the effects of numerous water users and other reservoirs on inflows to the eight reservoirs as well as multiple-purpose, multiple-reservoir operations of the eight-reservoir system. Flood storage frequency analyses are performed in the study reported here by applying the log-Pearson type III probability distribution to annual series of maximum reservoir storage contents in each year. Storage frequency analyses of peak annual storage volumes are performed for both historical observed storage levels and storage levels derived from the simulation model. The analysis of simulated storage levels overcome issues of non-stationarity and record length that are inherent in analysis of observed storage. Comparisons of observed and simulated storage provide insight on the validity of the simulation results. A key metric resulting from these analyses is the probability that the flood control storage capacity in each reservoir will be exceeded. Conventional WRAP reliability indices are employed to assess water supply capabilities provided by alternative storage allocations.

2. Reservoir System Operations

Many reservoirs are operated either for only flood control or for only conservation purposes. For reservoirs with both flood control and conservation storage, operations are based on the conflicting objectives of maximizing the amount of water available for conservation purposes and maximizing the amount of empty space available for storing future flood waters to reduce downstream damages.

Reservoirs contain one or more of the following four vertical zones called pools: inactive, conservation, flood control, and surcharge (Wurbs, 1996, 2016). Operations are based on maintaining reservoir contents as close to the top of the conservation pool as feasible while supplying needs of water users. Water use demands are supplied by releases or withdrawals from conservation storage. Flood control operations are activated whenever high inflows result in storage levels rising above the top of the conservation pool.

Most flood control reservoirs in the United States with operating decisions implemented by opening and closing of outlet gates are operated by the U.S. Army Corps of Engineers (USACE). Most of the numerous smaller flood retarding structures owned by non-federal entities are designed for releases to be controlled by the discharge capacity of ungated outlet structures.

USACE flood control operations are based on two sets of procedures referred to as regular and emergency operations (USACE, 1987; Wurbs 2016). Regular operations are employed whenever the storage level is within the flood control pool. Releases are based on emptying flood control pools as expeditiously as feasible without contributing to flows at downstream gaging stations exceeding maximum non-damaging flow levels. Multiple reservoirs share the same downstream gaging stations and channel capacity limits. In some cases, the USACE varies the maximum allowable non-damaging flow levels depending on storage contents of the flood control pools.

Emergency procedures are activated only during extreme flood events when the flood control storage capacity is exceeded, with the storage level encroaching into the surcharge pool. Emergency operations are based on assuring that the safety of the dam is never threatened. Releases and uncontrolled spills from the surcharge pool, above the top of flood control pool, will typically contribute to flows at downstream locations exceeding non-damaging levels.

The USACE owns and operates over 500 reservoirs throughout the United States constructed pursuant to the Flood Control Act of 1936 and subsequent legislation (Wurbs, 2016). The USACE is also responsible for flood control operations in multiple purpose reservoir projects constructed by the U.S. Bureau of Reclamation. The USACE owns and operates 28 reservoirs in Texas that provide water supply and recreation and in some cases hydropower in addition to flood control and two other flood control reservoirs that contain no water supply storage. The eight USACE reservoirs in the Trinity River Basin discussed in this paper are operated for both flood control and water supply following conventional USACE procedures.

Inclusion of water supply storage in USACE reservoirs is authorized by the Water Supply Act of 1958. All construction, maintenance, and operation costs allocated to water supply are the responsibility of nonfederal sponsors. The federal government funds all costs of federal reservoirs allocated to flood control. Reallocation of storage capacity between flood control and conservation pools has occurred at 44 USACE reservoirs following rules outlined in the Water Supply Act of 1958 (Carter, 2010). Recognizing a growing interest in additional storage reallocations, the USACE published proposed rules in the Federal Register in December 2016 clarifying and simplifying cost sharing and other institutional aspects of storage reallocations (USACE 2016). McMahon and Farmer (2004, 2009) and Carter (2010) outline institutional and technical issues involved in implementing reallocations of reservoir storage capacity.

3. Modeling And Analysis Of Reservoir System Operations

Wurbs (1996) and Labadie (2004) review the massive literature on applying systems analyses techniques to optimization of reservoir operations. Wurbs (2011) provides a comparative review of generalized reservoir/river system simulation models including the WRAP modeling system employed in the study reported in this paper. The numerous early reservoir systems analysis studies published in the literature focus on various aspects of conservation storage operations and to a lesser extent on flood control operations, but interactions between flood control and conservation purposes was addressed very little. However, more recent publications, such as those cited below, deal with flood control in multiple-purpose reservoirs and storage reallocations.

Dittman et al. (2009) developed operating schedules for reservoirs in Germany that combine flood control and ecosystem protection. Liu et al. (2010) developed operating rules for the Three Gorges Reservoir in China that provide seasonal flood control safety while optimizing water supply and hydroelectric energy objectives. Fu and Wang (2014) present a procedure applied to allocate flood reserve capacity of reservoirs in Yangtze River Basin. Song et al. (2015) balanced flood control and irrigation operations for three reservoirs in Korea. Ma et al. (2015) developed computational algorithms for balancing dam safety, downstream flood protection, irrigation, and hydropower generation in large reservoir projects. Wan et al. (2016) developed a probability based hedging rule refilling procedure for managing flood risk while meeting water supply needs for a reservoir in China. Chou and Wu (2013) investigate a pre-release strategy for improve flood control capabilities by partially emptying the conservation pool in anticipation of forecasted floods. Meng et al. (2016) varied the normal storage elevation during the flood season considering interactions between flood protection, hydropower, and water supply.

Chou and Wu (2015) developed a framework of reservoir release rules for managing flood risk based on dividing flood events into three stages. Che and Mays (2015) also investigate a modeling system that supports real-time reservoir operations before, during, and after an extreme flood event. Chen et al. (2014) explore the many sources of uncertainties in real-time reservoir flood control operations.

The U.S. Water Resources Council (1981) evaluated alternative probability distribution functions available for performing flood frequency analyses and adopted the log-Pearson type III for use by federal agencies in the United States. The log-Pearson III based procedure is explained by Wurbs and James (2002) and implemented in the WRAP and USACE software (Hydrologic Engineering Center, 2010) employed in the study presented here.

4. Modeling System Adopted For This Study

The modeling strategy employed in assessing changes in flood control and water supply capabilities associated with alternative plans for reallocating storage capacity between the flood control and conservation pools of the system of eight reservoirs in the upper Trinity River Basin operated by the USACE employs WRAP/WAM and USACE HEC computer programs (Demirel, 2015). Detailed flood control operating rules were incorporated in the Trinity WAM in conjunction with the research. HEC-DSSVue, HEC-SSP, and another WRAP post-simulation program were used to analyze WRAP simulation results.

Water Rights Analysis Package (WRAP) and Texas Water Availability Modeling (WAM) System

The Water Rights Analysis Package (WRAP) is a generalized modeling system for simulating water resources development, management, allocation, and use in river basins located anywhere in the world. WRAP is designed for assessing reliabilities in meeting water supply, hydroelectric power, and environmental flow needs and also includes optional capabilities for tracking salinity (Wurbs, 2006, 2015, 2015). WRAP was recently expanded to include simulation of reservoir operations for flood control (Wurbs and Hoffpauir, 2015).

The Texas Commission on Environmental Quality (TCEQ) in collaboration with the Texas Water Development Board (TWDB), university research entities, consulting engineering firms, and the water management community has developed and routinely applies a Water Availability Modeling (WAM) System consisting of WRAP and WRAP input datasets for the 23 river basins of Texas (Wurbs, 2005, 2015). The WAM system supports a regional and statewide planning process, administration of water allocation systems, and other water resources management functions. Activities of numerous water management entities operating 3,450 reservoirs and other facilities in accordance with a USA-Mexico treaty, five interstate compacts, two water right permit systems with 6,200 active permits, and other institutional arrangements are simulated. The generalized WRAP reservoir/river system modeling system combined with an input dataset from the WAM System for a particular river basin is called a water availability model (WAM). An expanded version of the daily Trinity River Basin WAM was employed in the study presented in this paper.

WRAP and the Texas WAM System employ a monthly step time. However, recent versions of WRAP also include capabilities for daily simulations (Wurbs and Hoffpauir, 2015). The daily version of the modeling system has been motivated largely by the need for expanded capabilities for modeling environmental flow requirements and issues (Wurbs and Hoffpauir, 2013; Pauls and Wurbs, 2016). The WRAP daily modeling system includes the following additional features used only with a daily computational time step: (1) disaggregation of monthly naturalized flows to daily, (2) flow routing and forecasting, (3) disaggregation of diversion, hydropower, and instream flow targets, (4) simulation of high flow pulse environmental flow requirements, (5) simulation of reservoir flood control operations, and (6) additional frequency analysis capabilities.

