How Many Times did 2,100 Watershed Dams in Oklahoma Experience Auxiliary Spillway Flows in 67 Years?

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Abstract
Since 1948, local project sponsors in Oklahoma constructed 2,107 dams with assistance of the Natural Resources Conservation Service (NRCS) Small Watershed Program. NRCS staff in Oklahoma has kept detailed records of auxiliary spillway flows on these dams over the past 67 years. NRCS and conservation district field office staffs conducted field reviews to verify spillway flows and depths following storm events. NRCS prepared special storm reports including performance of the dams and auxiliary spillway flows following many of the major storms.

This paper provides a summary of the 1,047 dams that have experienced 1,890 auxiliary spillway flows since 1948. The authors analyzed the auxiliary spillway flow records by the location of the dams and the storms, depths of flows, and damages. The reasons why some spillways flowed, while others did not are also discussed with respect to the changes in design criteria at the various times the dams were planned and designed. A history of the changes in NRCS, formerly Soil Conservation Service (SCS), dam design criteria from 1948 thru 1997 is provided. This analysis revealed the actual recurrence frequencies of auxiliary spillway flows and compares them to current design criteria. The results of this analysis should be applicable to thousands of similar age dams in the Midwest.

Oklahoma watershed dams are typically earthen embankments ranging from 20 to 80 feet in height with earthen vegetated auxiliary spillways and concrete or metal principal spillway conduits. Climatic conditions associated with average annual precipitation range from less than 22 inches to more than 56 inches per year. The dams are designed primarily for flood control, grade stabilization, water supply, or recreation.

The authors believe that these Oklahoma records covering 67 years of auxiliary spillway flows for 2,107 dams are the most complete dataset of spillway flows that exist.

Watershed Program Background
Since 1948, the NRCS has assisted project sponsors construct almost 12,000 dams in 47 states with assistance from one of the USDA Watershed Programs (Public Law 78-534, Public Law 83-566, Pilot Watershed Program, and Resource Conservation and Development (RC&D).

These watershed dams are federally-assisted, not federally-owned; they are locally-owned and maintained by project sponsors. The sponsors are generally local conservation districts, special use conservancy districts, or municipalities and usually have easements on private lands to construct, operate, and maintain the watershed dams. In almost all cases, sponsors have non-technical personnel in charge of the operation and maintenance of the dams, so many of the project sponsors rely on NRCS for technical assistance with operation and maintenance issues.

Oklahoma Watershed Program Background
Oklahoma has been a national leader in the Watershed Program since its inception. Oklahoma has many national watershed firsts including the first watershed dam built in the nation in 1948 (Cloud Creek Watershed dam no. 1 near Cordell, OK). There have been 2,107 watershed dams constructed in 120 watershed projects in Oklahoma since 1948; more than any state in the nation. The 120 watershed projects cover 12,310,000 acres; more than one-fourth of the state of Oklahoma.

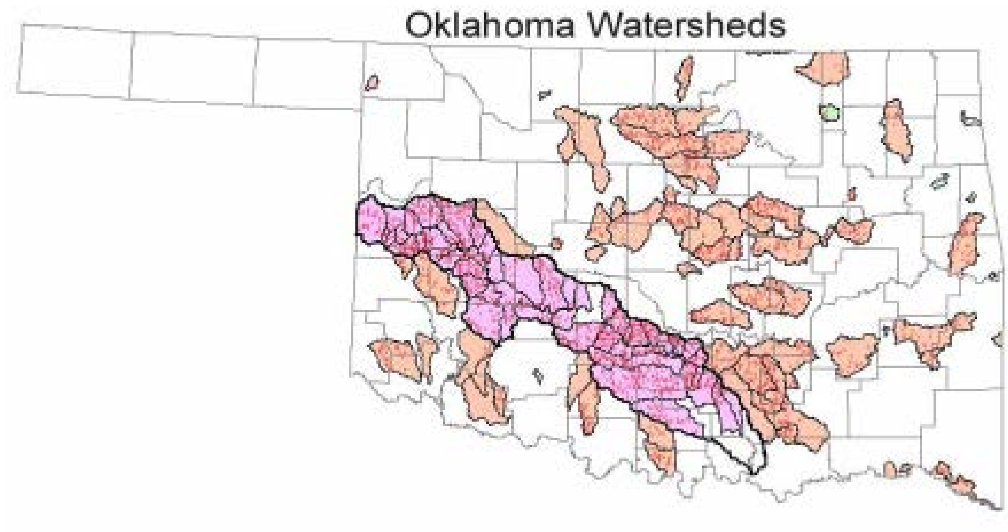

Figure 1: 120 watershed projects contain 2,107 watershed dams in Oklahoma.

Ages of Watershed Dams

According to the National Inventory of Dams (NID), Oklahoma has the most watershed dams and oldest watershed dams in the nation. The majority of the watershed dams in Oklahoma and across the nation have a 50-year planned service life. Figure 2 illustrates the number of watershed dams constructed in Oklahoma per year since 1948, including the authorizing legislation that provided funds for the planning, design, and construction of the dams. The peak of construction in Oklahoma was 1965 with 157 dams completed. Ninety-five percent of the watershed dams in Oklahoma were constructed by 1983.New construction of watershed dams in Oklahoma has stalled with only seven watershed dams completed since 2000. By the end of 2015, there were over 1,000 watershed dams in Oklahoma that had reached the end of their planned service life. By 2020, over 1,500 watershed dams will have reached this milestone. By the end of 2015, the oldest watershed dam in Oklahoma was 67 years old.

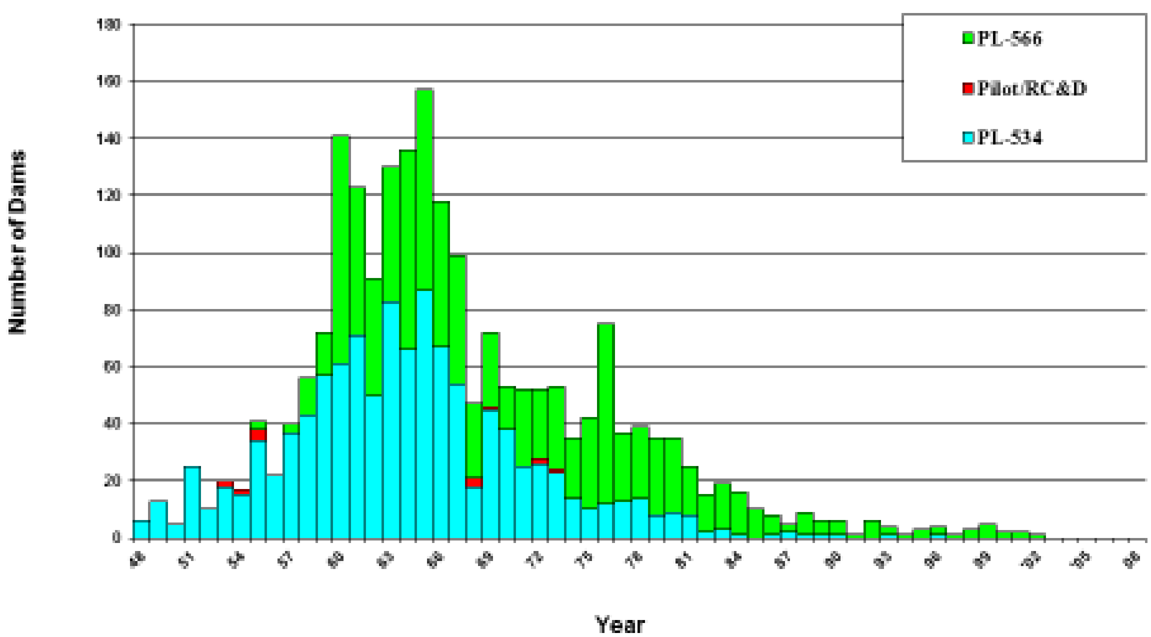

Figure 2: Number of watershed dams built in Oklahoma each year since 1948, summarized by the authorizing authority (i.e. PL-534, PL-566, Pilot, and RC&D)

Watershed Dam Description
Typically, Oklahoma watershed dams are earthen embankments ranging from 20 to 80 feet in height with earthen vegetated auxiliary spillways and concrete or metal principal spillways. Most watershed dams were planned to provide flood control for agricultural land and thus were constructed in rural areas. Some dams provide grade stabilization, water supply, and/or recreation. Figure 3 provides a schematic of a typical watershed dam. The majority of the reservoirs provided storage for the anticipated sediment accumulation during a 50-year period. The area above the principal spillway crest elevation, as illustrated in Figure 4a, provides temporary detention storage for runoff from large storms. Water temporarily stored in the reservoir is slowly released through a principal spillway conduit as shown in Figure 4b. This controlled release through the principal spillway reduces flood damages downstream. Grade stabilization structures generally have larger principal spillway conduits with less detention storage than typical floodwater retarding dams. NRCS typically designed principal spillways for a 25 to 100-year frequency storm depending on their hazard classification. Watershed dams typically include an earthen vegetated auxiliary spillway designed to safely pass excessive runoff generated by less frequent yet larger storm events around the earth embankment.

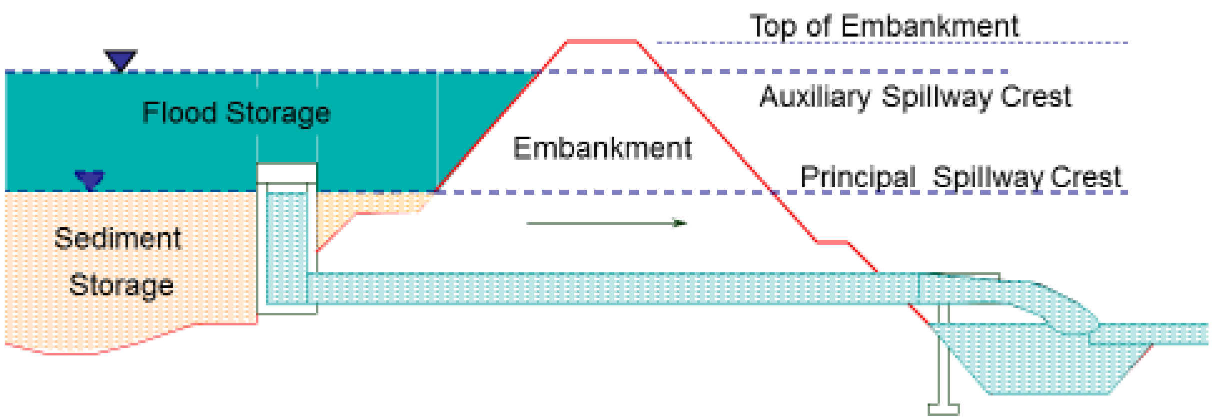

Figure 3: Section of Typical Watershed Dam

(a) (b)

Figure 4: (a) Runoff from large storms is temporarily stored in the detention pool (below yellow line) and (b) slowly released through the principal spillway conduit

Figure 5: Auxiliary spillways are typically vegetated channels that safely convey runoff from large storms around the dam to avoid overtopping of the embankment

Figure 6: Auxiliary spillway functioning as designed

The following is a summary of the sizes of the Oklahoma watershed dams:

Dam Characteristic	Median	Maximum
Height	33 ft.	101 ft.
Drainage area*	1.7 sq. mi.	72 sq. mi.
Principal spillway conduit diameter	18 inches	72 inches
Auxiliary spillway width	80 ft.	1,000 ft.
Sediment storage	94 ac.-ft.	2,192 ac.-ft.
Detention storage	366 ac.-ft.	20,000 ac.-ft.
Maximum storage	682 ac. ft.	86,000 ac. ft.
Embankment volume	63,900 cu. yds.	1,203,000 cu.yds.
Embankment length	1,040 ft.	10,020 ft.

