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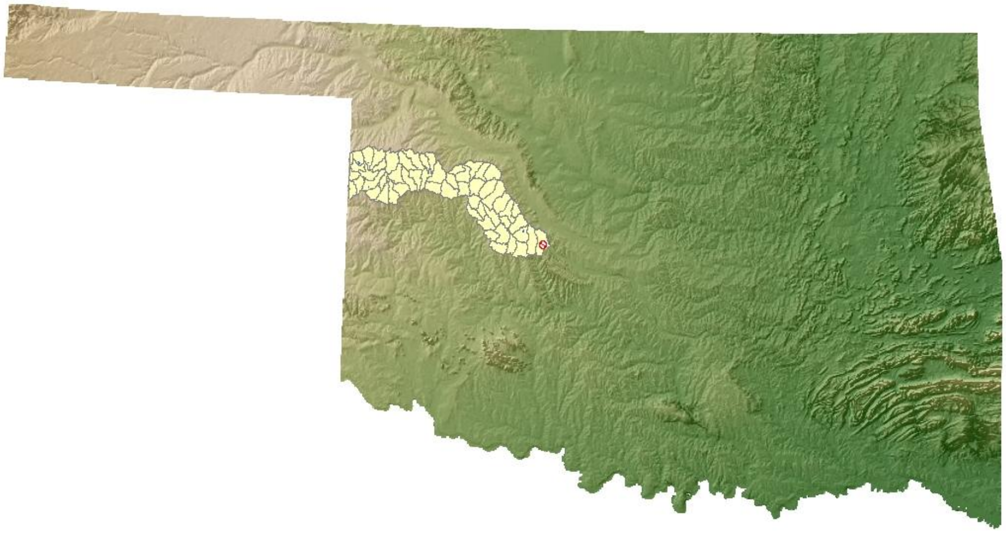
UPPER CANADIAN RIVER BASIN



HYDROLOGIC INVESTIGATION

TECHNICAL REPORT TR-2009-01

2009

OKLAHOMA WATER RESOURCES BOARD

Planning and Management Division

UPPER CANADIAN RIVER BASIN

HYDROLOGIC INVESTIGATION

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INTRODUCTION

The Oklahoma Water Resources Board is authorized by state law to conduct hydrologic investigations for stream systems to ascertain the amount of unappropriated water available and determine if proposed uses would interfere with domestic and existing appropriative uses.

In 2009, the OWRB initiated the Stream Water Allocation Modeling Program as a supporting tool for the effective management of surface water allocation. The program develops models on a statewide basis specifically to estimate availability of unappropriated water and identify potential interference of water rights. Other applications of the models include evaluating new permit applications based on water availability and reliability; performing drought analyses to anticipate interference and areas sensitive to water shortages; and evaluating water policy scenarios involving transfers of water, instream flows, or interstate stream compacts.

This report is a hydrological investigation of the Upper Canadian River basin that includes a hydrologic characterization of the basin and a description of the stream water allocation model developed for the system for the estimation of water reliability. Results from the calibrated model are also presented, showing the expected available water after appropriation for each sub-basin of the system. This assessment Is necessary to accurately manage current water rights, and to determine the future appropriation of water in the stream systems.

HYDROLOGIC CHARACTERIZATION

BASIN CHARACTERISTICS

The Upper Canadian Basin River basin (OWRB System 2-6-3) is located in western Oklahoma (Figure 1). The basin has a drainage area of 2,059 mi^2 in Oklahoma, and includes portions of Ellis, Roger Mills, Dewey, Custer, Blaine, and Caddo Counties. The Canadian River originates in Colfax County, New Mexico, and flows through the Texas Panhandle, entering Oklahoma as a meandering stream for about 150 miles to the UGSG Canadian River stream gage at Bridgeport (USGS 07228500), which is the only active gage in this watershed as of 2009. Elevation in the basin ranges from 1,360 to 2,580 feet, and the bed of the Canadian River has an average slope of 0.1% from the state line. The basin is part of the Canadian River interstate stream compact between New Mexico, Oklahoma, and Texas.