Multiple-reservoir system flood control operations based on procedures employed at USACE reservoirs are modeled in the new expanded version of the WRAP simulation model. Regular and emergency flood control operations are modeled as follows. Only conservation operations are in effect unless the storage level exceeds the specified conservation pool capacity. If the storage level is above the top of conservation pool and below the top of flood control pool, the flood waters are released as quickly as possible subject to the constraints of (1) not exceeding the discharge capacity of the outlet structures and (2) allowing no releases that contribute to river flows exceeding specified channel capacities at downstream gauged control points. If flood inflows exceed the flood control storage capacity at the designated top of flood control elevation, the flows are passed through a reservoirs as spills over an emergency spillway. Multiple-reservoir system operations are based on user-specified rules for balancing the volume of water stored in the flood control pools of each of the multiple reservoirs.

5. Modeling And Analysis Of The Usace Reservoir System In The Upper Trinity River Basin

The Fort Worth District Office of the USACE constructed and now operates a system of eight large multiple-purpose reservoirs located in the upper Trinity River Basin. The USACE is solely responsible for flood control operations. The water supply storage capacities are controlled by non-federal project sponsors that include the Trinity River Authority, Tarrant Regional Water Authority, North Texas Municipal Water District, Dallas Water Utilities, City of Fort Worth, and several smaller cities. This complex multiple-purpose, multiple-reservoir system provides a case study to support development and demonstration of the modeling strategy presented in this paper.

The objective of the simulation modeling study is to develop meaningful information to support assessments of the impacts on both flood control and water supply capabilities of alternative reallocations of storage capacities. The water supply reliability metrics incorporated in the WRAP/WAM modeling system are adopted. Flood risk is analyzed as the probability of exceeding flood control storage capacity. The fundamental concept of flood control operations is to make no releases that contribute to damages unless the flood control storage capacity is expected to be exceeded. If the flood control capacity is exceeded, spills causing downstream damages are necessary to protect the safety of the dam.

Trinity River Basin

The Trinity River Basin extends 400 miles from north of the Dallas-Fort Worth metropolitan area to Galveston Bay, east of the city of Houston, as shown in Figure 1. The watershed area is approximately 47,000 square kilometers. Mean annual rainfall ranges from 1,350 mm near Galveston Bay to 74 mm in the northwestern extreme of the upper basin.

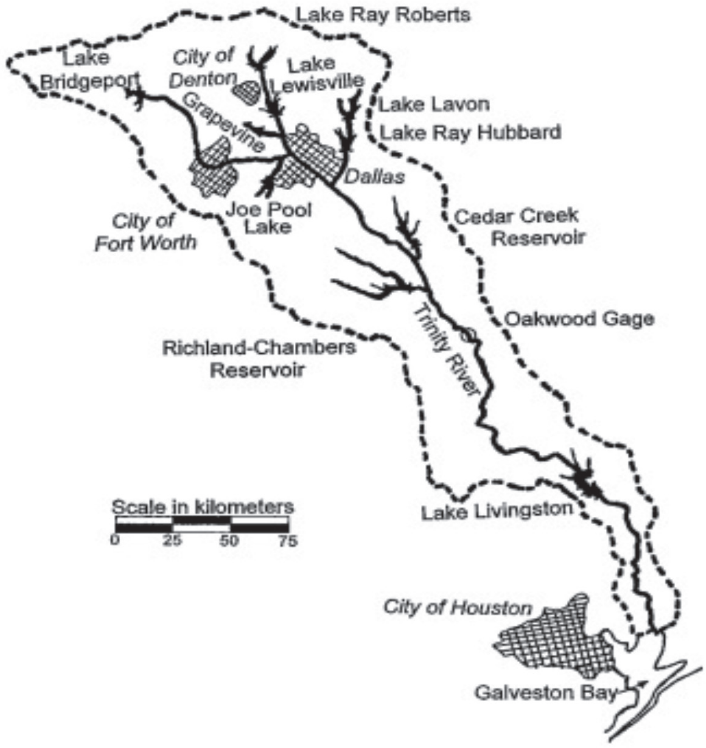

Figure 5.1. Trinity River Basin

The population of the state of Texas increased from 20,850,000 people in 2000 to 25,390,000 in 2010 and is projected to increase to 29,510,000 by 2020 and 46,355,000 by 2060 (Texas Water Development Board, 2017). With a combined 2010 population of 6,372,000 people, the many cities of the Dallas-Fort Worth metroplex in the upper Trinity River Basin account for 25.3 percent of the population of Texas. This is one of the fastest growing large metropolitan areas in the United States. The City of Houston in the San Jacinto River Basin has a pipeline from Lake Livingston on the lower Trinity River to supplement its other water supply sources in meeting intensifying water demands.

The TCEQ WAM System WRAP input dataset for the Trinity River Basin, called the Trinity WAM, models about 600 water rights permits that include storage capacity in 697 reservoirs and water supply diversions of 6.57 billion m3/year, with about 58% municipal, 35% industrial, and 7% agricultural irrigation use. Recreation is popular at the eight USACE reservoirs and most of the nonfederal reservoirs. The eight USACE reservoirs listed in Table 5.1 contain 31.9 percent of the total conservation storage capacity of the 697 reservoirs and all of the flood control storage capacity. Lakes Livingston, Richland-Chambers, Cedar Creek, and Ray Hubbard, which are the four largest non-federal reservoirs in the basin, contain 53.4 percent of the total conservation capacity of the 697 reservoirs and zero flood control storage capacity. Several of the nonfederal water supply sponsors for the USACE reservoirs also own other reservoirs. Water supply reliabilities for water right holders associated with the eight USACE reservoirs and stream flows throughout the river system are affected by all of the reservoirs, water right diversions, and return flows in the WAM. Drawdowns of conservation pools in the multiple-purpose reservoirs increase flood control storage capabilities.

Table 5.1.

USACE reservoirs

USACE	Storage Capacity (acre-feet)		Storage Capacity (1,000 m^3)	
Reservoir	Conservation	Flood Control	Conservation	Flood Control
Benbrook	88,250	76,550	108,900	94,460
Joe Pool	176,900	127,100	218,300	156,840
Ray Roberts	799,600	265,000	986,710	327,010
Lewisville	618,400	340,777	763,110	420,520
Grapevine	162,500	244,400	200,530	301,590
Lavon	456,500	291,700	563,320	359,960
Navarro Mills	63,300	148,900	78,110	183,740
Bardwell	54,900	85,100	67,750	105,010
Total	2,332,100	1,579,527	2,986,710	1,949,140

6. Results

Flood Frequency Analysis for Trinity River Basin Reservoirs

In this article, risk of the exceedance probability of the flood control pool capacity of the Trinity River Basin dams were analyzed based on observed annual maximum reservoir storage. The annual exceedance probability (P) is probability that a specified storage magnitude will be equaled or exceeded in any year. The return period or the recurrence interval (T) is the mean interval, in years, between occurrence of flood events equaling or exceeding a specified storage magnitude. The relationship of between annual exceedance probability (P) and recurrence interval (T) in years is

$$T=1/(P) \text{ or } P=1/T \quad (1)$$

After obtaining the report of analyses, interpolation was done in order to find the exact risk of exceedance probability based on reservoirs` flood control storage capacity. After obtaining the percent chance of exceedance values, Equation 1 was used to calculate recurrence time for exceeding flood control pool capacity in years. Wurbs (1996) noted that for federal reservoirs, flood control storage capacities typically were designed for at least 50-year recurrence interval; in addition to that, most projects` flood control pools were sized for 100-year recurrence interval. As an example, Benbrook Reservoir's plots and tables are as follows.

Benbrook reservoir FFA based on observed annual storage

A frequency analysis for peak annual storage contents of Benbrook Reservoir was performed in HEC-SSP alternatively applying the log-normal and log-Pearson type III probability distributions. The total storage capacity of Benbrook Reservoir below the top of flood control pool is 164,800 acre-feet, which can be to the storage-frequency relationships presented in Table 6.1, Table 6.2, Figure 6.1 and Figure 6.2.

Table 6.1.