* 2,021 of 2,107 dams have a drainage area less than 10 sq. mi. (96%)

Table 1: Summary of dam characteristics of Oklahoma watershed dams

Typically, the upstream and downstream side slopes of the embankments constructed prior to 1970 were 2.5:1, although a few were as steep as 2:1 and some were 3:1. Few of the embankments had downstream stability berms. Most of the embankments were constructed higher in the center to allow for settlement of the foundation and embankment. With few exceptions, most of the embankments are still higher in the center as either the anticipated settlement did not occur to planned extent or else much of the consolidation occurred during construction.

Conceptually, the three major variables that determine whether an auxiliary spillway flows are:

1. Volume of inflow: dependent on runoff amount which is dependent on rainfall amount, intensity, and distribution, drainage area, soils (infiltration), and land use.
2. Volume of storage (temporary detention in reservoir): dependent on height of embankment and topography of reservoir area.
3. Volume of outflow (principal spillway discharge): dependent on conduit size, material, and length, the proportioning of the inlet, and if there is an orifice that restricts full pipe flow.

General Description of Oklahoma’s Climate and Storms

Oklahoma has long periods of extreme drought followed by periods of extreme rainfall events. For example, the Dust Bowl occurred during what became famously known as the Dirty Thirties (1930’s era), and encompassed a large portion of Oklahoma. These dry conditions were followed by storm events of historic proportions that often occur during the spring and fall.

The following information from the Oklahoma Climatological Survey describes the variability of Oklahoma’s weather patterns: Average annual precipitation across Oklahoma typically decreases from east to west. Figure 7 illustrates this rainfall pattern from 1981 to 2010. Average annual precipitation ranges from about 17 inches in the far western panhandle to about 56 inches in the far southeast. However, precipitation is quite variable on a year-to-year basis, as shown in Figure 8. The greatest annual precipitation recorded at an official reporting station in Oklahoma was 89.69 inches at Daisy in Atoka County in 2015. The least annual precipitation recorded at an official reporting station in Oklahoma was 6.54 inches at Regnier, OK, located in the northwestern part of the Oklahoma Panhandle in 1956.

The frequency of days with measurable precipitation follows the same gradient as the annual accumulation, increasing from 45 days per year in western Oklahoma to 115 near the Arkansas border. On average, more precipitation falls during the nighttime hours, while greatest rainfall intensities occur during late afternoon. The largest officially recorded rainfall in a 24-hour period was 15.68 inches near Enid on October 11, 1973.

The character of precipitation also varies by season. Wintertime precipitation tends to be somewhat widespread. Summertime precipitation is almost entirely convective in nature. A significant portion of the state's precipitation occurs during the spring and fall seasons and is generally associated with systems of severe thunderstorms.

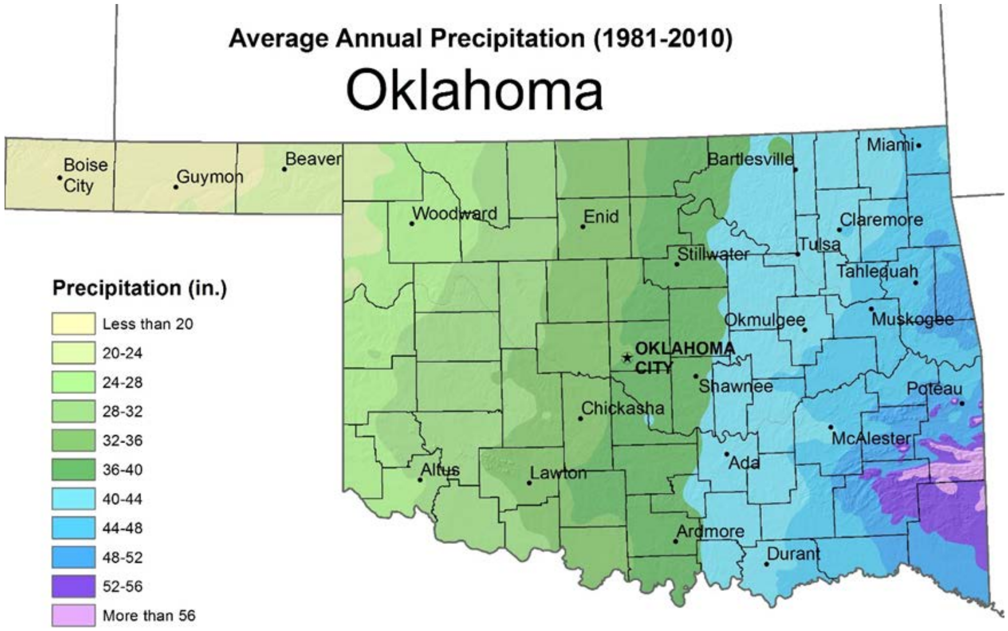

Figure 7: Map showing normal annual precipitation (in inches) for Oklahoma using data from 1981 to 2010

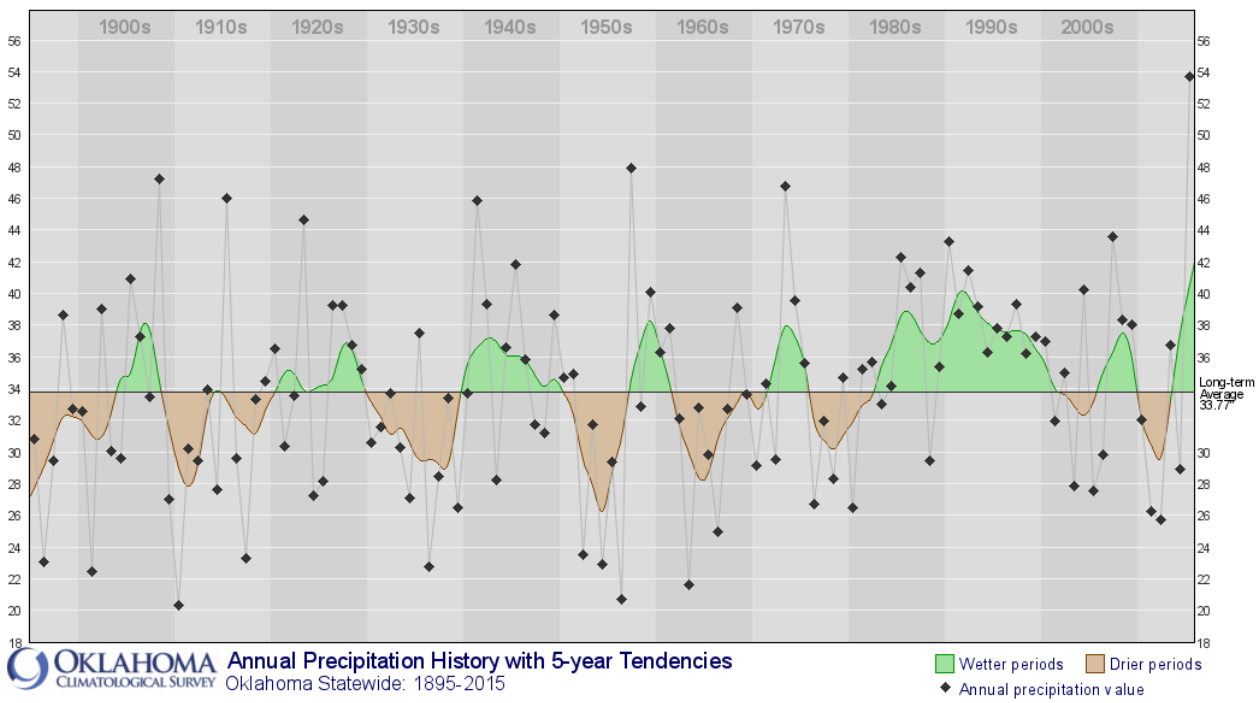

Figure 8: Graph of the statewide average annual precipitation (in inches) for Oklahoma using data from 1895 to 2015. Green shading (above the horizontal line) highlights wetter periods and brown shading (below the line) highlights drier periods than average.

Oklahoma NRCS Auxiliary Spillway Reporting Policy
SCS personnel in Oklahoma recognized early on the importance of monitoring extreme weather events in relation to the performance of watershed dams and the reduction of flooding that resulted. When large storms occurred over watershed projects, considerable staff time was devoted to conducting site-specific studies to determine high water levels and crop and road damages in downstream areas. SCS and local sponsors used the studies to document the success of the watershed projects, the performance of the dams, and the benefits the dams actually provided.

In 1970, Ray Riley, a new hydrologist on the state staff at that time, gathered and summarized data on auxiliary spillway flows of dams constructed up until that time. This data was used to help evaluate the design criteria and propose changes if needed. All field office staffs reported known spillway flows up to that date to Riley. He also reviewed all storm reports in the files and summarized the data. Riley sent the resulting data to all field offices for review and comment. Oklahoma NRCS recognized the value of this performance data and developed a state policy in 1972 that required all field office staffs in Oklahoma to document rainfall and structure data for every dam that experienced auxiliary spillway flow. This policy continues in effect to date and is contained in an Oklahoma supplement to the National Engineering Manual, section 504.12. Due to this long-term policy, Oklahoma has one of the most comprehensive state data sets of auxiliary spillway flows and performance of dams in the nation.

To provide a consistent record to document the field investigations of auxiliary spillway flow events, NRCS developed the form shown in Figure 9 for field office staffs to complete for every dam that experienced auxiliary spillway flow. After each major storm event, the data from the data sheets were transferred to the master auxiliary spillway summary file was updated every year there were storms that resulted in auxiliary spillway flows.

In the mid 1970's, there was national attention given to improving the integrity and stability of auxiliary spillways. Technical staffs from the Agricultural Research Service and NRCS collaborated to study both principal and auxiliary spillway performance. In 1983, following a major flood in Arkansas, a national Emergency Spillway Flow Study Task Group (ESFSTG) was formally established and national policy was issued that directed all state conservation engineers to report all auxiliary spillway flows with over one foot flow depth to the national office. This policy is contained in NRCS National Engineering Manual section 504.12. NRCS later revised the policy to three-foot flow depth, which remains the policy to date. There were several site specific studies completed by this task group during the 1970's and 1980's, including three studies in Oklahoma. This task group continued to gather data into the early 1990's when the Design and Analysis of Earth Spillways team was formed to analyze the data and develop new design criteria and procedures.

In 2010, NRCS contracted with USEngineering Solutions to implement their DamWatch® application to include all watershed dams in Oklahoma. DamWatch is a patented web-based system that allows users to monitor storm events and quickly respond to potentially destructive flood events. Users can access the system from any computer or mobile device with internet access. It gathers real-time meteorological, hydrologic, and seismic data sources and compares it against established site-specific thresholds; then automatically alerts predetermined users of anticipated spillway flows via cell phone text and e-mail. Upon notification, NRCS or project sponsors can dispatch staff to dams when the system issues alerts. This software has improved the response time as well as identifying dams that likely have experienced auxiliary spillway flow. Personnel from NRCS and project sponsors can generate electronic "tickets" (i.e. reports) within DamWatch to document the performance of the spillways, as well as describe repair needs. These tickets are maintained in the DamWatch system for future reference.