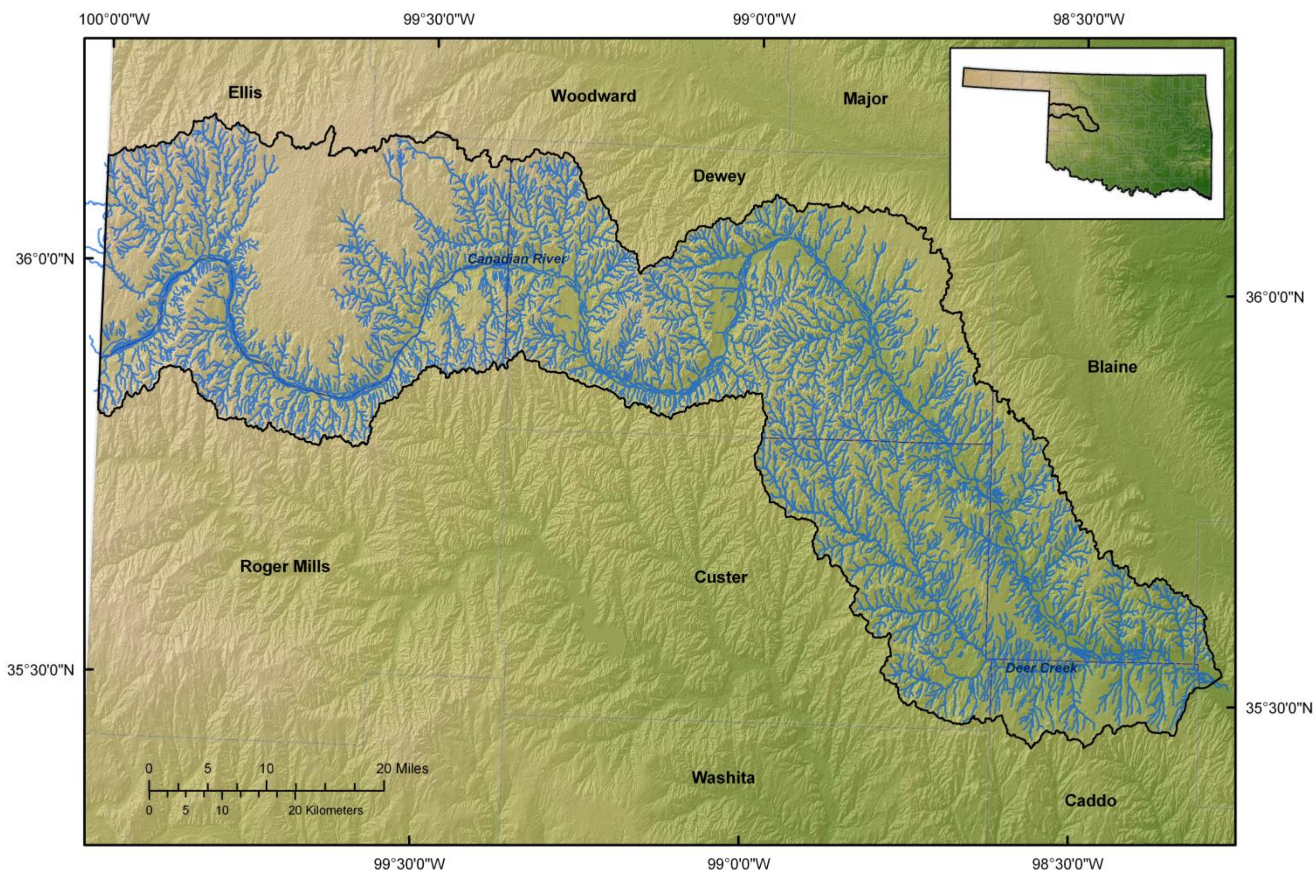


FIGURE 1: SHADED RELIEF OF THE UPPER CANADIAN RIVER (OWRB STREAM SYSTEM 2-6-3)

LAND COVER/USE

Irrigation is a prevalent water use in the Upper Canadian River basin. A land cover map based on the National Land Cover Dataset (USDA, 2009) is shown in Figure 2. The main crops are pasture, winter wheat, sorghum, and cotton. Both crops and permitted surface water diversions are concentrated on the southeastern part of the basin, where streamflow is supported by baseflow from the Rush-Springs and Ogallala aquifers. The watershed is composed of alluvial sands, red sandstones, shales, and sand dunes of alluvium and terrace deposits.