Benbrook Reservoir FFA log-normal probability distribution

Computed Curve (ac-ft)	Expected Probability (ac-ft)	Percent Chance Exceedance	Confidence 0.05 (ac-ft)	Limits 0.95 (ac-ft)
226,597	235,244	0.2	262,153	202,948
209,852	215,901	0.5	239,725	189,637
196,970	201,409	1	222,717	179,275
183,797	186,908	2	205,567	168,552
165,670	167,426	5	182,422	153,544
151,070	152,077	10	164,231	141,181
135,103	135,571	20	144,920	127,266
109,106	109,106	50	115,334	103,215
88,112	87,808	80	93,538	82,144
78,799	78,277	90	84,319	72,485
71,855	71,101	95	77,530	65,257
60,437	59,105	99	66,402	53,450

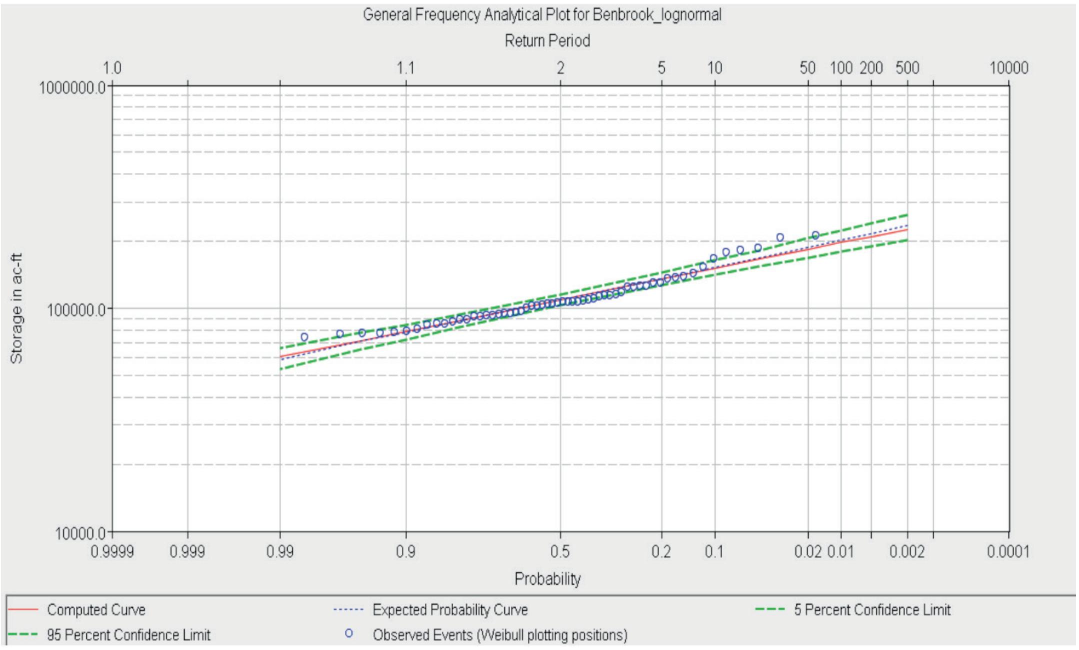

Figure 6.1. Benbrook Reservoir FFA log-normal probability distribution

Table 6.2.

Benbrook Reservoir FFA log-Pearson type III probability distribution

Computed Curve (ac-ft)	Expected Probability (ac-ft)	Percent Chance Exceedance	Confidence 0.05 (ac-ft)	Limits 0.95 (ac-ft)
290,532	311,578	0.2	350,631	252,474
253,354	266,527	0.5	298,667	223,901
227,566	236,324	1	263,461	203,713
203,545	209,127	2	231,371	184,578
174,101	176,798	5	193,116	160,565
153,195	154,613	10	166,850	142,998
132,979	133,563	20	142,406	125,376
105,485	105,485	50	111,442	99,682
87,792	87,579	80	93,217	81,813
81,174	80,845	90	86,654	74,955
76,728	76,277	95	82,289	70,329
70,347	69,703	99	76,060	63,689

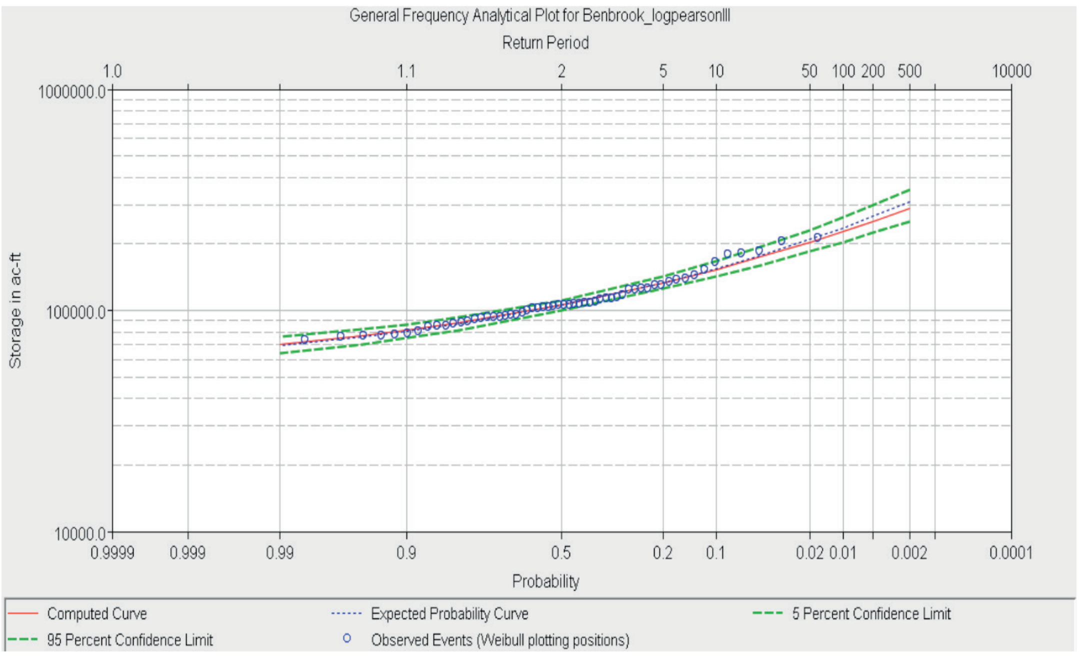

Figure 6.2. Benbrook Reservoir FFA log-Pearson type III probability distribution

Discussion of the Frequency Analysis Results

Total storage volumes associated with specified annual exceedance probabilities are presented in the preceding Tables 2-3 and Figures 2-3 for Benbrook Reservoir. HEC-SSP was applied alternatively using the log-normal and log-Pearson type III probability distribution for comparison. The frequency analyses are based on the maximum actual observed storage volume for each year since the reservoir initially filled after construction.

Although the reservoirs are in the same river basin and operated by the same agency, results of the frequency analyses of observed annual maximum storage are significantly different between the reservoirs. These differences might be the cause of different reservoir operation strategies. As shown in the Table 4, return periods vary between 10 to 1,000 years and 11 to 416 years based on log-normal and log-Pearson type III distributions, respectively. According to Wurbs, federal dams are typically designed for at least a 50-year recurrence interval (Wurbs, 1996). Unfortunately, as these results show us, in reality, return period is as low as 10 years for log-normal and 11 years for log-Pearson type III probability distributions for Lewisville Dam. On the other hand, some of them have over 100-year return periods.

The log-normal and log-Pearson type III yield similar results for six of the results. However, the two alternative probability distributions result in very different probability estimates for Joe Pool and Navarro Mills Reservoirs. The return periods shown in Table 4 for Joe Pool and Navarro Mills Reservoirs are 1,000 years and 98 years based on the log-normal distribution and are 140 years and 416 years based the log-Pearson type III distribution, respectively. Log-Pearson type III probability distribution fits the data better than the log-normal probability distribution. Samples are generally between confidence intervals in the log-Pearson type III probability distribution. Different periods-of-analysis (sample sizes) might cause large differences between the log-normal and log-Pearson type III distributions. The analyses for Benbrook, Joe Pool, Ray Roberts, Lewisville, Grapevine, Lavon, Navarro Mills, and Bardwell Reservoirs have periods-of-analyses of 58, 26, 26, 25, 58, 38, 50, 49 years.

Table 6.3.