Auxiliary Spillway Flow Summaries
Since the beginning of the Oklahoma watershed program in 1948, there have been numerous storms that have resulted in many auxiliary spillway flows. The first auxiliary spillway flows were reported in southwestern Oklahoma for four dams on May 1, 1950. At that time, only 25 watershed dams had been constructed in the state. As more dams were constructed, the number of reported auxiliary spillway flows increased with each extreme rainfall event. For instance, twenty-three auxiliary spillways flowed in May and June of 1957 when a wide spread storm occurred in north central Oklahoma; by that time 194 watershed dams in Oklahoma had been constructed.

Since 1948, there have been 64 storms that resulted in one or more auxiliary spillway flows. Eighty percent of the 1,890 auxiliary spillway flows occurred as a result of ten storm events as summarized in Table 2. Table 3 summarizes these 64 storm events that resulted in a total of 1,890 auxiliary spillway flows in 37 of the 67 year history of the Small Watershed Program in Oklahoma. Several of these storms exceeded 500-year return frequencies. There were no spillway flows during 30 of the past 67 years.

Rainfall Event		No. of AS Flows
Start Date	End Date	
4/26/1990	5/4/1990	352
5/27/1987	5/29/1987	206
5/6/2015	5/26/2015	204
5/28/2015	6/19/2015	195
9/28/1986	10/4/1986	178
10/19/1983	10/20/1983	101
6/9/1995	6/10/1995	90
10/12/1981	10/18/1981	75
10/7/1970	10/8/1970	59
6/26/2007	7/10/2007	59

Table 2: Summary of ten storm events that resulted in 1,519 auxiliary spillway flows (80% of the total) in Oklahoma from 1948 to 2015

U. S. Department of Agriculture
Natural Resources Conservation Service

OK-PDM-4

WATERSHED STRUCTURE SPECIAL STORM INSPECTION REPORT

Field Office	Watershed	Site Number
Original Notification (check or circle one) Site Visit Local Report DamWatch Alert: “Rainfall” or “Spillway Flow”		
Date(s) of rainfall	Approximate inches of rainfall	
Approximate maximum depth of flow *(ft.)* in Auxiliary Spillway: Estimate hours Auxiliary Spillway has functioned:		
Condition of Auxiliary Spillway		
Condition of Principal Spillway Outlet		
Condition of Embankment		
Date DamWatch Alert was terminated? _______ No DamWatch Alert was Issued_______		
General remarks		

District Conservationist   Date

Figure 9: Form used in Oklahoma to gather basic field data on auxiliary spillway flows

Year	No. of AS Flows	No. of Storms	No. of Dams Built by that Year
1950	4	1	25
1957	23	2	154
1959	8	4	250
1965	12	1	943
1968	1	1	1,319
1969	3	1	1,368
1970	64	2	1,440
1971	2	1	1,493
1973	20	4	1,597
1974	28	4	1,650
1975	4	1	1,685
1977	7	1	1,803
1980	4	1	1,914
1981	75	1	1,950
1982	2	1	1,977
1983	101	1	2,012
1985	4	1	2,028
1986	178	1	2.039
1987	207	1	2,047

Year	No. of AS Flows	No. of storms	No. of Dams Built by that Year
1988	2	1	2,053
1989	4	1	2,062
1990	380	2	2,068
1991	2	1	2,074
1992	5	1	2,075
1993	10	1	2,081
1995	105	3	2,085
2001	1	1	2,102
2003	1	1	2,105
2004	2	2	2,102
2007	127	8	2,102
2008	15	2	2,102
2009	6	1	2,102
2010	2	1	2,102
2011	2	1	2,106
2012	3	1	2,107
2013	2	1	2,107
2015	485	4	2,107

Table 3: Summary of 1,890 auxiliary spillway flows
that resulted from 64 storms in 37 years

From 1950 to 2015, 1,047 of the 2,107 watershed dams experienced 1,890 auxiliary spillway flow events. Auxiliary spillways on several of the dams flowed more than once as shown in Table 4. The auxiliary spillways on 1,060 dams have never experienced flow.

Number of dams that experienced auxiliary spillway (AS) flows from 1948 to 2015								
0 AS flows	1 AS flow	2 AS flows	3 AS flows	4 AS flows	5 AS flows	6 AS flows	7 AS flows	Total
1,060	548	280	131	65	11	10	2	1,047

Table 4: Summary of watershed dams that experienced multiple auxiliary spillway flows

Almost half of the 1,890 auxiliary spillway flows had flow depths less than 1.0 foot deep and 90% were less than 2.5 feet deep as summarized in Table 5. The maximum reported flow depth was 5.3 feet. Reports indicated that approximately ten embankments overtopped either partially or along the entire length of the dam with minimal or no damage to the embankment.

Summary of AS Flows by Flow Depth			
AS Flow Depth (feet)	No. of AS Flows	% of Total	Accum %
0.1 to 0.4	341	18%	18%
0.5 to 0.9	546	29%	47%
1.0 to 1.4	470	25%	72%
1.5 to 1.9	194	10%	82%
2.0 to 2.4	150	8%	90%
2.5 to 2.9	57	3%	93%
3.0 to 3.4	21	1%	94%
3.5 to 3.9	9	0.5%	95%
4.0 to 4.4	6	0.3%	95%
4.5 to 4.9	1	0.1%	95%
5 to 5.2	3	0.2%	95%
unknown	92	5%	100%
Total	1,890	100%	

Table 5: Range of flow depths of auxiliary spillway flows

Damages resulting from auxiliary spillway flows

Following spillway flow events, field inspectors reported damages using ratings of “severe”, “moderate”, or “slight or none”. The ratings for the damages were somewhat subjective, but provided an indication of the need for repairs. The majority of the reported “severe” and “moderate” damaged auxiliary spillways required special designs and formal contracting for the repairs.

Of the 1,890 auxiliary spillways that flowed during the past 67 years, only 325 were reported with ratings of “severe” or “moderate” damage. Almost half of the auxiliary spillways with flow depths greater than 3.0 feet were damaged, while about one-third of those with flow depths between 2.0 and 2.9 feet were damaged. Less than 15% of those with flow depths less than 2.0 feet were damaged. Table 6 summarizes the damages resulting from auxiliary spillway flows.

Auxiliary Spillways Damaged with Various Flow Depths				
AS Flow Depth (ft.)	Severe Damage	Moderate Damage	Total No. of AS Flows	% Damaged
> 3.0	7	10	40	43%
2.0 - 2.9	39	36	207	36%
1.0 - 1.9	70	74	664	22%
< 1.0	34	55	887	10%
Unknown	0	0	92	0%
Totals	150	175	1,890	17%

Table 6: Summary of auxiliary spillway flow depths that resulted in severe or moderate damage ratings

Why did half of the auxiliary spillways flow while the other half did not?
An examination was made of the auxiliary spillway flow data to determine if patterns emerged in the frequency and/or location of the dams experiencing these flows.. The following were determined to be possible reasons why half of the watershed dams experienced auxiliary spillway flows, but the other half did not.

1. "Luck of the draw" as to the location of heavy thunderstorms and high rainfall events.
2. Age of the dam played a role; some dams have existed much longer than others, so they had more opportunities to experience high rainfall events
3. High and significant hazard dams were designed with more detention storage which in turn affected the frequency of auxiliary spillway flows.
4. Drought conditions proceeding extreme rainfall events affected occurrence of auxiliary spillways flows. Some dams had more than designed detention storage at the time of high rainfall events due to previous drought conditions that lowered the permanent reservoir.
5. Wetter than normal conditions proceeding extreme rainfall events affected occurrence of auxiliary spillways flows. Some of the dams had less than designed detention storage at the time of high rainfall events either due to accumulated sediment in the detention pool or a higher than normal reservoir due to runoff from prior storms that had not yet drained down.
6. Land use change, drought conditions, heavy growth and/or dense vegetation in the watershed affected infiltration rates that resulted in different runoff conditions than assumed in the original design.
7. The principal spillways could not function as designed due to principal spillway inlet restrictions from debris or inlet modifications.

Interpretation of the auxiliary spillway flow data
All of the above reasons are reasonable contributing factors for auxiliary spillways flowing for a specific dam or group of dams. However, upon more detailed analysis, the authors found that the following primary variables were the most critical to analyze:

1. <u>Changes in design criteria for detention storage and principal spillway discharge:</u>
   The design of dams has evolved over the years as more experience was gained, research was conducted, and issues developed that had to be addressed. This resulted in the dams designed in the 1950's having different detention storage volumes and principal spillway discharges than required

for similar dams designed in the 1970's or later. The authors considered this variable by analyzing the auxiliary spillway flows by the following four planning and design time periods:

   a. 1948 to 1957
   b. 1958 to 1964
   c. 1965 to 1971
   d. 1972 to 1997

2. The location and number of high rainfall events:
   Theoretically, the frequency of auxiliary spillway flows should be similar regardless of the average annual rainfall amounts across the state, since design storms also vary across the state. The authors considered this variable by analyzing the auxiliary spillway flows by the following four average annual rainfall zones in the state:
   a. less than 26 inches
   b. 26 to 32 inches
   c. 32 inches to 40 inches
   d. greater than 40 inches.

3. Age of the dams:
   Older dams have more opportunities to experience more extreme rainfall events. The authors considered this variable by determining the "structure-years" for specific dams or groups of dams. A "structure-year" for a specific dam is the age of the dam. The "structure-years" for a group of dams is the summation of the ages of all of the dams in that group.

The following summarizes each of the variables examined for the detailed analysis of auxiliary flows:

Variable 1: Changes in design criteria for detention storage and principal spillway discharge:
By 1948, SCS had assisted farmers and ranchers with building an estimated 100,000 farm ponds since the agency's creation in 1935. SCS designed almost all of these small dams were designed with little or no detention storage. SCS employees were knowledgeable and experienced in most of the dam construction techniques of the time. However, the agency was still gaining knowledge and experience in the principals of hydrology and hydraulics and their impacts on   detention storage or auxiliary spillway design.

During the 1950's and 60s, SCS gained considerable experience during the planning, design, and construction of hundreds of dams in Oklahoma and the nation. Additionally, research by USDA-Agricultural Research Service were assisting with the development of engineering design criteria and understanding of hydrology, climate, and other related topics that could affect the development of design criteria and/or policy within the USDA-SCS. The culmination of first-hand field experience and research resulted in many improvements in engineering criteria that influenced the design of dams for years to come. A listing of selected historic SCS criteria documents are shown in appendix 1

From 1948 to 1997, SCS in Oklahoma developed and authorized 120 watershed project plans that resulted in the construction of 2,107 dams. Since 1948, 1,047 dams in 88 of these projects experienced 1,890 auxiliary spillway flows, while 1,060 dams have never experienced auxiliary spillway flows. Figure 11 shows the locations of the watershed projects and the number of auxiliary spillway flows by watershed project.