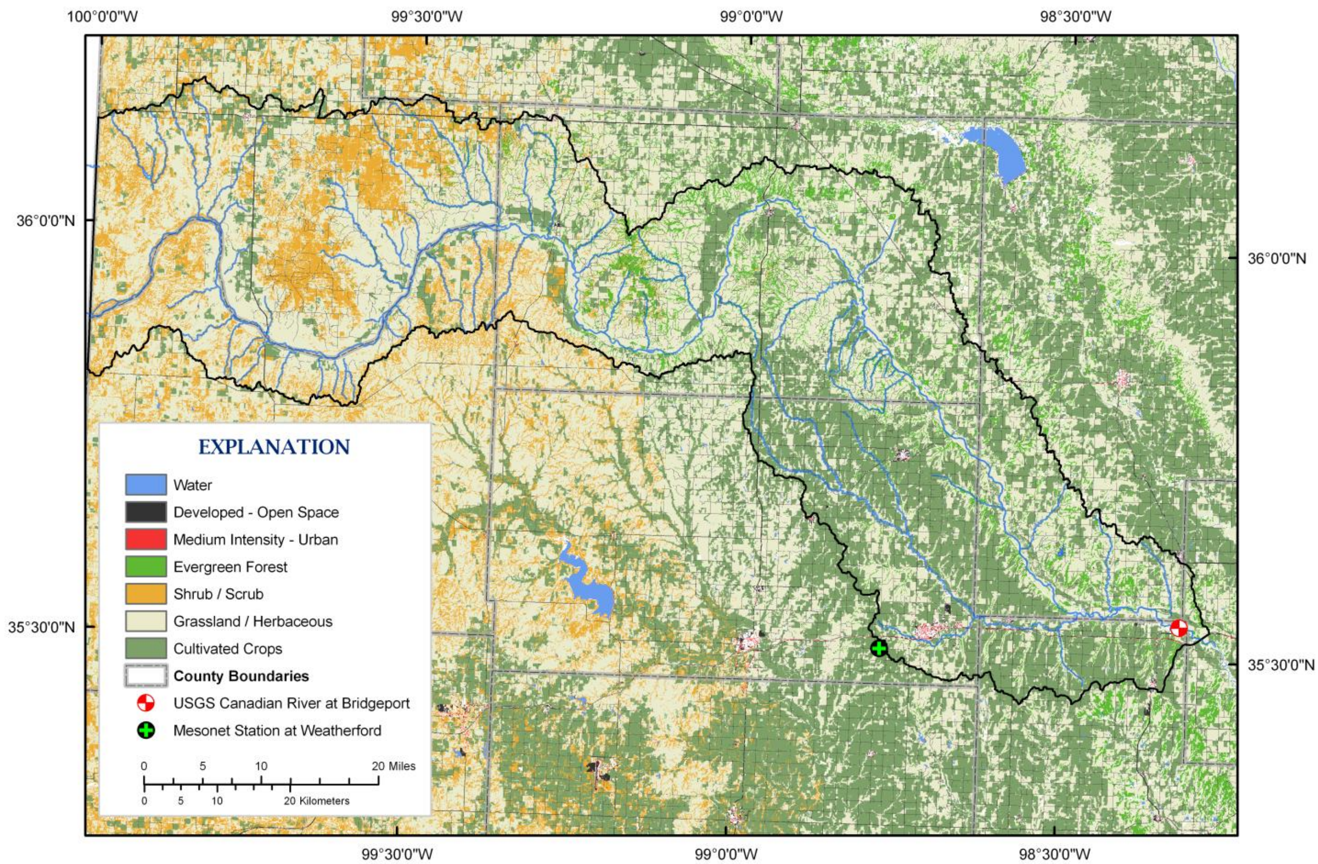


FIGURE 2: NATIONAL LAND COVER CLASSIFICATION FOR THE UPPER CANADIAN RIVER BASIN, OK

WATER BALANCE

The change in storage of water in a hydrologic system is affected by precipitation, surface runoff, groundwater discharge (baseflow), and evapotranspiration. The proportion of these components is presented in the form of a water balance for the basin, using hydro-meteorological data from 1995 to 2008, as available. For this purpose, precipitation and pan evaporation data were gathered from the Mesonet station at Weatherford (Oklahoma Mesonet, 2009), while streamflow data was obtained from the USGS gage at Bridgeport (NWIS, 2009) and separated into baseflow and runoff using the PART program, a hydrograph-separation application developed by the USGS (Rutledge, 1998). Seasonal variation of the components in the water budget is presented in Table 1. The budget shows that annual precipitation averages 3,346,985 acre-feet (31 inches) and is the main input of the hydrologic system. Figure 3 shows the components of the water budget expressed as percentage of precipitation. Actual evapotranspiration is the main output of the system and accounts for 92% of the mean annual precipitation in the basin, while both runoff and baseflow constitute 4% of the mean annual precipitation.

TABLE 1: SEASONAL WATER BALANCE FOR THE UPPER CANADIAN RIVER BASIN (1995-2008), IN ACRE-FEET (AF)
Budget estimated based on Pan Evaporation and Precipitation data recorded at the Weatherford Mesonet station.

Mean Monthly Water Budget for the Upper Canadian Basin, OK (1995-2008)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	112,132	141,571	300,907	291,831	435,497	515,165	230,238	411,187	284,539	356,217	150,563	117,136	**3,346,985**
R	10,133	11,504	17,839	16,523	17,392	22,045	4,724	9,686	7,694	6,488	7,368	8,680	**140,077**
BF	9,354	10,619	16,467	15,252	16,054	20,349	4,361	8,941	7,102	5,989	6,801	8,013	**129,302**
aET	92,646	119,448	266,601	260,057	402,051	472,771	221,153	392,559	269,743	343,740	136,394	100,443	**3,077,606**

P = Precipitation; R = Surface runoff; BF = Baseflow discharge; aET = Actual Evapotranspiration

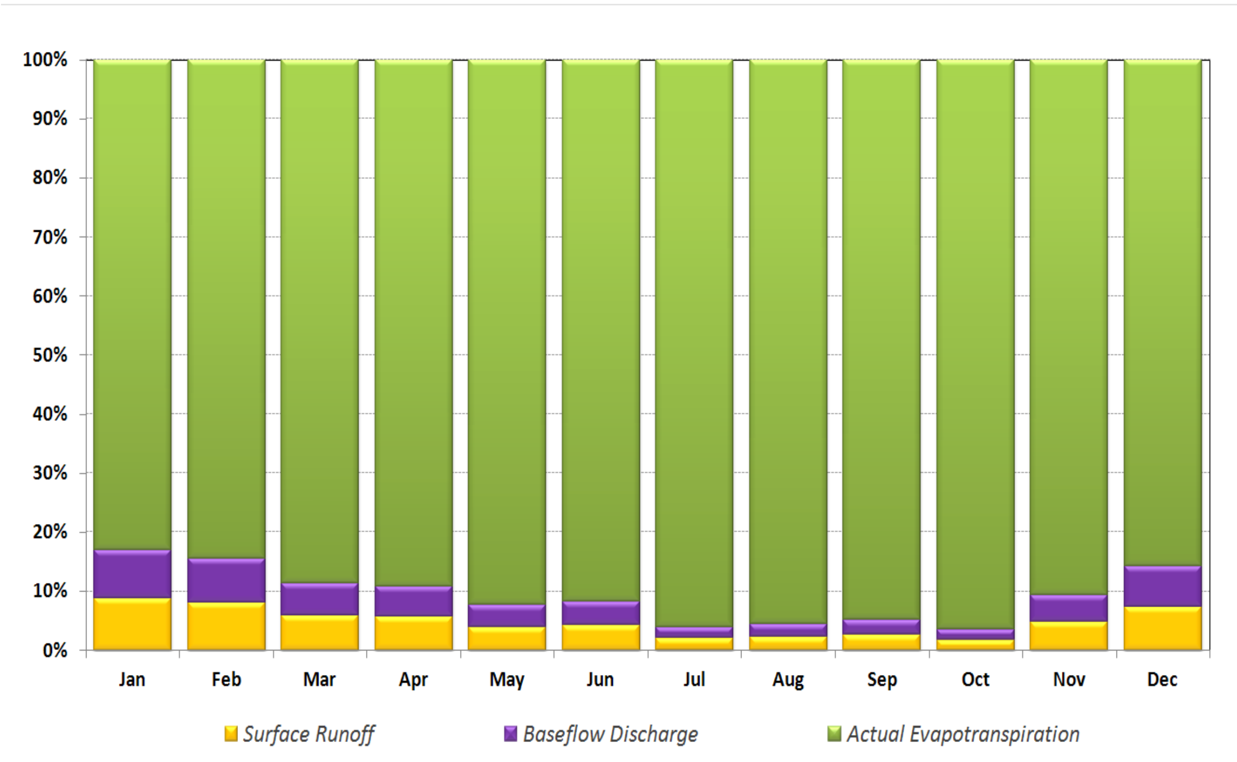


FIGURE 3: PERCENTAGE OF PRECIPITATION OF THE WATER BALANCE COMPONENTS FOR THE UPPER CANADIAN RIVER BASIN, OK

GROUNDWATER

The Canadian River basin is hydraulically connected to alluvium and bedrock aquifers that sustain the surface flow of streams and some tributaries in the basin. The northern part of the basin overlies part of the Ogallala aquifer, a shallow bedrock formation consisting of semi-consolidated sand, which is considered the most abundant source of fresh water in Oklahoma; the Ogalalla is utilized primarily for irrigation (Luckey and Becker, 1999). The Rush Springs is a bedrock aquifer that underlies the southeastern part of the basin with an average thickness of 300 feet (OWRB, 2007). The waters coming from this formation are mainly pumped for irrigation and domestic uses. The Canadian River alluvial aquifer underlies the basin along the main stream and extends from one to fifteen miles from the river banks (OWRB, 2007).