Recurrence interval of exceeding top of flood control pools

No	Reservoirs	Top of Flood Control (ac-ft)	Percent Chance Exceedance (log-normal)	Return Period (log-normal) (year)	Percent Chance Exceedance (log-Pearson Type III)	Return Period (log-Pearson Type III) (year)
1	Benbrook	164,800	5.30	18.87	7.22	13.85
2	Joe Pool	304,000	0.10	1000.00	0.71	140.85
3	Ray Roberts	1,064,600	6.89	14.51	6.75	14.81
4	Lewisville	959,177	9.60	10.42	8.89	11.25
5	Grapevine	406,900	3.63	27.55	4.57	21.88
6	Lavon	748,200	8.79	11.38	7.08	14.12
7	Navarro Mills	212,200	1.02	98.04	0.24	416.67
8	Bardwell	140,000	0.43	232.56	0.39	256.41

The WRAP Simulations and Storage Reallocations for Trinity River Basin Reservoirs

The TCEQ WAM system involves variation of datasets for alternative scenarios. Full authorized water use (run 3) and current water use (run 8) are two scenarios that were simulated for water usage. Full authorized scenario (run 3) are performed based on all water right permit holders which withdraw full amount of water that they authorized in their permit and there is not return flow. On the other hand, current water use (run 8) are performed based on water right permit holders which withdraw less amount of water than authorized.

WRAP alternative simulation runs

This article involved six alternative simulation runs in order to enhance understanding impacts on permanent storage reallocation on water supply and flood frequency analysis and confirm its validity. Daily time step simulations` hydrologic period-of-analysis were 1940 through 2012. Alternative simulation runs, as shown in Table 5, include six daily time step. Some of reservoirs were simulated as component (multiple-owner) reservoirs while rest of them were simulated as single owner reservoirs. Also, simulations included current water use and full authorized water use scenarios. Three of six daily time step runs were performed for storage reallocation. Permanent reallocations simulations involved three alternative scenarios which were allocating reservoir storage from flood control pool to conservation pool with amount of 10%, 20%, and 50% for eight reservoirs in the Trinity River Basin. Alternative simulation runs are defined as follows.

Table 6.4.

Alternative simulation runs

Simulation Label	Time Step	Water Use Scenario	Flood Control Operation	Component Reservoir	Reallocation
D1	Daily	Authorized	Yes	No	No
D2	Daily	Authorized	Yes	Yes	No
D3	Daily	No Withdrawn	Yes	No	No
D4	Daily	Authorized	Yes	No	Yes (10%)
D5	Daily	Authorized	Yes	No	Yes (20%)
D6	Daily	Authorized	Yes	No	Yes (50%)

Simulation results

The six alternative simulation runs were evaluated by comparing simulation results and observed data in order to enhance understanding the impact of alternative permanent storage reallocations on water reliabilities and flood frequency analyses for the system of eight reservoirs in the Trinity River Basin. Simulation D1 is main run which was in daily time step, modeled as full authorized water use, set up as existing storage allocation, has flood control operation and designed as single-owner reservoirs. Simulation D2 is identical with D1 except reservoirs were modeled as multiple-owner. D3 is identical with D1 except water rights were entered as zero in order to see flood frequency changes when conservation pool is full. Three of six daily time step simulations, D4, D5, and D6 were only for alternative permanent storage reallocation for eight reservoirs.

Simulation D1 versus observed annual maximum reservoirs storage

The simulation D1 represents existing reservoir storage as shown Figure 4, full authorized water use, daily time step, single-owner, and has flood control operation. The simulation D1 was considered as base simulation and compared with other alternative simulation runs. In order to check it`s validity, D1 storage capacity, flood return periods were compared with observed values. In addition to that, water reliability summary table was developed to compare with other simulations result in order to show differences.

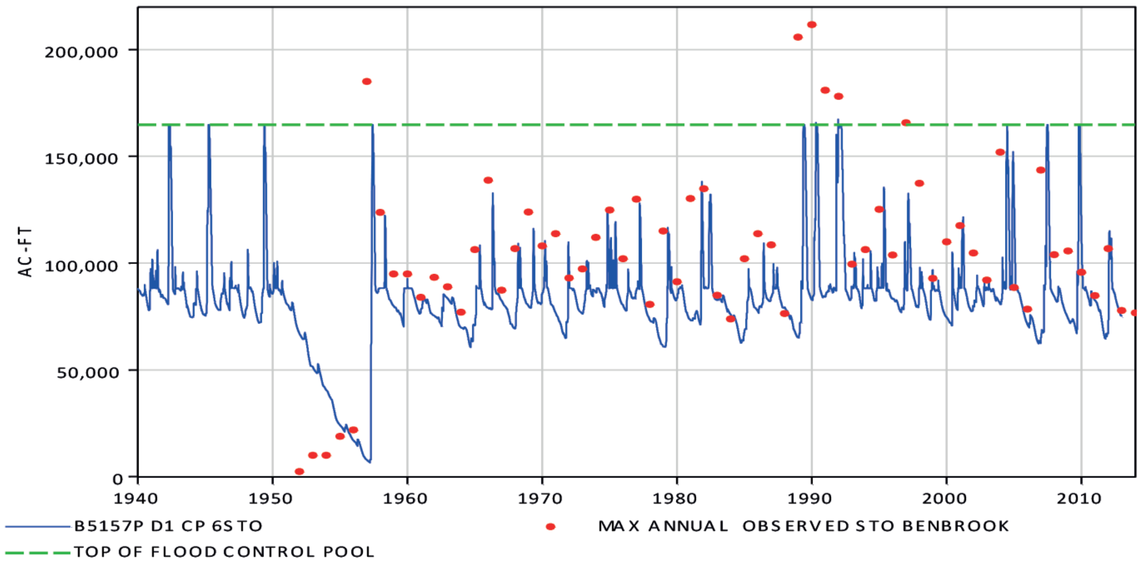

Figure 6.3. Benbrook Reservoir simulation D1 versus max annual observed storage

Comparison of flood frequency analyses

Flood frequency analyses and return periods were performed with HEC-SSP and WRAP for observed data and simulation D1 respectively for the eight reservoirs. WRAP post simulation has capabilities to perform flood frequency analysis based on only for reservoir storage and summation of reservoir storage and excess flow. Excess flow represents maximum daily flow volume for each year whenever flows exceed the top of controlled flood control pool.

Flood frequency analyses were performed by employing both log-normal and log-Pearson type III probability distributions for simulation D1 and observed reservoir storage. Table 6.5 were created by using log-normal distribution and compared with observed data and only reservoir storage, and summation of reservoir and excess flow. Likewise, Table 6.6 were created by using log-Pearson type III distribution and compared with observed data, only reservoir storage, and summation of reservoirs and excess flows.

Return period of observed storage for both log-normal and log-Pearson type III distribution were close to each other except Joe Pool and Navarro Mills. Return period of D1 simulation storage for both log-normal and log-Pearson type III distribution were far away from each other for only reservoir and summation of reservoir storage and excess flow. Log-normal distribution`s results for simulation D1 were closer to observed reservoir storage return period than log-Pearson type III distribution. However, specifically, Ray Roberts, Lewisville, and Grapevine Reservoirs' simulation D1 storage levels were lower than observed storage level. Although, for these reservoirs, simulation D1 storage levels were low, return period for flood event was very frequent for log-normal distribution. Log-normal probability distribution did not reflect storage level`s value for flood frequency analysis. Because of that, log-Pearson type III distribution exceedance probability of controlled flood control pool fit better than log-normal probability distribution.

Joe Pool and Ray Roberts Reservoirs were completed after 1980 and their periods-of-analysis are shorter than for the other reservoirs. Fewer years of record means a smaller sample size for the statistical analyses. Also, for Lewisville and Lavon Reservoirs, storage reallocations were made in 1989 and 1976 respectively. Because of reallocation, flood frequency analyses were performed by maximum storage level after reallocation was done, so sample size was low for these reservoirs. However, in the all simulation, hydrologic period was from 1940 to 2012. This difference affected return period. In addition to that as mentioned before, D1 was performed for full authorized water use scenario.

Table 6.5.

Comparison of observed storage and simulation D1 exceedance probability of top of controlled flood control pool log-normal distribution

No	Reservoir	Top of Flood Control (ac-ft)	Observed		Sim D1 (Res. Sto.)		Sim D1 (Res. Sto.+Excess Flow)	
			Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)
1	Benbrook	164800	5.30	18.87	10.73	9.32	17.38	5.75
2	Joe Pool	304000	0.10	1000.00	9.32	10.73	9.32	10.73
3	Ray Roberts	1064600	6.89	14.51	7.84	12.76	7.84	12.76
4	Lewisville	959177	9.60	10.42	8.04	12.44	8.04	12.44
5	Grapevine	406900	3.63	27.55	11.46	8.73	11.55	8.66
6	Lavon	748200	8.79	11.38	11.28	8.87	12.09	8.27
7	Navarro	212200	1.02	98.04	3.38	29.59	3.44	29.07
8	Bardwell	140000	0.43	232.56	1.90	52.63	1.90	52.63

Table 6.6.