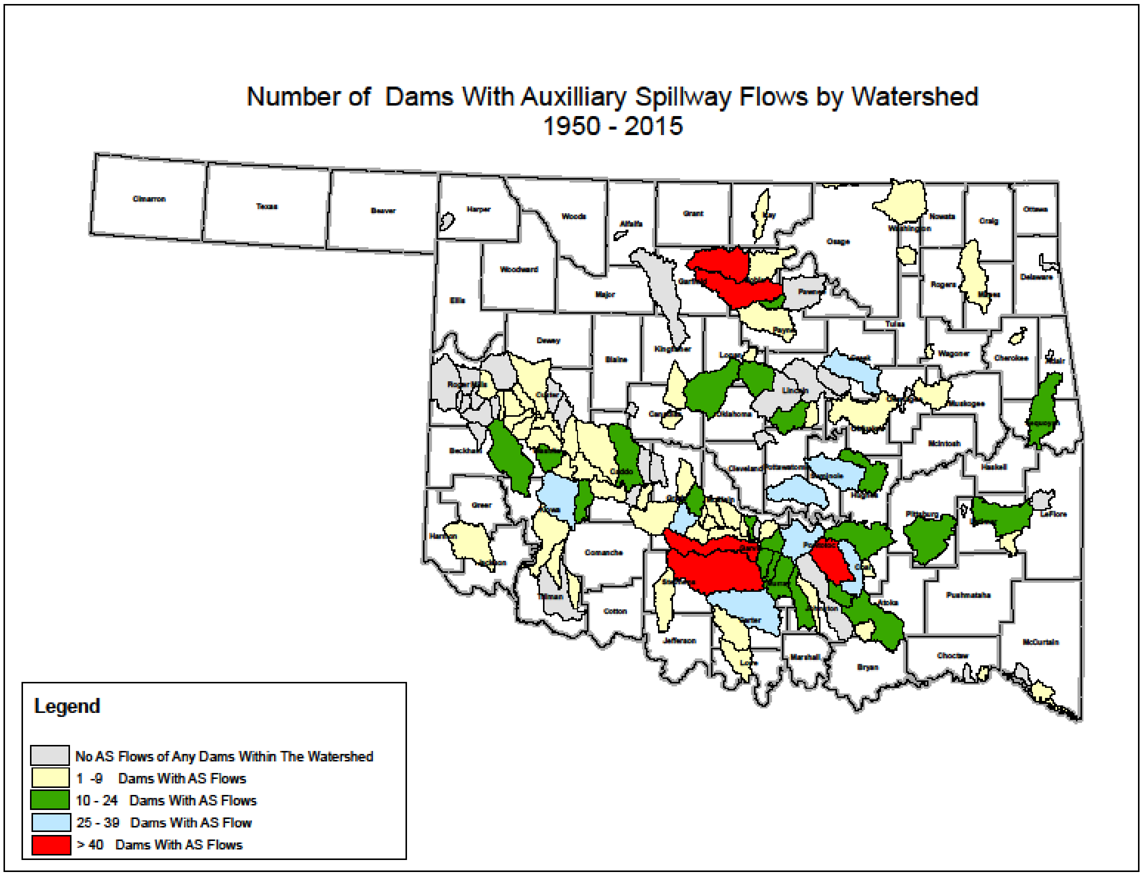

Figure 11: Watershed projects with dams showing number of auxiliary spillway flows

Because the design criteria changed over the years, the authors analyzed the auxiliary spillway flows by dividing the data into four time periods when the dams were planned, designed, and constructed. The following is a summary of the SCS/NRCS design criteria for each time period and the auxiliary spillway flows that occurred on the dams that were constructed during in that era.

Watershed Projects Planned from 1948 to 1957:

From 1948 to 1957, SCS planned and authorized 32 watershed projects in Oklahoma. SCS eventually built 605 dams in these watersheds. Since 1948, 301 of these dams experienced 598 auxiliary spillway flows, while the remaining 304 dams have never experienced auxiliary spillway flows. Fifty percent of the 605 dams built during this nine-year period have experienced auxiliary spillway flows through 2015. Table 7 provides a summary of auxiliary spillway flows for dams planned from 1948 to 1957.

In these early years of the watershed program, SCS used a conservative application of existing farm pond criteria for dam design. One of the problems with early hydrology was the lack of good rainfall probability data. Rainfall data published by Yarnell in 1935 was the only source of rainfall - frequency data. It was recognized fairly early in the planning process that Yarnell's data were generally too low. SCS designers continually increased the Yarnell values by arbitrary amounts called “p” factors. However, in some instances, SCS used the actual Yarnell values as a minimum. SCS built 40 to 50 dams in Oklahoma during the 1950's using the Yarnell minimum values. An evaluation of auxiliary spillway flows through 1978 showed that 17 of 19 dams designed with Yarnell minimum storage values had flowed at least twice. This gives strong credibility to the later detention storage criteria which increased Yarnell values by roughly 25 percent.

Watershed projects planned prior to 1957 used various versions of a method of manual watershed modeling called “concurrent flow”. The concurrent flow method was based on a 20-year period of rainfall deemed representative of the watershed. Normally a two-day rainfall amount (deemed 24-hour rainfall) using three or more 24-hour reporting precipitation stations was determined by using a weighted Theissen Polygon method. All stations were second order stations which measured daily precipitation at a specific time each day. This procedure also required a survey of high water marks from the flood of record which was used to establish the rainfall-runoff relationship for all storms for flood damage estimates in the watershed. Planners also used the rainfall-runoff relationship developed by this procedures one part of the detention storage determination for planning and designing the dams in the watershed. The maximum rainfall event was checked against the 1935 Yarnell 25-year, 24-hour precipitation. If it did not exceed the Yarnell 25-year, 24-hour value, planners used the Yarnell 25-year, 24-hour value as the minimum. Further, planners used the Yarnell 25-year, 24-hour storm if the largest event in the 20-year rainfall series was determined to be excessively high (a subjective outlier).

In Oklahoma, SCS used the concurrent flow procedure for watersheds west of the 26-inch average annual rainfall line (less than 2.0 inches average annual runoff) such as Sandstone Creek, Barnitz Creek, Sergeant Major Creek and Quartermaster Creek. SCS constructed 245 dams (with 13,376 structure-years of record) west of the 26-inch average annual rainfall line. Only 20 of these dams have experienced auxiliary spillway flows to date with two of them flowing twice (all with 2.0-foot flow depth or less). SCS planned and designed almost all of these dams using concordant flow procedures. The minimal number of flows (one flow per 608 structure-years of record) results primarily from the drier climate rather than the use of concordant flow procedures.

The authors concluded that the analysis of auxiliary spillway flows indicate that watersheds east of the 26-inch average annual rainfall line were progressively under designed by the methods SCS used during this period. Four good examples of watersheds planned prior to 1957 with apparently deficient auxiliary spillway designs are Sandy Creek, Little Deep Fork, Little Wewoka Creek, and Chigley Sandy Creek. A prime example of deficiencies in Yarnell minimum design criteria is the Chigley Sandy Creek Watershed planned in 1951. The detention storage for all dams was at or slightly above Yarnell minimums. Since SCS constructed the first dam in 1955, all fourteen sites have experienced auxiliary spillway flow with one dam flowing only once while six sites have flowed 6 times. To date, Chigley Sandy dams have flowed 60 times in 833 structure-years of record or once for every 13.9 years of record. This frequency of auxiliary spillway flow is over three times the rate of other dams planned and constructed later in the same rainfall-runoff zone.

The first auxiliary spillway flows occurred soon after the first dams in Oklahoma were built. In May, 1950, when only 24 watershed dams had been constructed statewide, a large storm occurred in western Oklahoma where most of those dams were built. Auxiliary spillways of four dams in the Owl Creek Watershed flowed. The drainage areas of these four dams were less than one square mile. The other 11 dams in this watershed that did not flow had drainage areas greater than one square mile with 4.60 inches of detention storage.

In 1951, the design of the detention storage of the dams in the Chigley Sandy Creek Watershed did not appear to involve flood routing. Ten of the dams in this watershed have 4.20 inches of flood storage, one with 4.10 inches, and one with 4.30 inches. There was essentially no difference in detention storage regardless of drainage area size or principal spillway release rate. All of the 14 dams in this watershed have flowed; nine of the 14 dams flowing three to six times.

SCS Washington Engineering Memo 3 was issued October 7, 1954. It contained the first SCS national criteria for design of flood retarding dams. It included criteria to determine minimum capacities and elevations for auxiliary spillways. It was the first document to include the concept of hazard potential in the design of the dam. It required greater capacities for a dam that might cause loss of life if it should fail.

In July 1956, a revision to SCS Washington Engineering Memo 3 was issued. It provided definitions of three hazard potential levels (low, moderate, and high) and provided criteria for auxiliary spillway design and freeboard capacities based on the hazard potential. It also provided more detailed national hydrologic, hydraulic, and embankment criteria for the design of dams. The 1956 document set the detention storage requirements for determining the auxiliary spillway elevation based on the following design storms depending on the hazard classification:

Low hazard: 25yr.-6 hr. storm
Moderate hazard: 25 to 50 yr.-6 hr. storm
High hazard: 100yr.-6 hr. storm

This document was the predecessor of SCS Washington Engineering Memo 27 that was issued March 14, 1958 and was completely replaced by a revision dated March 19, 1965. This document provided dam design guidance during the period when most of the watershed dams were planned, designed, and constructed.

Principal spillway release rates in the early structures were very low. As an example, the Cobb Creek Watershed Workplan in 1951 had principal spillway release rates that varied from 2 - 3 cubic feet per second per square mile (csm).The feeling in1951 was that the dams should store all the flood volume and release it slowly over a long time period. The use of lower csm rates contributed to the number of auxiliary spillway flows since detention pools were not always completely evacuated between flood producing events. The floods of 1957 would cause SCS to re-evaluate this release rate philosophy.

Projects Planned from 1948 to 1957

Watershed	Program	Year Planned	No of Dams in Project	Years Dams Built		No. of Dams with AS Flow	No. of AS Flows	% Dams with AS Flows
				Ist Dam	Last Dam			
Sandstone Creek	PL-534	1949	42	1951	1965	0	0	0%
Barnitz Creek	PL-534	1950	76	1948	1975	2	2	3%
Chigley Sandy Creek	PL-534	1951	14	1955	1973	14	60	100%
Cobb Creek	PL-534	1951	12	1956	1959	4	5	33%
Peavine Creek	PL-534	1951	10	1959	1961	8	13	80%
Pennington Creek	PL-534	1951	3	1953	1953	2	2	67%
Wayne Creek	PL-534	1951	2	1953	1953	1	4	50%
Beaver Dam Creek	PL-534	1952	6	1953	1970	0	0	0%
Big Kiowa Creek	PL-534	1953	6	1953	1956	0	0	0%
Sergeant Major Creek	PL-534	1953	6	1948	1963	0	0	0%
Double Creek	Pilot	1954	6	1954	1955	6	12	100%
Owl Creek	PL-534	1954	15	1949	1957	10	15	67%
Rush Creek	PL-534	1954	55	1959	1986	43	52	78%
Saddle Mountain Creek	PL-534	1954	12	1958	1974	12	37	100%
Washington Creek	PL-534	1954	3	1981	1981	0	0	0%
Big Wewoka Creek	PL-566	1955	41	1957	1967	36	80	88%
Cavalry Creek	PL-534	1955	30	1948	1977	16	24	57%
Little Wewoka Creek	PL-566	1955	16	1958	1969	15	36	94%
Long Branch Creek	PL-566	1955	11	1957	1976	10	27	91%
Mill Creek	PL-534	1955	18	1949	1985	15	39	83%
Nine Mile Creek	PL-534	1955	18	1957	1964	1	1	6%
Colbert Creek	PL-534	1956	3	1958	1958	3	5	100%
lonine Creek	PL-534	1956	2	1961	1961	0	0	0%

Panther Creek	PL-534	1956	6	1958	1958	2	3	33%
Round Creek	PL-534	1956	9	1959	1979	9	12	100%
Sandy Creek	PL-566	1956	29	1959	1981	28	68	97%
South Clinton Laterals	PL-534	1956	16	1959	1978	2	2	13%
Bear Fall Coon Creek	PL-566	1957	31	1960	1963	24	31	77%
Broken Leg Creek	PL-534	1957	3	1959	1963	0	0	0%
Dead Indian Wildhorse	PL-534	1957	12	1959	1964	0	0	0%
Little Deep Fork	PL-566	1957	56	1960	1972	38	69	68%
Quartermaster Creek	PL-534	1957	36	1949	1974	0	0	0%
Totals			605			301	598	50%

Table 7: Summary of auxiliary spillway flows on dams planned from 1948 to 1957

Watershed Projects Planned from 1958 to 1964:

From 1958 to 1964, SCS planned and authorized 53 watershed projects in Oklahoma. SCS eventually built 1,124 dams in these watersheds. Since 1958, 611 of these dams experienced 1,079 auxiliary spillway flows, while 513 dams never experienced auxiliary spillway flows. Fifty-four percent of the 1,124 dams planned during this six-year period experienced auxiliary spillway flows through 2015. Table 8 provides a summary of auxiliary spillway flows for dams planned from 1958 to 1964.