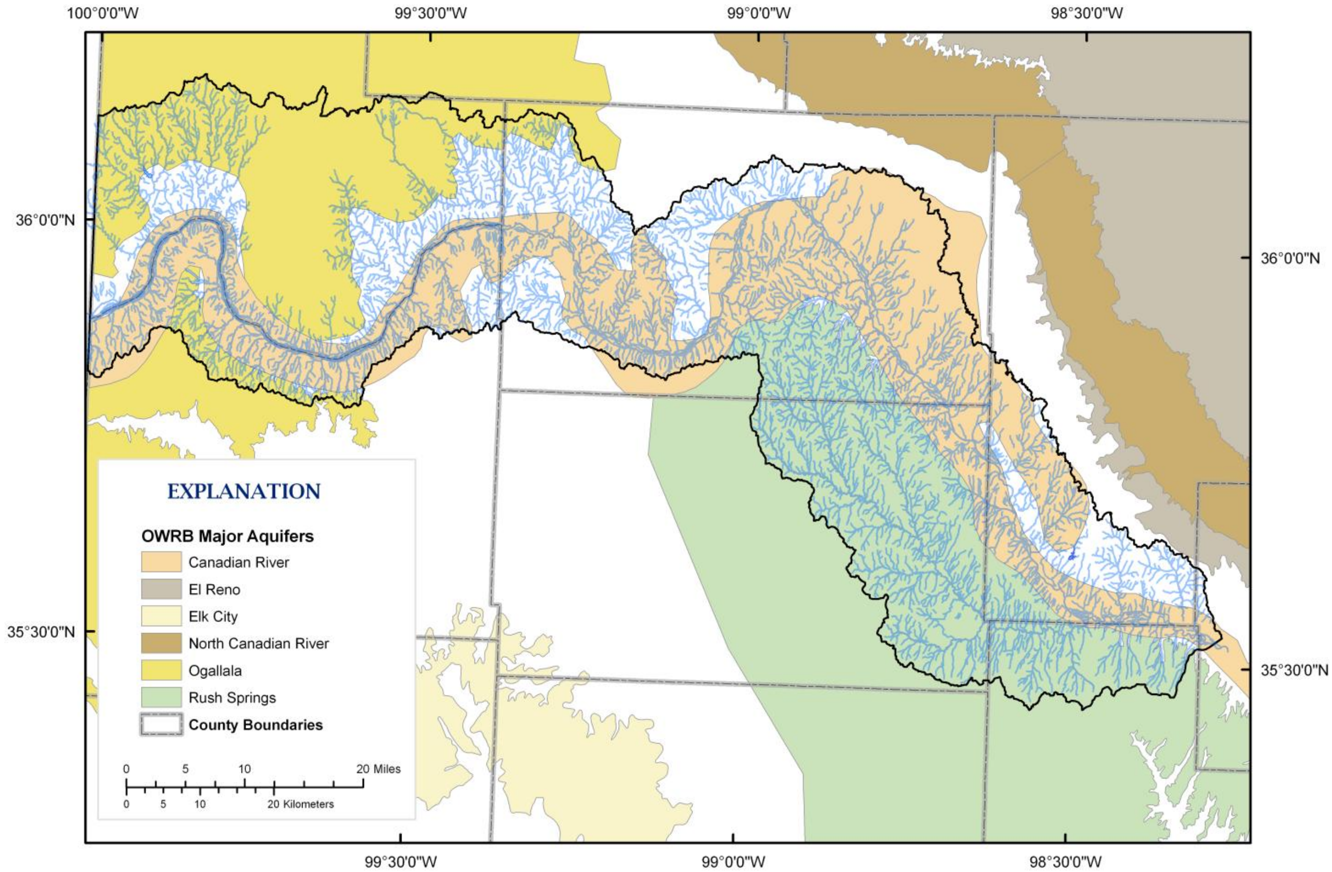


FIGURE 4: MAJOR GROUNDWATER BASINS OF THE UPPER CANADIAN RIVER BASIN

Streamflow records in the basin were analyzed taking into consideration the impact on flows before and after the construction of Lake Meredith in 1965. The lake is located to the west of Oklahoma in Texas, only 94 miles upstream from the state line on the Canadian River, as shown in Figure 5. The reservoir is managed by the National Park Service and has a contributing drainage area of 9,090 mi^2, a total capacity of 1,407,600 AF, and a surface area of 21,640 acres (Texas State Historical Association, 2012).

Figure 6 shows the historic streamflow at the USGS gages on the Canadian River near Canadian, TX, and on the Canadian River at Bridgeport, OK, where the impact of the reservoir on flows is apparent. The gage near Canadian experienced an average 76% decrease in streamflow after construction of the lake, while flows at Bridgeport decreased 28% on average. Releases from the reservoir create slowly varying flows in the Canadian River that are very similar to those of groundwater discharge. Those releases support the flow particularly during the summer months.