Comparison of observed storage and simulation D1 exceedance probability of top of controlled flood control pool log-normal distribution

No	Reservoir	Top of Flood Control (ac-ft)	Observed		Sim D1 (Res. Sto.)		Sim D1 (Res. Sto.+Excess Flow)	
			Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)
1	Benbrook	164800	7.22	13.85	0.10	1000.00	16.68	6.00
2	Joe Pool	304000	0.71	140.85	0.10	1000.00	0.10	1000.00
3	Ray Roberts	1064600	6.75	14.81	0.01	10000.00	0.01	10000.00
4	Lewisville	959177	8.89	11.25	3.52	28.41	3.52	28.41
5	Grapevine	406900	4.57	21.88	0.23	434.78	0.40	250.00
6	Lavon	748200	7.08	14.12	0.10	1000.00	0.10	1000.00
7	Navarro	212200	0.24	416.67	1.26	79.37	1.43	69.93
8	Bardwell	140000	0.39	256.41	0.10	1000.00	0.10	1000.00

Water supply reliability for D1

The water supply reliability table was developed for control points located at dams for simulation D1 as shown in Table 6.7. Benbrook, Lavon, Navarro Mills, and Bardwell Reservoirs water diversion target 100% met in terms of simulation duration and diversion amount. On the other hand, Joe Pool, Ray Roberts, Lewisville, Grapevine Reservoirs have water shortage. Joe Pool water reliability was almost 100%. However, Ray Roberts Reservoir had very low water reliability in terms of period and volume. One of the research objectives is how reallocation affects water reliability.

Table 6.7.

Water supply reliability for D1

Daily Data from January 1940 through December 2012

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	VOLUME (%)	PERCENTAGE OF DAYS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT							PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT						
					100%	95%	90%	75%	50%	25%	1%	100%	95%	90%	75%	50%	25%	1%
B5157P	125768.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B3404A	400242.1	170.20	98.95	99.96	99.0	100.0	100.0	100.0	100.0	100.0	100.0	98.9	100.0	100.0	100.0	100.0	100.0	100.0
B2335A	799601.8	634935.06	20.38	20.59	20.4	20.5	20.5	20.8	21.2	21.6	22.8	11.3	11.4	11.9	14.5	18.7	26.1	42.8
B2456A	921060.9	534674.75	53.56	41.95	53.6	53.6	53.7	54.1	55.1	57.0	74.5	45.0	45.9	46.8	48.9	54.8	61.6	81.6
B2362A	171537.5	72116.69	58.34	57.96	58.3	58.4	58.4	58.8	59.5	61.5	70.1	51.0	51.8	52.3	53.9	59.0	65.4	81.2
B2410A	128754.7	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B4992A	176698.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B5021A	151885.5	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total	2875550.0	1241896.75		56.81														

Simulations D1 versus D2

The simulation D2 represents existing reservoir storage, full authorized water use, daily time step, has flood control operation, and was developed as component reservoir system. Component (multiple-owner) reservoir system means, for same reservoir, different agencies have water right contracts. To protect their water rights from other contractor, reservoirs were split up as components. Thus, contractor cannot withdraw much water that they were authorized. Because of that, conservation and flood control pools were divided based on contract proportion for Benbrook, Ray Roberts, Lewisville, Grapevine, and Lavon Reservoirs. However, flood control operation for component reservoirs did not work out. Component reservoir system for some years, even if water level in reservoir was lower than top of controlled flood control pool (FCGATE), in AFF file, there was excess flow. That was not supposed to be occurred. Excess flow was supposed to be only occurred when water level exceeded the top of controlled flood control pool. The reason for excess flow for component reservoir might be that one of the components in the same reservoir might overtop to top of flood control pool while others had low water level. Even if one of components was exceed flood control pool, it would cause excess flow.

Originally, Trinity WAM was designed as component reservoir for water allocation. However, the research focused on flood control operation, because of that, reservoirs were converted to single owner reservoir and base simulation (D1) was single owner reservoir. Simulation D1 and D2 were compared for water storages and water reliabilities to check how single-owner simulation make changes as shown Figure 6.4.

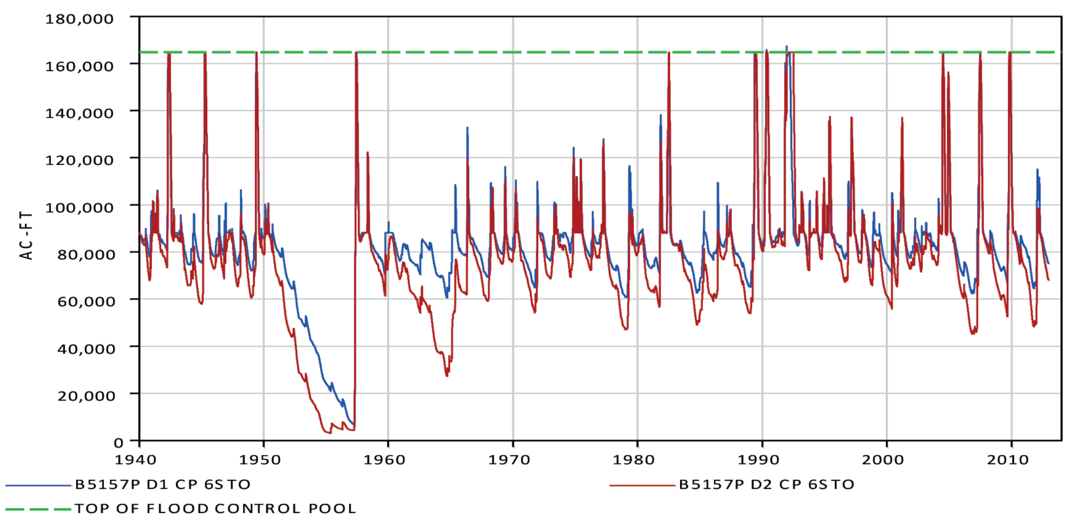

Figure 6.4. Benbrook Reservoir simulations D1 versus D2

Simulations D1 versus D3

The simulation D3 represents existing reservoir storage as shown Figure 6.5, no water withdrawn from the eight reservoirs, daily time step, has flood control operation, and was developed as single-owner reservoir system. Simulation D3 was executed in order to show how conservation pool affected flood frequency analysis. After a severe drought conservation, pool becomes empty and after drought season ends, at first conservation pool becomes full then starts to fill flood control pool. In other words, at the beginning of flood event, conservation pool behaves as flood control pool and stores water. In order to see how conservation pool affect flood control operation, simulation D3 was developed by changing water rights values as zero thus conservation pool remain full for the eight reservoirs.

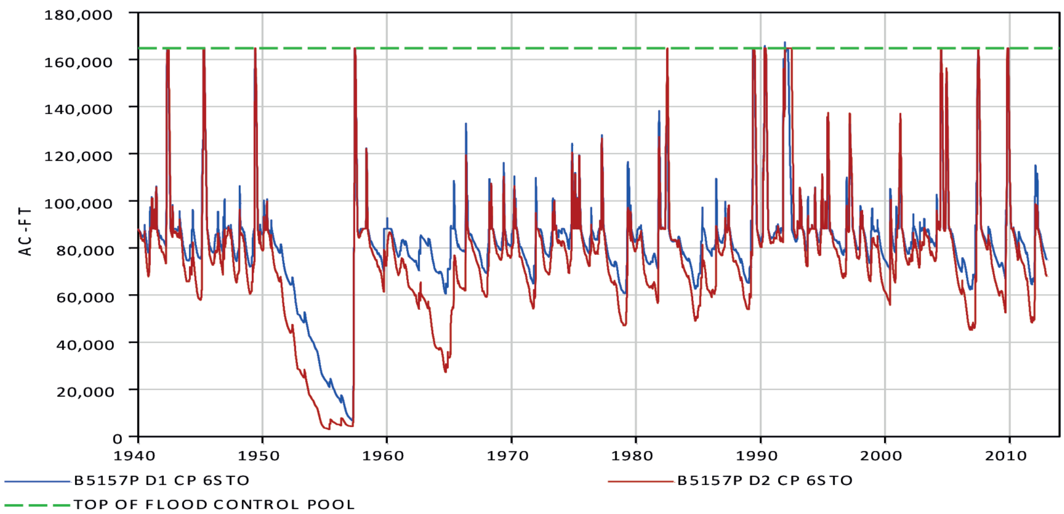

Figure 6.5. Benbrook Reservoir simulations D1, D3 versus max annual observed storage
3.2.3.1. Comparison of flood frequency analyses

Exceedance probability of top of controlled flood control for simulation D3 was performed for log-normal and log-Pearson type III distribution, compared with simulation D1 and observed flood frequency analysis. For both distributions, simulation D3 return period values were expected lower than simulation D1 because there was not withdrawn for simulation D3 and water levels were higher than simulation D1.