Numerous changes in watershed planning occurred between 1958 and 1964. The first was the introduction of runoff curve numbers as a method to define rainfall-runoff relationships in the 1956 revision of the 1954 National Engineering Handbook. Curve numbers are based on soils and land use data. The curve number approach also recognized initial abstractions from rainfall and account for antecedent moisture conditions. Victor Mockus and others led the pioneering effort to develop the concept of curve numbers, with the intended usage on small ungaged watersheds. The team collected extensive rainfall – runoff research data in small plots. It took some time to train field personnel and planners on the use of the procedure. In Oklahoma, the first use of curve numbers appeared in a 1958 watershed plan. In the1964 revision of the National Engineering Handbook, Section 4 Hydrology, Victor Mockus authored Chapter 10, “Estimation of direct runoff from storm rainfall”.

A game-changer for watershed planning occurred in May 1961 with the release of Technical Paper No. 40 - Rainfall Frequency Atlas for the United States by the Weather Bureau (later National Weather Service) of the U.S. Department of Commerce. David M. Hershfield prepared TP-40 under contract with the Engineering Division of the Soil Conservation Service. Many more stations were available for Hershfield's study as compared to Yarnell's study. Yarnell’s data was based only on limited rainfall records from a few recording gaging stations across the nation and were supplemented with data from dedicated observers. After Yarnell’s data was published, a network of recording gages were installed that increased the amount of data by a factor of 20. The analysis of this expanded data was the basis for Weather Bureau’s studies starting with Technical Papers 24, 25, 28, 29 and eventually 40. The precipitation data in these technical papers were generally larger than Yarnell’s values; in some instances as much as three times larger (TP-40 introduction, 1961).

TP-40 was a very important occurrence in SCS hydrology history. It replaced the outdated and somewhat unreliable Yarnell data as a source of rainfall-frequency data. It quickly became the national standard for rainfall frequencies. At times, some have questioned its reliability, but it has never been replaced. In 1970-72, John Miller from the National Weather Service, Arlin Nix from the Agricultural Research Service, and Ray Riley, SCS, served on a national committee to determine the adequacy of TP-40. They concluded that it was statistically reliable and that it was still the best rainfall - frequency source available.

TP-40 generally gave higher values for the 25-year 24-hour rainfall than previous procedures. On Chigley Sandy Creek discussed above, the Yarnell 25-year rainfall was approximately 6.2 inches while the TP-40 value was 7.1 inches. The resulting runoff from these rainfalls using a 75 curve number would be 3.45 and 4.24 inches respectively. The 15 percent increase in 25-year; 24-hour rainfall does not seem very significant, but consideration of the resulting 23 percent increase in design runoff and the modest increase in detention storage would have prevented over half of the flows and reduced the depths on the remaining.

TP-40 plus new curve number procedures provided the basis for converting from concordant flow methods to statistically more reliable flood-frequency analysis for detention storage requirements and watershed flooding and damages. Converting from concordant flow methods to computerized modeling of watersheds took time and training to achieve a total conversion. Concordant Flow analysis still appears in a 1964 Oklahoma watershed plan. SCS began implementing digital reservoir routing (PESIN and RESIN) and water surface profiles computation programs between 1960 and 1964.

Changes in the methods of computing detention storage requirements occurred in a relative short period of time. In 1957, major floods occurred throughout the Midwest from mid-April through mid-June. Hennessey, Oklahoma in the north central part of the state reported 22.38 inches of rain for the month of May with 35.39 inches for the period of April through June. Besides major flooding, two significant changes in dam design resulted from the 1957 floods. In late 1958 or early 1959, the SCS EWP unit at Fort Worth, Texas released a storm report for the 1957 flood. The water level in the reservoirs of some dams remained near the auxiliary spillway elevation for periods of up to 60 days. Most all of the vegetation died in the detention pool area. This report recommended that dams be designed with a drawdown period of approximately 10 days. Several years later SCS added the concept of 10-day drawdown to address repetitive storms in dam design criteria. The report also recommended increasing the principal spillway release rates of two to five csm to a more reasonable value of "say 10 csm". For the next 10 years and for some planners the next 15 years, almost every dam in Oklahoma was planned with a restricted release rate of exactly 10 csm even though it might be 90 percent or more of full pipe flow.

In March, 1958, SCS issued Engineering Memo 27 (the entire document was revised and reissued on March 19, 1965). It contained design criteria for earth dams that was used for the design of all watershed dams until SCS Technical Release 60 was issued in 1976. Although Engineering Memo 27 included hazard classification, it did not include a procedure for predicting a breach discharge and measuring its downstream impact. The 1958 definitions for hazard classification are exactly the same as the current TR-60 definitions except that TR-60 uses the word "dams" where Engineering Memo 27 used the word "structures".

In September 1958, SCS in Oklahoma issued Engineering Memo 28. This document contained a breach procedure and guidelines for evaluating the breach impacts. The breach defined in Oklahoma Engineering Memo 28 is the same rectangular breach that is still a part of the current TR-60. These Oklahoma procedures were used as the basis for SCS EWP Technical Guide 24 dated December 8, 1969. The example used in EWP Technical Guide 24 was an actual breach analysis of a proposed Washita River dam upstream from the town of Colony, Oklahoma that Ray Riley had completed in the spring of 1969. Oklahoma SCS was certainly a leader, if not the actual creator, of breach analysis procedures for dam hazard classification.

In May 1959, SCS Oklahoma issued Engineering Memos 33 and 35. They included design storm inflow hydrograph development and requirements for estimating storage requirements for dams. These two documents served as the basic procedure for determining detention storage requirements until the "Washington Minimum" procedures were adopted in 1976.

Two notable dams planned and designed using late 1950s criteria demonstrate the significant impacts of the differences between later 1950’s and early 1960’s design criteria. These dams are Upper Clear Boggy Creek

Dam 14 (planned in 1959) and Rainy Mountain Creek Dam 24 (planned in 1960). Since the construction of the two sites, the auxiliary spillway for Upper Clear Boggy Creek Site 14 flowed seven times with two flows greater than 1.0 foot while the auxiliary spillway for Rainy Mountain Creek Site 24 also flowed seven times with all flows less than or equal to 1.0 foot. The number of flows on these two dams and other dams planned prior to 1960, would have been greatly reduced if the following criteria introduced after 1960 had been used:

- longer duration 10-day storms for determining detention storage
- use of a+b/2 criteria for larger low hazard dams
- climatic index criteria (which included base flow considerations)
- 10-day drawdown criteria requiring add-back storage

In approximately 1960, SCS developed the first watershed workplans with 100-year sediment life. Provisions for 100-year evaluations were contained in the Public Law 566 law. The authors are not aware of any PL-534 or PL-566 workplans prepared prior to 1960 that were planned with a 100-year sediment life. The 1961 Oklahoma Water Resources Board (OWRB) resolution resulted from SCS inquiries about the possibility of building dams with a 100-year life. OWRB was apparently apprehensive about granting 100-year sediment pools without obtaining a water right.

Projects Planned from 1958 to 1964

Watershed	Program	Year Planned	No of Dams in Project	Years Dams Built: Ist Dam	Years Dams Built: Last Dam	No. of Dams with AS Flow	No. of AS Flows	% Dams with AS Flows
Beaver Creek	PL-534	1958	15	1964	1968	0	0	0%
Cherokee Sandy Creek	PL-534	1958	19	1962	1989	12	16	63%
Criner Creek	PL-534	1958	22	1960	1961	6	8	27%
Salt Creek	PL-566	1958	35	1960	1983	27	41	77%
Turkey Creek	PL-566	1958	3	1960	1960	0	0	0%
Upper Washita River	PL-534	1958	35	1960	1970	0	0	0%
Whitegrass-Waterhole	PL-566	1958	9	1960	1962	0	0	0%
Caney Coon Creek	PL-566	1959	3	1965	1975	3	6	100%
Rock Creek (PL-534)	PL-534	1959	17	1961	1969	17	48	100%
Soldier Creek	PL-534	1959	12	1962	1970	7	15	58%
Sugar Creek	PL-534	1959	51	1961	1976	12	14	24%
Upper Black Bear Creek	PL-566	1959	72	1961	1993	52	64	72%
Upper Clear Boggy Cr.	PL-566	1959	49	1961	1980	40	79	82%
Bear Hyberger Creek	PL-534	1960	11	1964	1966	1	1	9%
Boggy Creek	PL-534	1960	36	1965	1967	6	7	17%
Caddo Creek	PL-534	1960	28	1965	1971	28	71	100%
Fourche Maline Creek	PL-566	1960	14	1962	1971	11	28	79%
Lead-Mid. Clear Boggy	PL-566	1960	33	1962	1973	32	68	97%
Rainy Mountain Creek	PL-534	1960	29	1964	1981	25	82	86%
Roaring Creek	PL-534	1960	40	1963	1990	28	46	70%
Timber Creek	PL-566	1960	7	1962	1963	0	0	0%
Upper Red Rock Creek	PL-566	1960	43	1964	2006	41	59	95%
Bear Creek	PL-534	1961	10	1969	1972	0	0	0%
Cane Creek	PL-566	1961	21	1964	1988	8	10	38%
Kickapoo Sandy Creek	PL-534	1961	20	1963	1980	14	25	70%
Sallisaw Creek	PL-566	1961	34	1963	1971	10	15	29%
Upper Blue River	PL-566	1961	2	2000	2000	0	0	0%
Whiteshield Creek	PL-534	1961	19	1948	1974	3	6	16%