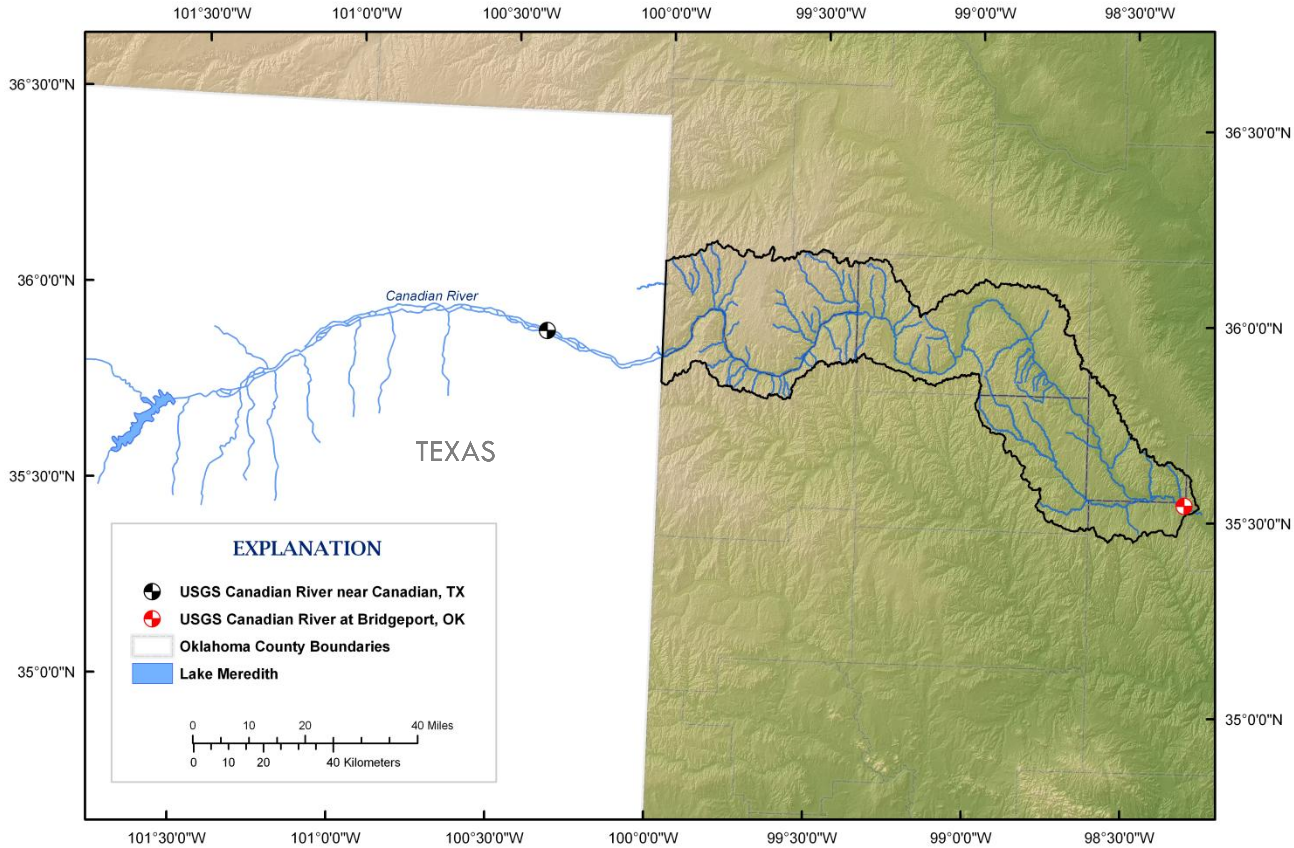


FIGURE 5: LAKE MEREDITH AND USGS GAGING STATIONS ON THE CANADIAN RIVER

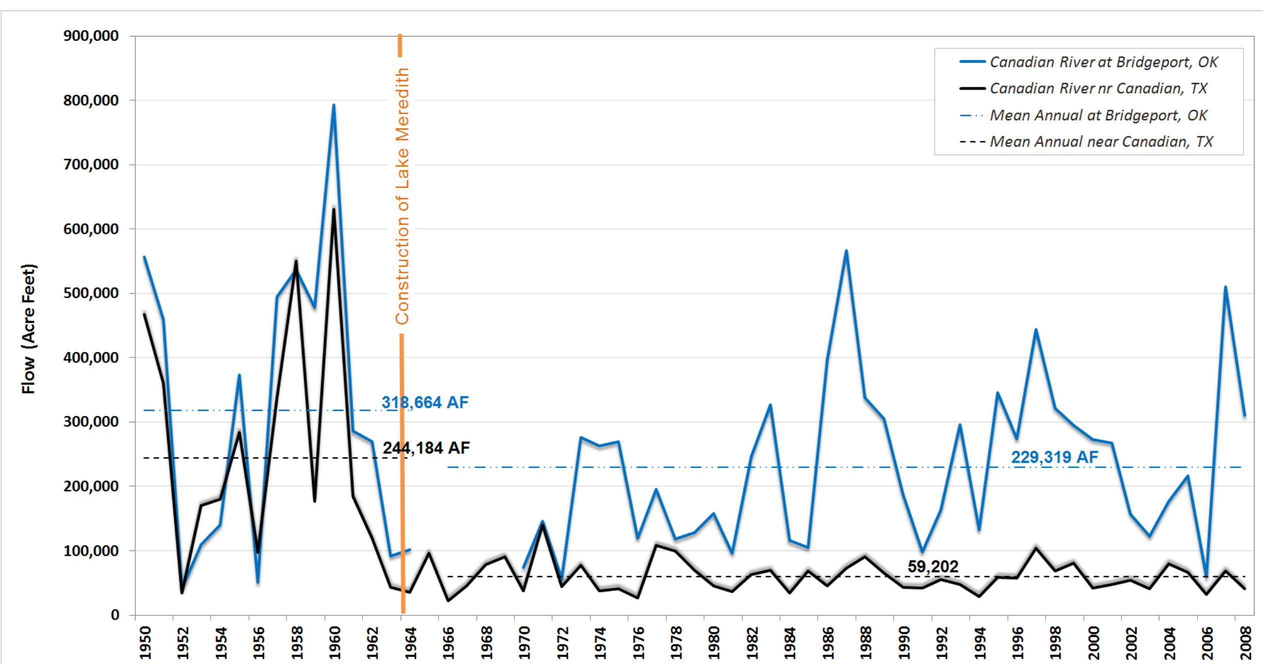


FIGURE 6: HISTORIC STREAMFLOW AT USGS GAGES BELOW LAKE MEREDITH

Baseflow index is the ratio of baseflow to total flow volume for a given period. A summary of the mean monthly baseflow index at the Bridgeport gage before and after construction of Lake Meredith is presented in Table 2. The baseflow index was computed using the hydrograph separation program PART (Rutledge, 1998). On an annual basis, the baseflow index at the gage has increased three times since construction of the reservoir. Increases in the baseflow index can be attributed to releases from Lake Meredith, as almost 40% of the contributing drainage area at Bridgeport is controlled by this reservoir.

TABLE 2: BASEFLOW INDEX AT BRIDGEPORT BEFORE AND AFTER CONSTRUCTION OF LAKE MEREDITH

		Baseflow Index* at USGS 07228500 Canadian River at Bridgeport												
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
1945-1964	Mean	0.2	0.3	0.2	0.1	0.0	0.1	0.1	0.2	0.1	0.1	0.2	0.2	0.1
	Median	0.1	0.2	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1
1965: Construction of Lake Meredith														
1970-2008	Mean	0.5	0.5	0.5	0.5	0.4	0.4	0.2	0.3	0.3	0.4	0.5	0.5	0.4
	Median	0.4	0.4	0.3	0.4	0.2	0.3	0.1	0.1	0.1	0.2	0.3	0.3	0.4