Return period and statistical tables were developed for log-normal distribution as shown in Tables 7. However, return period values for simulation D3 was higher than simulation D1 except for Ray Roberts and Lewisville Reservoirs. The result for log-normal distribution was not expected since D3 simulation return period should have been lower than D1. Log-normal distribution did not work well.

Return period and statistical tables were developed for log-Pearson type III distribution as shown in Table 6.8 and Table 6.9. Return period for simulation D3 values were lower than Simulation D1 and observed flood frequency analysis as expected. Simulation D1 flood return periods were significantly higher than simulation D3. For this study, log-Pearson Type III distribution fit better. Because of that, rest of the simulation was evaluated only with log-Pearson type III distribution.

These results show that conservation pools have great impact on flood control operation and flood frequency analysis. Especially after a severe drought like 1950-1957 drought, there was a flood event. The simulation D3 showed that in 1957 controlled flood control pools were overtopped for most of reservoirs. Consequently, conservation pools reduce flood events when they have water storage place.

Table 6.8.

Comparison of observed storage, D1 and D3 exceedance probability of top of flood control pool log-Pearson type III distribution

No	Reservoir	Top of Flood Control (ac-ft)	Observed		Sim D1 (Res. Sto.)		Sim D1 (Res. Sto.+Excess Flow)	
			Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)
1	Benbrook	164800	7.22	13.85	16.68	6.00	16.53	6.05
2	Joe Pool	304000	0.71	140.85	0.10	1000.00	0.10	1000.00
3	Ray Roberts	1064600	6.75	14.81	0.01	10000.00	12.28	8.14
4	Lewisville	959177	8.89	11.25	3.52	28.41	9.87	10.13
5	Grapevine	406900	4.57	21.88	0.40	250.00	5.66	17.67
6	Lavon	748200	7.08	14.12	0.10	1000.00	9.62	10.40
7	Navarro	212200	0.24	416.67	1.43	69.93	3.13	31.95
8	Bardwell	140000	0.39	256.41	0.10	1000.00	1.14	87.72

Simulations D1, D4 versus observed annual maximum reservoirs storage

The simulation D4 represents 10% flood control reservoir storage converted to conservation pool capacity as shown Figure 6.6, full authorized water use, daily time step, has flood control operation, and was developed as single-owner reservoir system. Simulation D4 was executed in order to show how 10% storage reallocation from flood control pool to conservation pool affects flood frequency analysis and water reliability.

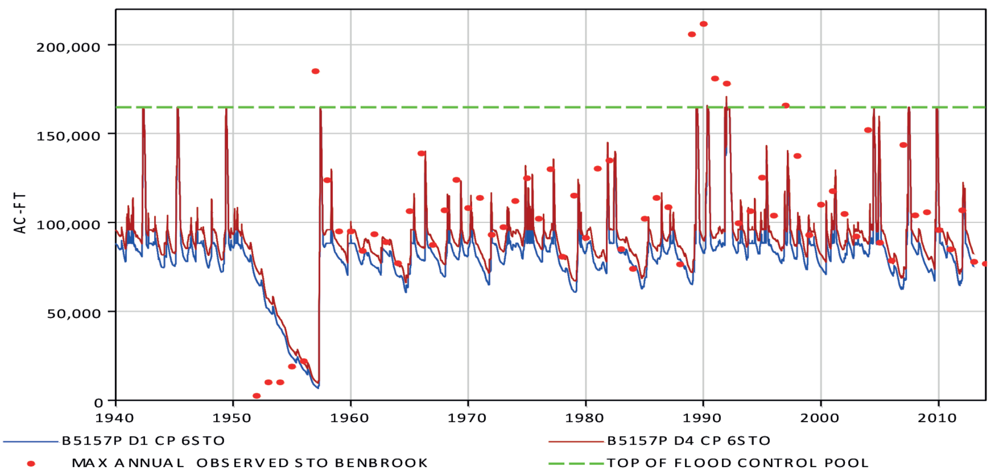

Figure 6.6. Benbrook Reservoir simulations D1, D4 versus max annual observed storage

Comparison of flood frequency analyses

Exceedance probability of top of controlled flood control for simulation D4 was performed for log-Pearson type III distribution for summation of reservoir storage and excess flow, then compared with simulation D1 and observed flood frequency analysis. The simulation D4 return period values were expected lower than simulation D1 return period because conservation storage capacity increased and flood control storage capacity decreased in simulation D4 and water levels were higher than simulation D1.

Return period table was developed for log-Pearson type III distribution as shown in Table 10 Return period for simulation D4 for values were lower than simulation D1 as expected.

Table 6.9.

Comparison of observed storage, D1 and D4 exceedance probability of top of flood control pool log-Pearson type III distribution

No	Reservoir	Control Point	Top of Flood Control (ac-ft)	Observed		Sim D1 (Res. Sto. +Excess Flow)		Sim D4 (Res. Sto. +Excess Flow)	
				Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)
1	Benbrook	B5157P	164800	7.22	13.85	16.68	6.00	19.68	5.08
2	Joe Pool	B3404A	304000	0.71	140.85	0.10	1000.00	0.10	1000.00
3	Ray Roberts	B2335A	1064600	6.75	14.81	0.01	10000.00	0.01	10000.00
4	Lewisville	B2456A	959177	8.89	11.25	3.52	28.41	3.75	26.67
5	Grapevine	B2362A	406900	4.57	21.88	0.40	250.00	1.79	55.87
6	Lavon	B2410A	748200	7.08	14.12	0.10	1000.00	0.10	1000.00
7	Navarro	B4992A	212200	0.24	416.67	1.43	69.93	2.50	40.00
8	Bardwell	B5021A	140000	0.39	256.41	0.10	1000.00	0.10	1000.00

Water supply reliability for D4

Water supply reliability table was developed for control points that located at dams for simulation D4 as shown in Table 6.10. Benbrook, Lavon, Navarro Mills, and Bardwell Reservoirs water diversion target is 100% met in terms of simulation duration and diversion amount. There were little increase of water reliabilities for Joe Pool, Ray Roberts, Lewisville, and Grapevine Reservoirs in simulation D4 than simulation D1. Joe Pool water reliability was almost 100%. However, like simulation D1, Ray Roberts Reservoir had very low water reliability in terms of period and volume.

Table 6.10.

Water supply reliability for D4

Daily Data from January 1940 through December 2012

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF DAYS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%
B5157P	132812.9	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B3404A	422737.6	110.80	99.22	99.97	99.2	100.0	100.0	100.0	100.0	100.0	100.0	99.2	100.0	100.0	100.0	100.0	100.0	100.0
B2335A	799601.8	634899.62	20.39	20.60	20.4	20.5	20.6	20.8	21.2	21.6	22.8	11.3	11.5	12.1	14.4	18.6	26.3	42.8
B2456A	918848.8	530853.25	53.84	42.23	53.8	53.9	54.0	54.4	55.4	57.3	74.6	45.1	46.0	46.8	49.0	54.9	62.2	82.0
B2362A	171130.4	69271.57	59.86	59.52	59.9	59.9	60.0	60.3	61.0	62.9	71.3	52.7	53.4	53.8	55.4	60.5	66.7	82.0
B2410A	128420.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B4992A	192768.9	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B5021A	158580.2	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total	2924901.2	1235135.38		57.77														

Simulations D1, D5 versus observed annual maximum reservoirs storage

The simulation D5 represents 20% flood control reservoir storage allocated to conservation pool capacity, full authorized water use, daily time step, has flood control operation, and was developed as single-owner reservoir system. Simulation D5 was executed in order to show how 20% storage reallocation from flood control pool to conservation pool affects flood frequency analysis and water reliability.