Caney Creek	PL-566	1962	14	1964	1985	9	16	64%
Cottonwood Creek	PL-566	1962	16	1965	1973	12	13	75%
Delaware Creek	PL-534	1962	2	1965	1979	1	1	50%
Delaware Creek	PL-566	1962	13	1964	1979	13	29	100%
Fourteen Mile Creek	RC&D	1962	2	1968	1968	2	2	100%
Scraper Hollow	RC&D	1962	2	1968	1969	0	0	0%
Squaw Creek	PL-566	1962	0			0	0	0%
Stillwater Creek	PL-566	1962	34	1965	2005	9	10	26%
Waterfall-Gilford Creek	PL-566	1962	11	1965	1980	6	6	55%
Big Caney Creek	PL-566	1963	1	1974	1974	1	2	100%
Four Mile Creek	PL-566	1963	1	1966	1966	1	1	0%
Lower Bayou Creek	PL-566	1963	15	1971	1990	4	6	27%
Lower Clear Boggy Cr.	PL-566	1963	23	1976	2005	21	47	91%
Oak Creek	PL-534	1963	14	1965	1969	1	1	7%
Okmulgee Creek	PL-566	1963	2	1966	1969	0	0	0%
Salt Camp Creek	PL-566	1963	5	1970	1981	0	0	0%
Tri-County Turkey Creek	PL-566	1963	31	1966	1982	5	5	16%
Turkey Creek	PL-534	1963	12	1960	2010	7	9	58%
Upper Bayou Creek	PL-566	1963	8	1976	1981	8	15	100%
Winter Creek	PL-534	1963	24	1965	1977	20	27	83%
Quapaw Creek	PL-566	1964	38	1968	1979	11	12	29%
Tonkawa Creek	PL-534	1964	13	1968	1970	0	0	0%
Uncle John Creek	PL-566	1964	12	1967	1976	3	3	25%
Upper Elk Creek	PL-566	1964	35	1968	1990	16	21	46%
Wildhorse Creek	PL-534	1964	107	1949	1993	78	144	73%
Totals			1124			611	1079	54%

Table 8: Summary of auxiliary spillway flows on dams planned from 1958 to 1964

Watershed Projects Planned from 1965 to 1971:

From 1965 to 1971, SCS planned and authorized 29 watershed projects in Oklahoma. SCS eventually built 328 dams in these watersheds. Since 1965, 115 of these dams experienced 177 auxiliary spillway flows, while 213 dams never experienced auxiliary spillway flows. Thirty-five percent of the 328 dams planned during this six year period have experienced auxiliary spillway flows through 2015. Table 9 provides a summary of auxiliary spillway flows for dams planned from 1965 to 1971.

During this period, several major actions influenced watershed planning for many years. In 1964, the Hydrology Branch of SCS in cooperation with the Hydrology Laboratory of the Agricultural Research Service (ARS) developed the original FORTRAN computer program for watershed scale modeling through a contract with C-E-I-R, Inc. This later became the "TR-20 Computer Program for Project Formulation – Hydrology". The program began wide-scale usage in 1965 and is still used today in an MS Windows version. The program was very versatile; accurately reproduced historical storms; and allows flexibility in evaluating numerous alternatives. In 1965, the TR-20 program was only available on the IBM 1620 mainframe computer in Beltsville, Maryland. Users mailed batch input data to Beltsville and Beltsville mailed boxes of output data back to users in about six weeks. The program with flexibility for more dams and cross-sections easily runs on a personal computer today.

SCS issued a complete revision to SCS Engineering Memo 27 on March 19, 1965. This revision included comprehensive additions to criteria for dams. In July 1967, SCS issued an amendment to SCS Engineering Memo 27. It contained guidance to use cost as a criteria to subdivide the (a) structure class into (a) and (a+b/2). Class (a) (now low hazard dams) required a minimum volume of detention storage from a routed 25-year, 10-day storm with a minimum auxiliary spillway freeboard design. Class (b) (now significant hazard dams) required a minimum volume of detention storage from a routed 50-year, 10-day storm and an increased auxiliary spillway design. In effect, the a+b/2 criteria averaged the precipitation requirements giving a 37.5 year, 10-day storm.

Initially, SCS used (a) criteria for dams costing less than $75,000 and (a+b/2) criteria for higher cost dams. SCS Engineering Memo 27, supplement 6 in September 1974 increased the dollar value to $110,000. In 1976, TR-60 eliminated the dollar criteria and replaced it with "storage x height product of 30,000" criteria.

SCS Engineering Memo 27 also required the use of 30-inch diameter conduits on class (a) structures where a joint extension safety margin of at least 1.5 could not be achieved with smaller diameter conduits. The impact of this requirement was that most class (a) dams required a 30- inch diameter conduit unless it could be located on a non-yielding foundation. At the time, manufacturers did not produce a product that would meet these requirements for diameters less than 30 inches. As a result, SCS designed many smaller class (a) dams with restricted flow inlets because a 30-inch diameter full pipe flow conduit has discharges greater than 100 cfs. SCS often did not have the option to downstream channel improvement during this period, so the designers used 30-inch diameter conduits with restricted flow inlets or two-stage inlets. Two-stage inlets cost significantly more than restricted-flow inlets and two-stage inlets usually produced overbank flow at the higher stages. Oklahoma primarily chose to use restricted flow inlets rather than the two-stage inlets.

The National Environmental Policy Act (NEPA) of 1969 (effective on January 1, 1970) significantly impacted watershed planning. The act had the impact of significantly increasing planning time by requiring more input from the public and review by all potentially affected federal and state agencies. SCS had to publish final plans in the Federal Register and, after a comment period, had to address all comments made during the comment period. In addition to planning time, prior to contracting any dam in a watershed, SCS had to prepare an individual Environmental Impact Statement (EIS) for extensive review.

Almost concurrently with NEPA, SCS decided to no longer justify watershed dams as a group. Instead, SCS required incremental analysis on each dam (later on small groups of similar dams) until no additional dams could be justified with a benefit-cost (B:C) ratio greater than 1.0. Prior to incremental analysis, most watersheds contained 50 to 60 percent control with 60 to 70 percent flood damage reductions. After the advent of incremental analysis, watersheds consisted of larger dams with only 20 to 30 percent watershed control with 25 to 35 percent damage reductions. Several watershed sponsors rescinded applications as a direct result of NEPA and the incremental analysis decision. For many, the "good ole days" of watershed planning were gone forever.

Projects Planned from 1965 to 1971								
Watershed	Program	Year Planned	No of Dams in Project	Years Dams Built		No. of Dams with AS Flow	No. of AS Flows	% Dams with AS Flows
				Ist Dam	Last Dam			
Finn Creek	PL-534	1965	35	1964	1977	9	10	26%
Frogville	PL-566	1965	2	1969	1969	2	2	100%
Lambert Creek	PL-566	1965	2	1971	1971	0	0	0%
Otter Creek	PL-566	1965	4	1973	1973	4	8	100%
Rock Creek (PL-566)	PL-566	1965	4	1969	1973	2	5	50%
Cotton Coon Mission	PL-566	1966	11	1977	1998	9	14	82%
Little Washita River	PL-566	1966	45	1969	1982	3	6	7%

Lower Black Bear Creek	PL-566	1966	19	1974	1986	0	0	0%
Okfuskee Tributaries	PL-566	1966	29	1972	1980	5	6	17%
Whitewater Creek	RC&D	1966	2	1972	1972	0	0	0%
Fitzgerald Soldier Creek	PL-566	1967	5	1969	1977	1	1	20%
Jack Creek	PL-566	1967	10	1974	1978	6	15	60%
Lower Red Rock Creek	PL-566	1967	7	1975	1977	7	7	100%
Pryor Creek	PL-566	1967	8	1976	1979	1	1	13%
Butler Laterals	PL-534	1968	9	1970	1975	6	6	67%
Canyon View	PL-566	1968	4	1962	1974	0	0	0%
Cowden Laterals	PL-534	1968	13	1970	1980	2	2	15%
Fort Cobb Lat.Creek	PL-534	1968	9	1972	1984	6	8	67%
Gyp Creek	PL-534	1968	1	1975	1975	1	4	100%
Lost Duck Creek	PL-566	1968	9	1981	1984	9	11	100%
Spring Creek	PL-534	1968	4	1958	1973	0	0	0%
Bitter Creek	PL-534	1969	19	1972	2006	9	10	47%
Brushy Peaceable Creek	PL-566	1969	18	1975	1999	18	38	100%
Kadashan Bottoms	PL-566	1969	5	1969	1979	1	3	20%
Paint Creek	PL-566	1969	1	1975	1975	0	0	0%
Cow Creek	PL-566	1970	29	1978	1993	8	10	28%
Deep Red Run Creek	PL-566	1970	2	1974	1979	2	5	100%
Boiling Springs	RC&D	1971	1	1073	1973	0	0	0%
Maysville Laterals	PL-534	1971	21	1971	1979	4	5	19%
Totals			328			115	177	35%

Table 9: Summary of auxiliary spillway flows on dams planned from 1965 to 1971

Watershed Projects Planned from 1972 to 1997:
From 1972 to 1997, SCS planned and authorized only 10 watershed projects in Oklahoma. SCS eventually built 45 dams in these watersheds. Since 1973, 22 of these dams in two watersheds experienced 42 auxiliary spillway flows, while 23 dams never experienced auxiliary spillway flows. Forty-nine percent of the 45 dams planned during this 25-year period have experienced auxiliary spillway flows through 2015. Table 10 provides a summary of auxiliary spillway flows for dams planned from 1972 to 1997.

After 1972, Oklahoma concentrated on getting previously planned dams constructed. No new watershed plans were approved in Oklahoma from 1971 to 1975 and only seven watershed plans containing dams have been authorized since 1975. The majority of the 508 dams built since 1972 were located in watersheds planned before 1972. Only 45 dams have been built in watersheds planned after 1972.

In February 1973, SCS issued Technical Release 52 as a guide for the design of earth auxiliary spillways for earth dams. This was one of Mel Culp's many contributions to dam design guidance in SCS. It significantly changed the layout and design of earthen auxiliary spillways. Most auxiliary spillways designed in Oklahoma prior to TR-52 used the hydraulic efficient case 8 auxiliary spillway profile (a critical exit slope, a 50-foot-wide level crest section, and a two-foot drop just upstream from the crest into the forebay section). The bulk length requirements in TR-52 virtually eliminated the use of case 8 spillways even though about 1,700 dams had been built by the time TR-52 was issued. Oklahoma SCS staffs believed that the resultant bulk length requirements in TR-52 were too conservative and that the location of the required bulk length measurement (two feet below the crest) greatly reduced the volume below the auxiliary spillway crest) was not realistic. To meet the requirements of TR-52, Oklahoma SCS developed the case 4(a) auxiliary spillway with a normally critical exit section, a level 50-foot crest section and a forebay slope of -0.004. Case 4 (a) has been the dominant auxiliary spillway profile since the mid 1970's. The arrival of the new technology in the new

SCS SITES program greatly improved the design capability and expanded the choices for auxiliary spillway profiles. The case 8 and case 4 (a) profiles became the case 14 and case 27 under SITES technology.

In June 1976, SCS issued Technical Release 60. This document brought together all criteria for dams with a height times storage product greater than 3,000. TR-60 was another iteration to improve the criteria used during the first 25 years of dam building.