**Values computed with the PART Program (Rutledge, 1998).*

RESERVOIRS IN THE BASIN

There are 102 ponds or lakes in the basin, most with less than 510 acre-feet of storage, including 14 NRCS flood control structures used primarily for flood control and domestic use, as depicted in Figure 7. Details about reservoir storage in the basin are presented in Table 3.

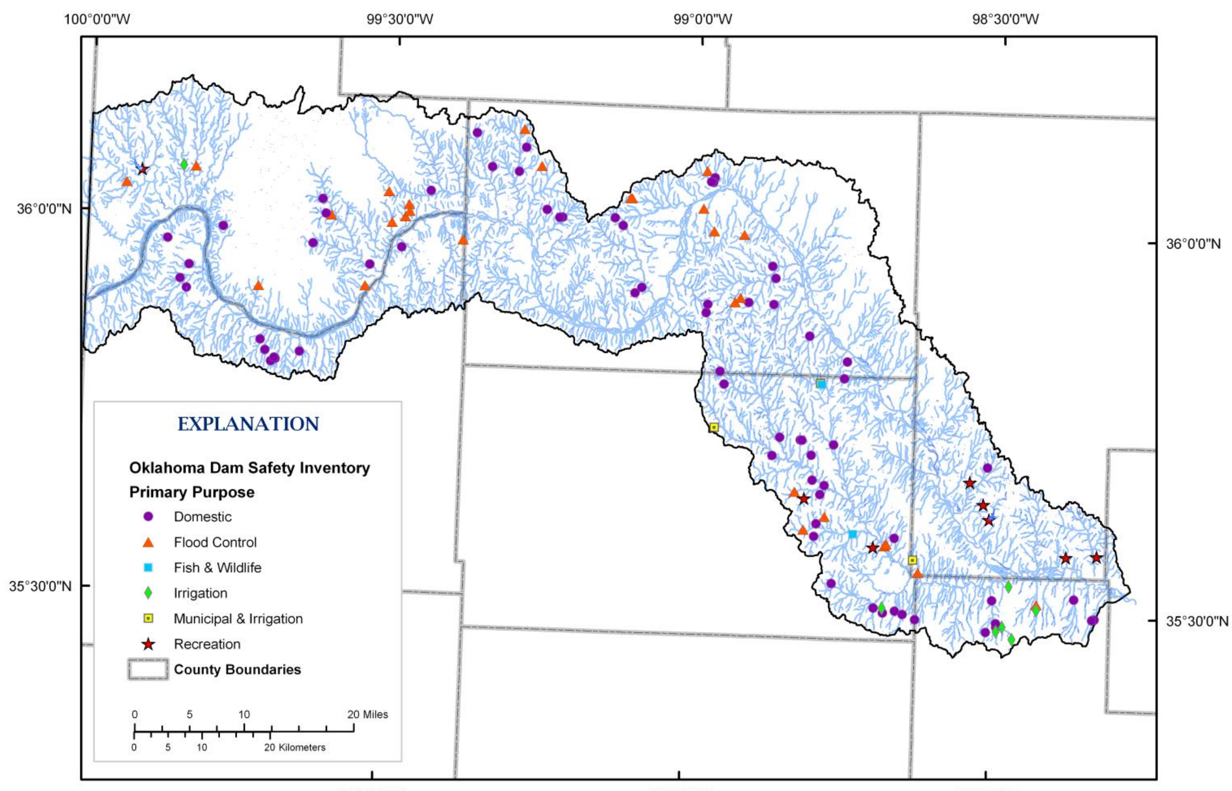


FIGURE 7: RESERVOIRS AND PONDS IN THE UPPER CANADIAN RIVER BASIN, AS ACTIVE ON THE OKLAHOMA DAM SAFETY INVENTORY

TABLE 3: RESERVOIR STORAGE IN THE UPPER CANADIAN RIVER BASIN, OK

Reservoir Storage in the Upper Canadian River Basin, OK			
Storage	**Number of Reservoirs**	**Name**	**Average Storage**
> 2,000 AF	2	Lloyd Vincent	2,579
		American Horse	2,200
< 2,000 AF	100		6,855

ANNUAL FLOWS, PEAKS AND FLOW DURATION

The USGS gage on the Canadian River at Bridgeport is located near the outlet of the basin. Streamflow data for the period 1950-2008 is depicted in Figure 8, where the mean annual flow is 4,251 cfs or 252,950 acre-feet per year. On average, the annual streamflow in the basin is composed of 65% runoff and 35% baseflow. Missing records for the period 1965-1969 at the gage at Bridgeport were reconstructed using mathematical regression analysis and data from the upstream USGS gage on the Canadian River near Canadian, TX.