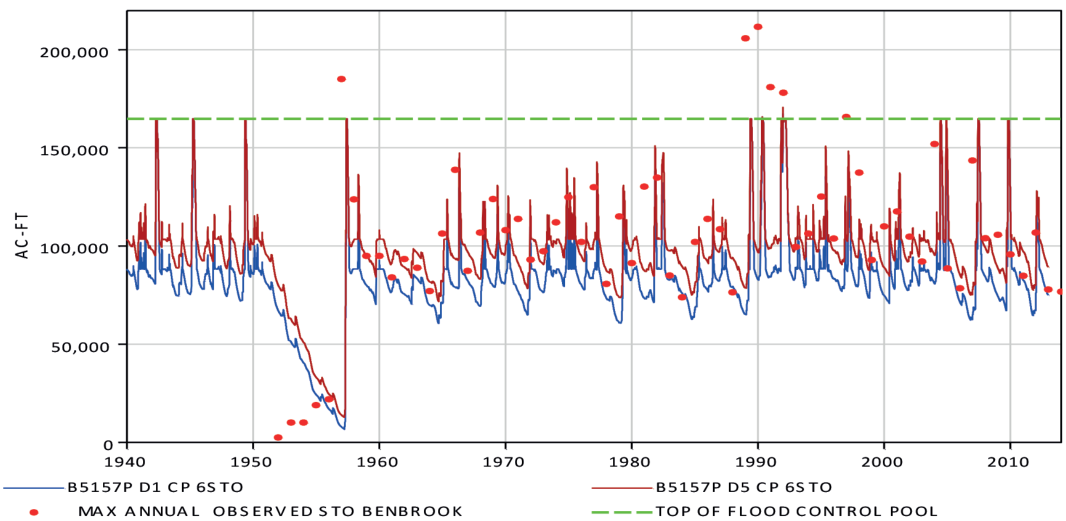

Figure 6.7. Benbrook Reservoir simulations D1, D5 versus max annual observed storage

Comparison of flood frequency analyses

Exceedance probability of top of controlled flood control for simulation D5 was performed for log-Pearson type III distribution for summation of reservoir storage and excess flow, then compared with simulation D1 and observed flood frequency analysis. The simulation D5 return period values were expected lower than simulation D1 and D4 return period because conservation storage capacity increased and flood control storage capacity decreased in simulation D5 and water levels were higher than simulations D1 and D4.

Return period and statistical tables were developed for log-Pearson type III distribution as shown in Table 6.11. Return period for simulation D5 for values were lower than simulation D1 as expected.

Table 6.11.

Comparison of observed storage, D1 and D4 exceedance probability of top of flood control pool log-Pearson type III distribution

No	Reservoir	Top of Flood Control (ac-ft)	Observed		Sim D1 (Res. Sto. +Excess Flow)		Sim D5 (Res. Sto. +Excess Flow)	
			Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)
1	Benbrook	164800	7.22	13.85	16.68	6.00	24.26	4.12
2	Joe Pool	304000	0.71	140.85	0.10	1000.00	0.10	1000.00
3	Ray Roberts	1064600	6.75	14.81	0.01	10000.00	0.01	10000.00
4	Lewisville	959177	8.89	11.25	3.52	28.41	4.03	24.81
5	Grapevine	406900	4.57	21.88	0.40	250.00	2.13	46.95
6	Lavon	748200	7.08	14.12	0.10	1000.00	0.10	1000.00
7	Navarro	212200	0.24	416.67	1.43	69.93	3.73	26.81
8	Bardwell	140000	0.39	256.41	0.10	1000.00	0.10	1000.00

Water supply reliability for D5

Water supply reliability table was developed for control point that located at dams for simulation D5 as shown in Table 6.12. Benbrook, Lavon, Navarro Mills, and Bardwell Reservoirs water diversion target 100% met in terms of simulation duration and diversion amount. There were little increase of water reliability for Joe Pool, Ray Roberts, Lewisville, and Grapevine Reservoirs in simulation D5 than simulation D1. Joe Pool water reliability was almost 100%. However, like simulation D1, Ray Roberts Reservoir had very low water reliability in terms of period and volume.

Table 6.12.

Water supply reliability for D5

Daily Data from January 1940 through December 2012

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF DAYS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%
B5157P	139237.4	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B3404A	467670.6	54.27	99.61	99.99	99.6	100.0	100.0	100.0	100.0	100.0	100.0	99.5	100.0	100.0	100.0	100.0	100.0	100.0
B2335A	799601.8	634597.25	20.44	20.64	20.4	20.5	20.6	20.8	21.2	21.7	22.8	11.3	11.6	12.0	14.5	18.7	26.4	42.8
B2456A	916337.8	526631.56	54.16	42.53	54.2	54.2	54.3	54.7	55.7	57.7	74.8	45.1	46.2	47.1	49.4	55.5	62.2	81.7
B2362A	170838.0	67141.30	61.00	60.70	61.0	61.1	61.1	61.4	62.2	64.1	72.2	53.8	54.5	55.3	56.6	62.1	67.5	82.4
B2410A	128827.1	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B4992A	212999.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B5021A	166852.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total	3002364.2	1228424.25		59.08														

Simulations D1, D6 versus observed annual maximum reservoirs storage

The simulation D6 represents 50% flood control reservoir storage allocated to conservation pool capacity, full authorized water use, daily time step, has flood control operation, and was developed as single-owner reservoir system. Simulation D5 was executed in order to show how 50% storage reallocation from flood control pool to conservation pool affects flood frequency analysis and water reliability.

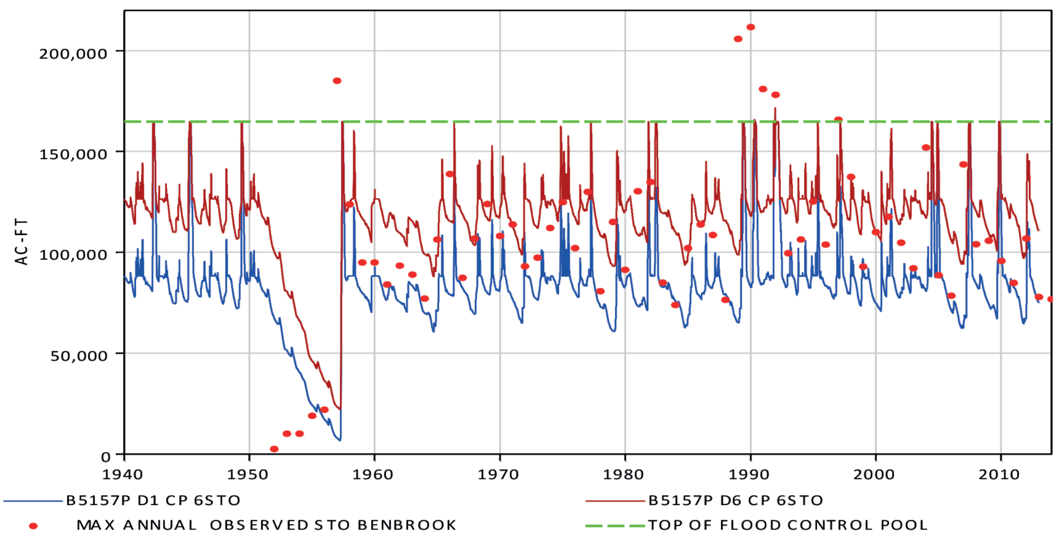

Figure 6.8. Benbrook Reservoir simulations D1, D6 versus max annual observed storage

Comparison of flood frequency analyses

Exceedance probability of top of controlled flood control for simulation D6 was performed for log-Pearson type III distribution for summation of reservoir storage and excess flow, then compared with simulation D1 and was observed flood frequency analysis. The simulation D6 return period values were expected lower than simulations D1, D4 and D5 return period because conservation storage capacity increased and flood control storage capacity decreased in simulation D6 and water levels were higher than simulations D1, D4 and D5.

Table 6.13.

Comparison of observed storage, D1 and D6 exceedance probability of top of flood control pool log-Pearson type III distribution

No	Reservoir	Top of Flood Control (ac-ft)	Observed		Sim D1 (Res. Sto. +Excess Flow)		Sim D5 (Res. Sto. +Excess Flow)	
			Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)
1	Benbrook	164800	7.22	13.85	16.68	6.00	38.63	2.59
2	Joe Pool	304000	0.71	140.85	0.10	1000.00	0.10	1000.00
3	Ray Roberts	1064600	6.75	14.81	0.01	10000.00	0.01	10000.00
4	Lewisville	959177	8.89	11.25	3.52	28.41	5.19	19.27
5	Grapevine	406900	4.57	21.88	0.40	250.00	4.38	22.83
6	Lavon	748200	7.08	14.12	0.10	1000.00	24.50	4.08
7	Navarro	212200	0.24	416.67	1.43	69.93	15.88	6.30
8	Bardwell	140000	0.39	256.41	0.10	1000.00	7.86	12.72

Water Supply Reliability for D6

Water supply reliability table was developed for control points that located at dams for simulation D6 as shown in Table 6.14. Benbrook, Joe Pool, Lavon, Navarro Mills, and Bardwell Reservoirs water diversion target 100% met in terms of simulation duration and diversion amount. There were little increase of water reliability for Ray Roberts, Lewisville, and Grapevine Reservoirs from in simulation D6 than simulation D1. However, like simulation D1, Ray Roberts Reservoir had very low water reliability in terms of period and volume. Storage reallocations increased water reliability but it was not much. However, return period of flood event increased especially simulation D6 was much than water reliability increase.