Projects Planned from 1972 to 1997								
Watershed	Program	Year Planned	No of Dams in Project	Years Dams Built		No. of Dams with AS Flow	No. of AS Flows	% Dams with AS Flows
				Ist Dam	Last Dam			
Upper Muddy Boggy Cr.	PL-566	1975	24	1980	1994	20	40	83%
Robinson Creek	PL-566	1978	5	1981	1985	2	2	40%
Kickapoo Nations Creek	PL566	1979	5	1983	1999	0	0	0%
Hoyle Creek	PL-566	1979	0			0	0	0%
Carney Creek	PL-566	1982	1	2002	2002	0	0	0%
Campbell Creek	PL-566	1984	0			0	0	0%
Dry Creek	PL-566	1986	8	1992	1998	0	0	0%
North Deer Creek	PL-566	1986	1	1996	1996	0	0	0%
Little Beaver Creek	PL-566	1990	0			0	0	0%
Middle Deep Red Run	PL-566	1997	1	2001	2001	0	0	0%
Totals			45			22	42	49%

Table 10: Summary of auxiliary spillway flows on dams planned from 1972 to 1997

Summary of the Design Criteria Changes Variable:

SCS revised design criteria for detention storage and principal spillway release rates several times during the 1950s , 60s , and 70s when the majority of the watershed dams were planned, designed, and constructed. The design criteria changes were due to results of hydrology studies, research data, and lessons learned after reviewing the performance of dams and auxiliary spillways following storm events. During the first 25 years of the watershed program, SCS went from an agency that assisted farmers and ranchers with the planning, design, and installation of conservation practices to one of the primary flood control dam building agencies in the country. The performance of these dams during the past 67 years has demonstrated that SCS adopted and quickly implemented the results of critical hydrologic and hydraulic studies and techniques to constantly improve design criteria through this period.

Tables 11 and 12 provide summaries of watershed projects planned, dams built, and auxiliary spillway flows since 1948. Approximately 50% of the dams planned and designed during each time period experienced auxiliary spillway flows. The number of dams experiencing multiple auxiliary spillway flows was also quite similar between time periods.

Upon the first look at the summaries, one could conclude that the design criteria changes did not significantly affect the potential for some dams experiencing auxiliary spillway flows. However, after reviewing the other two variables below, the authors concluded that the many variables counteract each other and the sole impact of design criteria changes is difficult to isolate directly.

AS Flow Summary										
Period Planned		Total No. of Projects Planned	Total No. of Dams Built	Projects with some dams with AS Flows				Projects with no AS Flows		% of dams w AS Flows
From	To			No. of Projects with AS Flows	No. of Dams with AS Flows	No. of AS Flows	No. of Dams with no AS Flow	No. of Dams with no AS Flows	No. of Projects with no AS Flows	
1948	1957	32	605	23	301	598	188	116	9	50%
1958	1964	53	1124	40	611	1079	409	104	13	54%
1965	1971	29	328	22	115	177	180	33	7	35%
1972	1997	10	45	2	22	42	7	16	8	49%
Totals		124	2,107	88	1,047	1,890	786	274	37	50%

Table 11: Summary of dams with auxiliary spillway flows
by date watershed projects were planned

Number of Dams with Auxiliary Spillway (AS) Flows from 1948 to 2015									
Time Period Dams Were Planned	Number of AS flows per dam								
	0	1	2	*3*	4	5	6	7	Total
1948 to 1957	304	144	83	36	26	6	8	0	605
1958 to 1964	513	326	163	78	36	5	1	2	1,124
1965 to 1971	213	72	22	13	3	0	1	0	328
1972 to 1997	23	6	12	4	0	0	0	0	45
All Dams	1,060	548	280	131	65	11	10	2	2,107

Table 12: Summary of dams with multiple auxiliary spillway flows
by date watershed projects were planned

Variables 2 and 3: Location and number of high rainfall events and the age of dams

The authors computed the actual recurrence frequencies of auxiliary spillway flows to determine the impact that location and age of the dams had on auxiliary spillway flows. This analysis considered the following factors for each location:

1. average annual rainfall
2. average annual runoff
3. drainage area
4. design detention storage
5. number of large storms
6. age of the dams

The analysis addressed the age of dams by computing a "structure-year of record" for each group of dams as a means of looking at the historical frequency of auxiliary spillway flows. For example, if there were 10 dams that were all 20 years old, they would represent 200 structure-years of record. In total, the 2,107 dams constructed over the past 67 years represent almost 110,000 structure-years of record. The analysis computes a structure-year of record per auxiliary spillway flow. This could be stated inversely as "We could expect one auxiliary spillway flow every "X" years (based on past history in this area)".

The authors divided the state into four zones according to the following average annual rainfall amounts:

Zone 1: 22 to 26 inches
Zone 2: 26 to 32 inches
Zone 3: 32 to 40 inches
Zone 4: 40 to 56 inches

Zone 1, with an average annual rainfall of up to 26 inches, might be a good view of what could be expected in areas like the Texas panhandle, non-mountainous areas of New Mexico and Arizona, and eastern Colorado and western Nebraska and Kansas. Zone 2 could apply to the plain states of Texas up to Nebraska. Zone 3 could represent the eastern portions of Kansas and northwest Missouri. Zone 4 could be more typical for those states to the east of Oklahoma where the average annual rainfall exceeds 40 inches per year.

Zone 1 includes all of the dams in the western drier area of the state where the average annual runoff is less than 2.0 inches. There were only 245 dams built in this zone. But they are some of the older dams in the state with an average age of 54 years. There have only been 22 auxiliary spillway flows reported in this area with 17 of the flows less than one-foot flow depth. Only two dams had more than one flow. The structure-years of record per flow was 608 years.

Zone 2 includes all of the dams in the west central portion of the state where the average annual runoff is between 2.0 and 4.0 inches. There were 437 dams built in this zone. Their average age is 48 years. This is a transitional zone where the number of flows begin to increase and number of multiple flows increases significantly. Flow depths also increased with several exceeding 2.0 feet. There have been 304 auxiliary spillway flows reported in this area with several dams having multiple flows (two to seven times). The structure-years of record per flow was 84 years.

Zone 3 includes all of the dams in the east central portion of the state where the average annual rainfall is between 32 and 40 inches and the average annual runoff is up to 8.3 inches. This zone has the largest sample size with 1,139 dams and almost 57,000 structure-years of record. Their average age is 49 years. In this zone, 732 dams have experienced 1,323 auxiliary spillway flows, with many of them having multiple flows and depths of flow greater than 2.0 feet. The structure-years of record per flow was 45 years.

Zone 4 includes all of the dams in the southeast portion of the state where the average annual rainfall is between 40 and 56 inches and the average annual runoff is up to 17 inches. This zone has the smallest sample size with 218 dams with an average age of 50 years. There have been 132 dams that experienced 243 auxiliary spillway flow in this zone, with all but 7 having less than three flows per dam. The frequency of number of auxiliary spillway flows and multiple flows are similar to zone 3. The almost 25% increase in average watershed inches of storage from zone 3 (4.7 inches) to zone 4 (5.8 inches) is largely responsible for zone 4 not showing a bigger increase in the number of flows, multiple flows, and frequency of flows. In addition, up to 10 inches per year of the average annual runoff in zone 4 occurs as base flow which has very limited impact on the frequency of auxiliary spillway flows. The structure-years of record per flow was 39 years, which is the closest to what the authors would expect according to current criteria.

Summary of the Location and Age of Dams Variables:

Tables 13 and 14 display summaries of the analysis of location and age of dams. How can these results be interpreted? The authors realize that the dams cover a wide range of changing design criteria over the years. This makes the analysis consider the set of dams as a whole. However, the authors reached the following two main conclusions:

1. The results of the analysis indicate less frequent auxiliary spillway flows than would be expected by current design criteria. Generally, the current design criteria would result in the following theoretical frequencies of auxiliary spillway flows depending on size and hazard of specific dams:
   a. Low hazard dams with height times storage of less than 30,000 = 25 yrs.
   b. Low hazard dams with height times storage of more than 30,000 = 37.5 yrs.
   c. Significant hazard dams = 50 years
   d. High hazard dams = 100 years

   With the larger number of smaller low hazard dams in the Oklahoma portfolio, one would expect the weighted average of the number of auxiliary spillway flows to be somewhere between one auxiliary spillway flow every 30 and 35 years based on current design criteria.

   The results of the analysis of actual auxiliary spillway flows from 2,107 dams built over a 67-year period indicate the following auxiliary spillway frequencies for dams in four rainfall zones:

   West (ave. annual rainfalls of 22 to 26 inches): one flow every 608 years
   West central (ave. annual rainfalls of 26 to 32 inches): one flow every 86 years
   East central (ave. annual rainfalls of 32 to 40 inches): one flow every 45 years
   Southeast (ave. annual rainfalls of 40 to 50 inches): one flow every 39 years
   Statewide weighted average; one flow every 58 years

2. The authors do not believe that design criteria have fully considered the impacts of the drier climate in the west and higher rainfall areas in the southeast. Even though the criteria reflect normal runoff determinations (soils, land use, etc.), it appears that the extreme dry conditions that occur frequently in the western part of the state have a larger impact on reduced runoff from larger storms than is reflected in the design criteria. Less than 10% of the dams in the dryer western area of Oklahoma have ever experienced auxiliary spillway flow, while almost two-thirds of the dams in the wetter areas of central and eastern Oklahoma have experienced auxiliary spillway flows, many of them multiple times.

   A comparison of the two extreme zones (1 and 4) demonstrates the impacts of climate on the actual auxiliary spillway flows over the 67-year period. SCS built approximately the same number of dams in each zone (245 and 218). However, only 22 auxiliary spillway flows on 20 dams occurred in Zone 1, while 245 flows occurred on 132 dams in zone 4. The flows in zone 4 were deeper and many dams experienced three or more flows, while only two dams had multiple flows in zone 1. The auxiliary spillway flow frequency ranged from 608 years in zone 1 to only 39 years in zone 4. Interestingly, the frequency in zone 4 comes close to the expected frequency of one flow every 37.5 years.

However, recognizing the many variables that affect the number of auxiliary spillway flows, the authors recommend this unique dataset be used for further in-depth study and analysis to identify and better define the impact of the most critical variables involved.

Zone/ Location	**1. West**		**2. West Central**		**3. East Central**		**4. South East**		**Statewide**	
Ave. annual rainfall (in.)	22	26	26	32	32	40	40	50	22	50
Ave. annual runoff (in.)	1.2	2.0	2.0	4.0	4.0	8.3	8.3	17.1	1.2	17.1
Range of years dams were built	1948-1999		1948-2010		1948-2006		1953-2005		1948-2010	
Median age (years)	54		48		49		46		50	
Drainage area max (sq. mi.)	33.2		59.0		38.5		17.9		59.0	

Drainage area median (sq. mi.)	2.0	1.9	1.5	2.1	1.9
Ave. detention storage (ac. ft.)	475	591	606	1,087	647
Watershed inches (in.)	2.74	3.53	4.66	5.79	4.26
AS flow depths:					
0.1 to 1.0 ft.	16	192	869	149	1,226
1.0 to 2.0 ft.	5	48	321	67	441
2.0 to 3.0 ft.		13	77	24	114
> 3.0 ft.		9	11	2	22
Unknown ft.	1	42	45	1	89
Number of times AS flowed:					
1	20	163	732	132	1,047
2	2	69	361	67	499
3		43	145	34	222
4		23	56	8	87
5		3	18	2	23
6		3	10		12
7		1	1		2
Total number of AS flows	22	305	1,323	243	1,890
Number of dams with AS flow	20	163	732	132	1047
Total number of dams built	245	437	1139	218	2107
Percent of dams with AS flow	8%	37%	64%	61%	50%
Structure years of record	13,376	25,425	59,645	9.495	109,815
Structure years per AS flow	**608**	**84**	**45**	**39**	**58**

Table 13: Summary of dams with auxiliary spillway flows by average annual rainfall zone

Number of Dams with Auxiliary Spillway (AS) Flows from 1948 to 2015									
Ave. Annual Rainfall Zone Where Dams are Located	Number of AS flows per dam								
	0	1	2	*3*	4	5	6	7	Total
22 to 26 inches	225	18	2	0	0	0	0	0	245
26 to 32 inches	274	94	26	20	20	1	1	1	437
32 to 40 inches	407	371	216	89	38	8	9	1	1,139
40 to 56 inches	86	65	33	26	6	2	0	0	218
All Dams	1,060	548	280	131	65	11	10	2	2,107

Table 14: Summary of dams with multiple auxiliary spillway flows
by average annual rainfall zone

Conclusions:
Since 1948, SCS/NRCS constructed 2,107 dams in Oklahoma with assistance of the NRCS Small Watershed Program. NRCS staff in Oklahoma has kept detailed records on the auxiliary spillway flows of these dams over the past 65 years. NRCS and conservation district field office staffs conducted field reviews to verify auxiliary spillway flows following storm events. SCS prepared special storm reports concerning performance of the watershed dams and auxiliary spillway flows for many of the major storms.