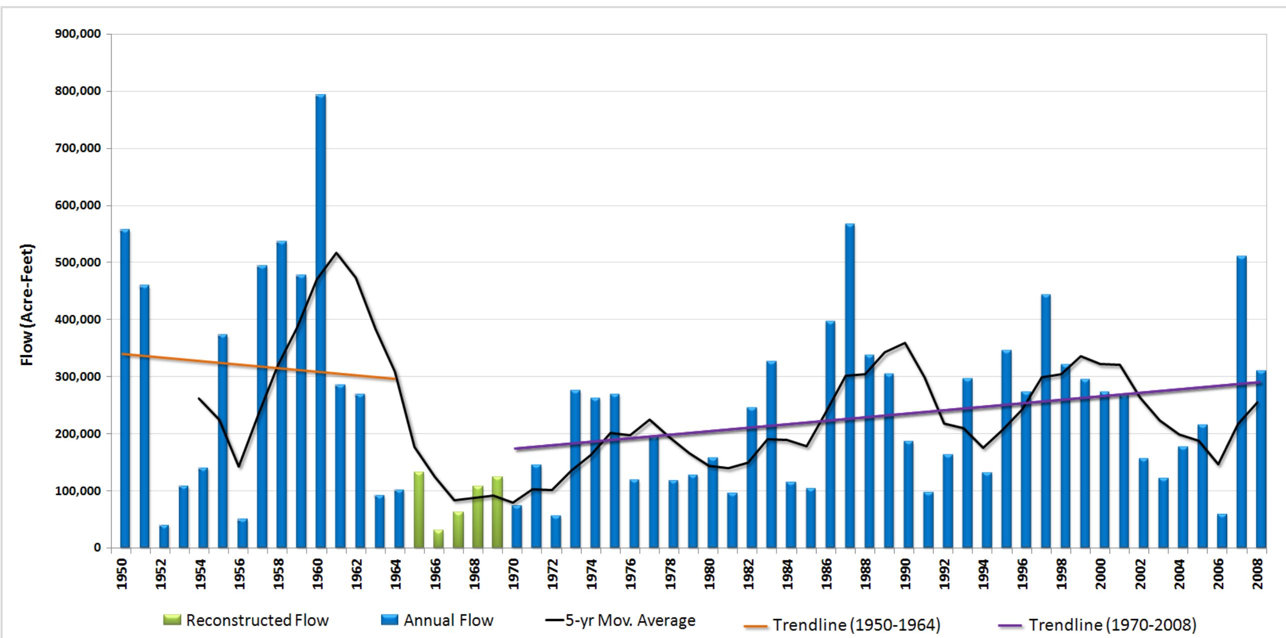


FIGURE 8: ANNUAL STREAMFLOW AT THE USGS GAGE ON THE CANADIAN RIVER AT BRIDGEPORT (1950-2008)

Figure 9 shows a plot of the annual peak flows at the gaging station on the Canadian River at Bridgeport with a downward trend. The largest discharge produced by the stream was 42,100 cfs in 1987. Figure 10 shows the flow duration curve for the USGS gage at Bridgeport, indicating the percentage of time that daily flow at the gage is likely to equal or exceed some specific flow of interest based on hydrologic data from 1950 to 2008. The Canadian River in this basin is predominantly a perennial stream where water is flowing more than 90% of the time. The shape of the flow duration curve provides information about the contribution of groundwater to streamflow. Significant inputs of groundwater contributions are observed from the lengthy period of low flows and the flat slope of the lower portion of the curve. Table 4 summarizes the monthly 20, 50, 80, and 90 percent exceedance, gathered from the flow duration curve.