Table 6.14.

Water supply reliability for D6

Daily Data from January 1940 through December 2012

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF DAYS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%
B5157P	160831.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B3404A	601974.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B2335A	799601.8	634122.00	20.52	20.70	20.5	20.6	20.7	20.9	21.3	21.8	22.9	11.3	11.6	12.1	14.6	19.3	26.3	42.7
B2456A	910953.8	517188.50	54.97	43.23	55.0	55.1	55.1	55.5	56.5	58.4	75.2	46.1	47.3	48.1	50.5	56.2	63.1	82.2
B2362A	170052.3	61839.68	64.17	63.63	64.2	64.2	64.2	64.5	65.2	66.9	74.2	57.8	58.2	59.0	60.4	65.4	70.1	83.7
B2410A	129264.4	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B4992A	271708.2	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B5021A	185777.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total	3230163.8	1213150.12		62.44														

7. Discussion And Conclusion

The probability of storage exceeding the top of flood control pool provides a concise metric for quantifying flood control capabilities. The recurrence interval computed as the reciprocal of this exceedance probability also provides a convenient storage capacity metric. Recurrence intervals associated with filling flood control pools are tabulated in Table 7.1. The recurrence interval estimates in Table 16 are based on the frequency analyses of observed storage.

Table 7.1.

Comparison of recurrence intervals for overtopping flood control pools based on applying the log-Pearson type III (LP) and log-normal (LN) distributions to observed storage, simulated storage, and simulated storage plus excess flow

Reservoir	Storage (ac-ft) at Top of		Observed		Simulation		Excess Flow	
	Conservation	Fld Control	LP	LN	LP	LN	LP	LN
Benbrook	88,250	164,800	13.9	18.9	1,000	9.32	6.00	5.75
Joe Pool	176,900	304,000	141	1,000	1,000	10.7	1,000	10.7
Ray Roberts	799,600	1,064,600	14.8	14.5	10000	12.8	10000	12.7
Lewisville	618,400	959,177	11.3	10.4	28.4	12.4	28.4	12.4
Grapevine	162,500	406,900	21.9	27.6	435	8.73	250	8.66
Lavon	456,500	748,200	14.1	11.4	1,000	8.87	1,000	8.27
Navarro	63,300	212,200	417	98.0	79.4	29.6	69.9	29.1
Bardwell	54,900	140,000	256	233	1,000	52.6	1,000	52.6

The recurrence intervals shown in Table 7.1 vary greatly between reservoirs, vary greatly between observed and simulated storage, and vary significantly between the log-Pearson III (LP) and log-normal (LN) distributions. The recurrence interval estimates are unrealistically high is some cases and too low in other cases.

In addition to the base daily simulation (D1) included in Table 7.1, eight other simulations are presented to explore the effects of various factors on storage levels. Various issues affecting storage contents are addressed. Key issues are highlighted as follows.

Analyses based on observed flows are appealing but reflect significant shortcomings. The sample size of the annual frequency analyses is limited by the number of years in the period-of-record of observed storage. Impoundment of flows in Benbrook, Joe Pool, Ray Roberts, Lewisville, Grapevine, Lavon, Navarro Mills, and Bardwell Reservoirs began in 1952, 1985, 1987, 1952 (1989), 1952, 1952, 1953 (1975), 1963, and 1965. Several years were required to initially fill the conservation pools. Storage reallocations raising the top of conservation pools of Lewisville and Lavon Reservoirs occurred in November 1989 and December 1975, respectively. The years required to initially fill the conservation pools and the years before the storage reallocations at Lewisville and Lavon were not included in the frequency analyses. The simulation model has a consistent 73-year 1940-2012 period-of-analysis. The simulation model also applies a constant specified water management scenario and reservoir operating rules throughout the 1940-2012 hydrologic period-of-analysis.

Storage draw-downs in conservation pools provide additional storage of flood waters reducing the storage contents of flood control pools. For example, the 1950-1957 most severe drought on record ended with a major flood in April-May 1957, with much of the flood waters captured in conservation pools. The WAM dataset adopted for this research incorporates the authorized use scenario which is based on the premise that all water users use the full amounts authorized in their water right permits. Simulations presented in the preceding pages show the significant increases in storage contents of flood control pools that result from adopting the current water use scenario or no water use in the simulations.

Simulation results are presented preceding pages for alternative hypothetical storage relocation plans consisting of converting 10%, 20%, and 50% of the flood control pool storage capacity in each of the eight reservoirs to water supply by raising the designated top of conservation pool. Simulations D4, D5, and D6 were described in the preceding pages are identical to simulation D1 except for the reallocation of storage capacity. The volume reliability for the aggregated totals of all water supply diversions from the eight reservoirs for the alternative storage allocations are tabulated in Table 7.2 along with the recurrence intervals for overtopping the flood control pools.

Table 7.2.

The recurrence intervals shown in Table 7.1 vary greatly between reservoirs, vary greatly between observed and simulated storage, and vary significantly between the log-Pearson III (LP) and log-normal (LN) distributions. The recurrence interval estimates are unrealistically high is some cases and

	D1	D4	D5	D6
Reliability	0%	10%	20%	50%
	56.81%	57.77%	59.08	62.44%
Recurrence Interval (years) for Overtopping FC Pool				
Benbrook	6.00	5.08	4.12	2.59
Joe Pool	1,000	1,000	1,000	1,000
Ray Roberts	10,000	10,000	10,000	10,000
Lewisville	28.4	26.7	24.8	19.3
Grapevine	250	55.9	48.0	22.8
Lavon	1,000	1,000	1,000	4.08
Navarro	69.9	40.0	26.8	6.30
Bardwell	1,000	1,000	1,000	12.7

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Extended Turkish Abstract (Genişletilmiş Türkçe Özet)

Alternatif Reservuar Hacim Değişimlerinin Taşkın Kontrolu Açısından Değerlendirilmesi

Barajların işletilmesi ve rezervuar hacimlerinde yapılan değişimler, belediye, endüstriyel kullanım, hidroelektrik enerji üretimi, rekreasyon, baraj gölünde taşımacılık, balık ve suda yaşayan canlılar için su sürekliliğinin sağlanması ve ayrıca insanların hayatını ve mülklerini taşkından korumak için su yönetim uzmanları açısından Teksas'da ve dünyanın heryerinde önemli bir görevdir. Bu makalede, alternatif rezervuar hacim değişimlerinin sonuçlarını değerlendirmek için, WAM (Texas Water Availibility Modeling) sisteminden alınan Trinity Nehir Havzası verileri ve WRAP (Water Right Analysis Package) programı kullanıldı. Çok amaçlı rezervuarlarda taşkın kontrol ve su temini hacimlerinin değişimleri sonucunda taşkın tekerrür periyodu ve su temini güvenirliliği değerlendirildi. Trinity Nehri Havzasında USACE'ye (United States Army Corps of Engineers) ait olan sekiz adet çok amaçlı rezervuar örnek olarak incelendi.

Taşkın kontrolü için WRAP/WAM rezervuar sistemi işletim similasyonu test edildi ve geliştirildi. Modellenen rezervuar işletim stratejisi similasyonları ve gözlenen maksimum yıllık hacim seviyesi verileriyle sıklık analizi yapıldı. Sıklık analizi, taşkın kontrol hacminin geçme olasılığı hesaplamasında kullanıldı. HEC-SSP (The Hydrologic Engineering Center-Statistical Software Package) programı gözlenmiş verilerin sıklık analizini yapmak için log-normal ve log-Pearson type III dağılımları ile kullanıldı. Çok amaçlı reservuar sistemi simulasyonunda ve hacim sıklık analizi sırasında ortaya çıkan problemler araştırıldı.

Sekiz rezervuar için yeniden hacim tahsisi, su temini hacminin maksimum su seviyesini yükselterek taşkın kontrolü hacminden su temini hacmine yer verilerek yapılabilir. Bu çalışmada, similasyon sonucunda yapılan değişikliğin taşkın kontrolündeki etkileri, taşkın kontrol hacminin tamamen dolma olasılığı açısından değerlendirildi. Su güvenirliliği değişikliği etkileri, su temini açısından değerlendirildi.

Trinity Nehri Havzası Rezervuarları için WRAP programı ile alternatif altı simülasyon yapıldı. Altı simülasyondan üç tanesi taşkın kontrol hacminden su temini hacmine tahsis edilerek yapıldı. Rezervuar su seviyeleri, taşkın sıklık analizi ve su temini güvenirliliği gözlenmiş ve similasyon sonuçlarıyla karşılaştırıldı ve değerlendirildi.

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