This paper provides a summary of the 1,047 dams that have experienced 1,890 auxiliary spillway flows since 1948. The records have been analyzed based on location of the dams and storm events resulting in auxiliary spillway flows. Auxiliary spillway flows were examined based on flow depth and damage resulting from the flow. In addition, the evolution of design criteria was reviewed to determine how changes to the criteria played a role in the frequency and location of auxiliary spillway flows. Climatic effects and land use changes were also examined

The following are the primary conclusions from this study:

1. From 1948 to 1997, SCS in Oklahoma planned and authorized 120 watershed projects that included dams. SCS built 2,107 dams in these watersheds. Since 1948, 1,047 of these dams in 88 watersheds experienced 1,890 auxiliary spillway flows, while 1,060 dams have never experienced auxiliary spillway flows.

2. Auxiliary spillways on 499 dams flowed more than once.
    a. 548 auxiliary spillways flowed once
    b. 280 auxiliary spillways flowed twice
    c. 131 auxiliary spillways flowed three times
    d. 65 auxiliary spillways flowed four times
    e. 11 auxiliary spillways flowed five times
    f. 10 auxiliary spillways flowed six times
    g. 2 auxiliary spillways flowed seven times
    h. 1,060 auxiliary spillways have never flowed

3. Almost half of the spillway flows were less than 1.0 foot deep and 90% were less than 2.5 feet deep. The maximum reported flow depth was 5.3 feet. Approximately ten embankments were overtopped.

4. Since 1948, when the first watershed dam was constructed in Oklahoma, 64 storms resulted in one or more auxiliary spillway flows. No spillway flows occurred during 30 of the past 67 years. Ten storms resulted in 80% of the total number of auxiliary spillway flows (1,519 of the 1,890 flows) since 1948.

5. The following primary variables were determined to be the most critical to analyze the reasons why some dams experienced auxiliary spillway flows and others did not:
    a. Changes in design criteria for detention storage and principal spillway discharge: The design of dams has evolved over the years as SCS and ARS gained more experience, conducted more research, and addressed issues that developed. Thus dams designed in the 1950's had different detention storage volumes and principal spillway discharges than similar dams designed using the design criteria in the 1970's or later. However, the analysis concluded that approximately 50% of the dams planned and designed during each of four time periods studied experienced auxiliary spillway flows. The number of dams experiencing multiple auxiliary spillway flows was also quite similar between time periods. The evolution of design and planning criteria during the 1950's to 1970's when thousands of dams were being planned, designed, and constructed is provided as a historical summary.

b. The location and number of high rainfall events: Theoretically, the frequency of auxiliary spillway flows should be similar regardless of the average annual rainfall amounts across the state, since design storms also vary across the state. This variable was considered by analyzing the auxiliary spillway flows by four average annual rainfall zones in the state. Less than 10% of the dams in the dryer western area of Oklahoma have ever experienced auxiliary spillway flow, while almost two-thirds of the dams in the wetter areas of central and eastern Oklahoma have experienced auxiliary spillway flows, many of them multiple times.

c. Age of the dams: Older dams have more opportunities to experience more extreme rainfall events. This variable was considered by determining the “structure-years” for specific dams or groups of dams. A “structure-year” for a specific dam is the age of the dam. The “structure-years” for a group of dams is the summation of the ages of all of the dams in that group. The dataset includes almost 110,000 structure years of data.

6. The analysis concluded that SCS design criteria did not fully considered the impacts of the drier climate in the west part of the state and progressing to the higher rainfall areas in the southeast. Even though the criteria reflects normal runoff determinations (soils, land use, etc.), it appears that the extreme dry conditions that occur during frequently in the western part of the state have a larger impact on reduced runoff from larger storms than is reflected in the design criteria.

   The impacts of climate on the actual auxiliary spillway flows over the 67-year period is demonstrated by a comparison of the two extreme rainfall in the state, zones 1 (western drier area) and zone 4 (higher rainfall area in the southeast). Approximately the same number of dams were built in each zone (245 and 218). However, only 22 auxiliary spillway flows on 20 dams occurred in Zone 1, while 245 flows occurred on 132 dams in zone 4. The flows in zone 4 were deeper and many dams experienced three or more flows, while only two dams had multiple flows in zone 1.

   Even though spillway flow frequencies should be similar across the state, the analysis concluded that the frequency of auxiliary spillway flows varied from one flow every 608 years in the drier western area of the state, to every 86 years in the west central, 45 years in the east central, and 39 years in the southeast portion of the state. The statewide weighted average of actual auxiliary spillway use was once every 58 years. This is much less than today’s design criteria would indicate.

7. Only 325 auxiliary spillways were damaged as a result of the spillway flows. Almost half of the auxiliary spillways that had greater than 3.0-foot flow depths were damaged, while about one-third of those with flow depths between 2.0 and 2.9 feet, and about a fourth of those with flow depths between 1.0 and 1.9 feet were damaged.

8. In addition to the three critical variables analyzed in this paper, the following were also determined to be reasons contributing to why some dams experienced auxiliary spillway flows while others did not:
   a. “Luck of the draw” as to the location of heavy thunderstorms and high rainfall events.
   b. Some dams were designed with more detention storage because they were required to meet a higher performance standard. High and significant hazard dams are required to be designed with more detention storage, which in turn affected the frequency of auxiliary spillway flows for these dams.

c. Drought conditions proceeding extreme rainfall events affected the occurrence of auxiliary spillways flows because some dams had more than designed detention storage at the time of high rainfall events due to previous drought conditions that lowered the permanent reservoir.
d. Wetter than normal conditions proceeding extreme rainfall events affected occurrence of auxiliary spillways flows. Some of the dams had less than designed detention storage at the time of high rainfall events either due to accumulated sediment in the detention pool or a higher than normal reservoir due to runoff from prior storms that had not yet drained down.
e. Land use change, drought conditions, heavy growth and/or dense vegetation in the watershed affected infiltration rates that resulted in different runoff conditions than assumed in the original design.
f. The principal spillways could not function as designed due to being plugged with debris or man-made modifications to the principal spillway inlet.

9. The authors recommend this comprehensive dataset of auxiliary spillway flows be used for further in-depth study and analysis to identify and better define the impacts the many variables that affect the number of auxiliary spillway flows

Appendix 1: Historic SCS Engineering Policy/Criteria Documents
SCS Engineering Memorandums

No.	Original Issue Date	Revisions / Supplements	Subject
1	2/19/1954		Policy - Engineering Drafting Involved in Preparing Construction Plans
2	3/12/1954		Measurement of the Hydrologic Effects of Applied Programs on the 65 Watershd Protection Projects
3	10/7/1954	7/16/1956	Limiting Criteria for the Design of Earth Fill Dams
6	7/20/1954	6/18/1964 7/19/1972 12/8/1977 2/6/1979	Review and Approval of Engineering Plans Establishment of Technical Standards Governing Engineering Work
10	11/8/1954		Geologic Investigations
16	10/31/1955		Allocation of Sediment Storage for Design of Floodwater Retarding Structures
17	4/2/1956	9/19/1961	"As Built" Plans
19	11/7/1956		Input data required for computing certain parameters used in water surface profile computations for natural channels and output of Univac
23	12/9/1957		Approval and Review of High Hazard Dams
27	10/7/1954	7/16/1956 1/7/1957 3/14/1958 3/19/1965 3/4/1966 5/18/1967 3/15/1968 5/21/1969 6/4/1971 2/4/1972 6/1/1976	Limiting Criteria for the Design of Earth Fill Dams
28	8/23/1957	4/1/1958	Water Surface Profiles - Use of Electronic Computing Machines
31	4/2/1959		Emergency Spillway Design
33	2/8/1960		Dam Site Investigations
34	7/12/1957	4/11/1966 10/12/1971	Engineering Handbooks - Section 4, Hydrology, Supplement A
35	7/31/1958	7/23/1964 10/10/1966 7/19/1968 2/24/1969	Specifications for Construction Contracts for FP, WP, or RC&D Projects
38	11/25/1958		SCS Approval of Engineering Services Under Public Law 566
40	8/20/1959		Multiple Purpose Flood Control and Storage Dams
41	9/24/1959	10/28/1965	Criteria - Dams Built in National Forests
42	2/20/1961		Reinforced Concrete Pipe Drop Inlet Barrels
43	1/17/1961		Design Criteria for Water Storage & Water Retarding Structures in Series
45	9/11/1961		Field Study of Movements of Inlet and Barrel Sections of Principal Spillways Under Earth Dams on Compressible Foundations
47	11/22/1961	7/15/1966	Standards for Clearing Reservoirs Above Floodwater-Retarding and Multiple-Purpose Dams

Appendix 1: Historic SCS Engineering Policy/Criteria Documents

SCS Engineering Memorandums

No.	Original Issue Date	Revisions / Supplements	Subject
No.	**Original Issue Date**	**Revisions / Supplements**	**Subject**
50	5/16/1963	11/23/1965 9/12/1966 10/5/1966 9/12/1966 10/5/1966 6/2/1967 4/3/1968	National Standard Detail Drawings of Standard Covered Risers for Pipe Drop Inlet Spillways
52	7/24/1963	6/4/1965 10/6/1966 6/12/1967	Inspection of Construction Work
54	5/18/1964		Use of Non-Federal Engineers - Industrial and Municipal Water Supply
74	7/29/1970		Field Study of Emergency Spillway Performance

Other Criteria Documents			
Technical Releases			
20	1982	1986, 1990, 2015	Computer Program for Project Formulation Hydrolgy
33		1978	Simplified Method for Determining Floodwater Storage
35	1967		Method of Reservoir Flood Routing
48		2005	SITES Water Resource Site Analysis Computer Program
52	Feb. 1973		Design and Layout of Earth Emergency Spillways
60	June 1976	1982, 1985, 1990, 2005	Earth Dams and Reservoirs
National Engineering Handbook			
4	1956	1964, 1965, 1971, 1972, 1985, 1993	Chapter 10 - "Hydrology" Includes background and description of the Runoff Curve Number (RCN) developed by Mockus (1949), Sherman (1949), Andrews (1954), and Agrosky (1956)
Other Documents			
	1935		D.L. Yarnell, "Rainfall Intensity - Frequency Data" Misc. Publication No. 204, USDA, Washington DC
TP-40	5/1/1961	US Weather Bueau	Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years

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