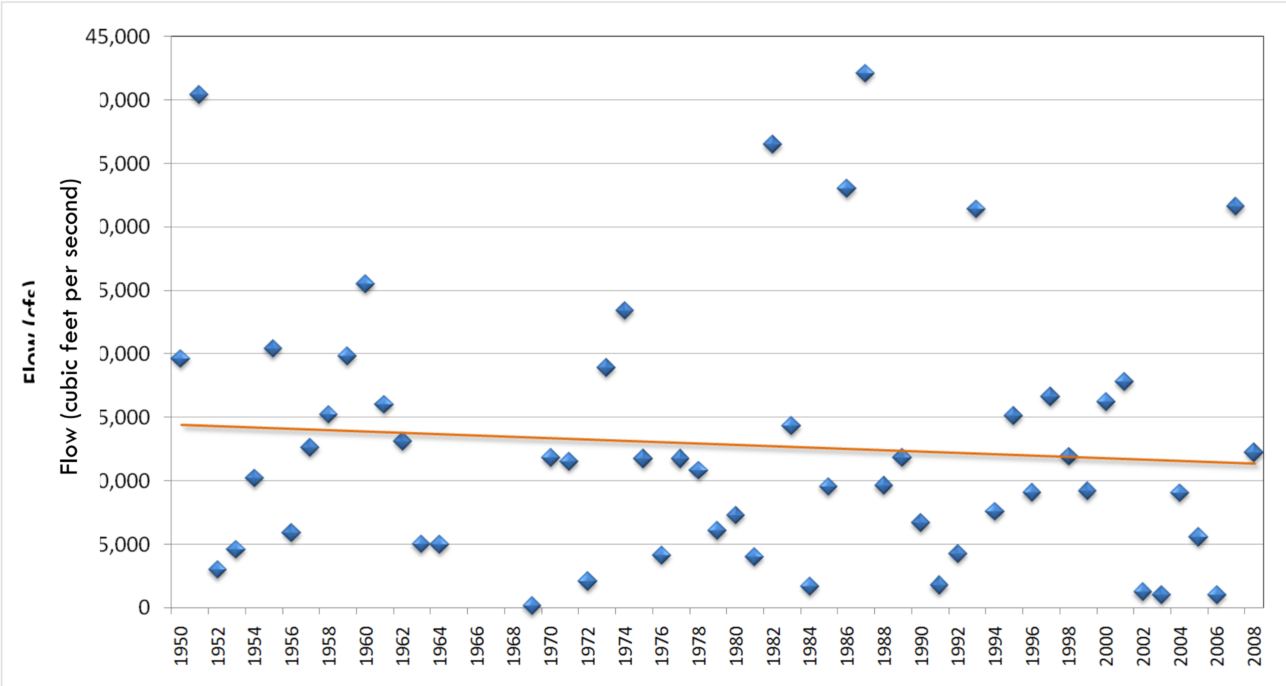


FIGURE 9: PEAK FLOWS MEASURED AT THE USGS GAGE ON THE CANADIAN RIVER AT BRIDGEPORT, OK (1950 - 2008)

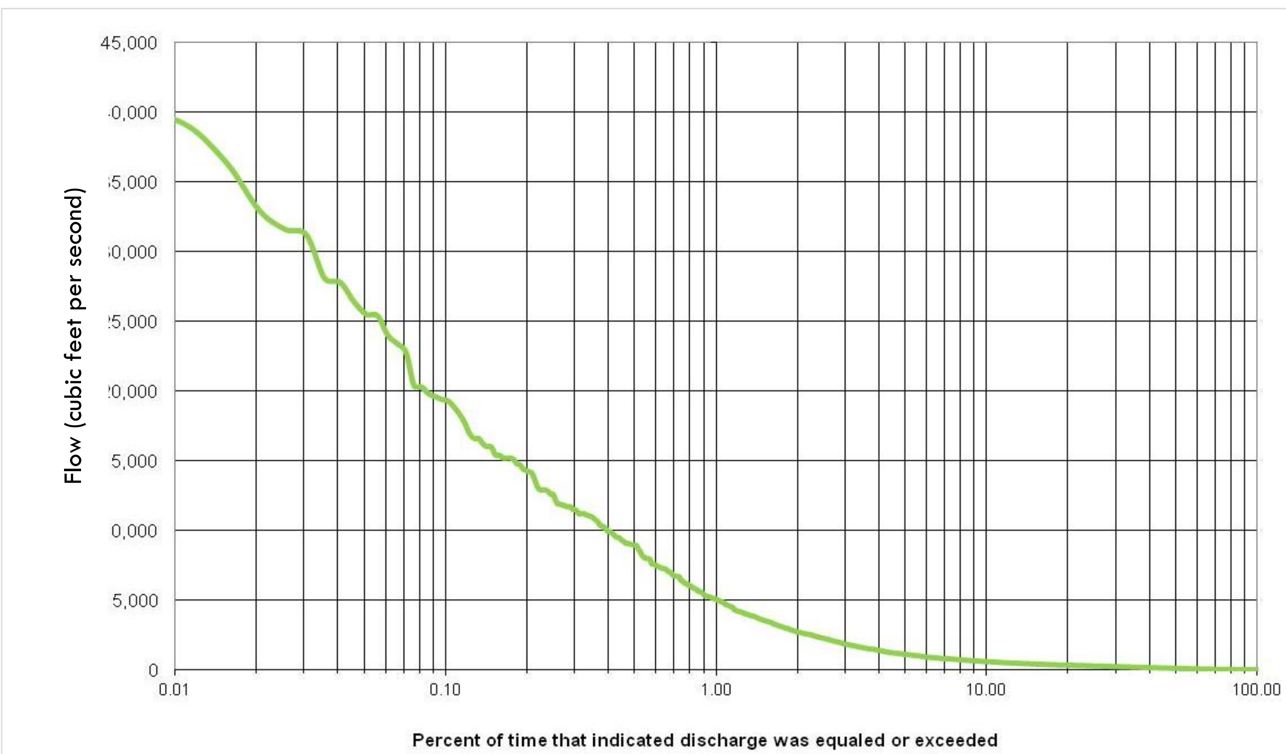


FIGURE 10: FLOW DURATION CURVE AT THE USGS GAGE ON THE CANADIAN RIVER AT BRIDGEPORT, OK (1950 - 2008)

TABLE 4: MONTHLY PERCENT EXCEEDANCE AT THE BRIDGEPORT GAGE (1950-2008)

Percent exceedance at the Canadian River gage near Bridgeport (USGS 07228500)					
	Exceedance in acre-feet (AF)				
	Mean Flow	**90%**	**80%**	**50%**	**20%**
Jan	12,954	1,565	3,647	9,258	18,421
Feb	15,051	2,725	5,081	12,108	22,753
Mar	23,651	2,207	6,450	14,518	31,303
Apr	20,759	1,416	4,915	13,721	28,453
May	50,173	3,588	5,670	28,376	76,154
Jun	37,684	4,498	6,902	21,065	71,396
Jul	23,150	493	1,041	5,902	17,273
Aug	18,838	214	583	2,898	32,457
Sep	14,908	571	708	2,743	29,417
Oct	15,846	851	1,160	5,504	21,277
Nov	11,730	1,101	1,559	4,762	17,350
Dec	11,632	1,297	2,410	6,307	18,159
Mean Monthly	**21,365**	**1,711**	**3,344**	**10,151**	**32,034**
Mean Annual	**256,375**	**20,526**	**40,127**	**121,818**	**384,413**

WATER RIGHTS AND WATER USE

As of 2008, the OWRB manages 27 active water rights for the beneficial uses of water in the Upper Canadian Basin totaling 3,170 acre-feet. A summary of all the active permits in this basin is presented later in this section. Figure 9 shows the location of the permitted uses of water.

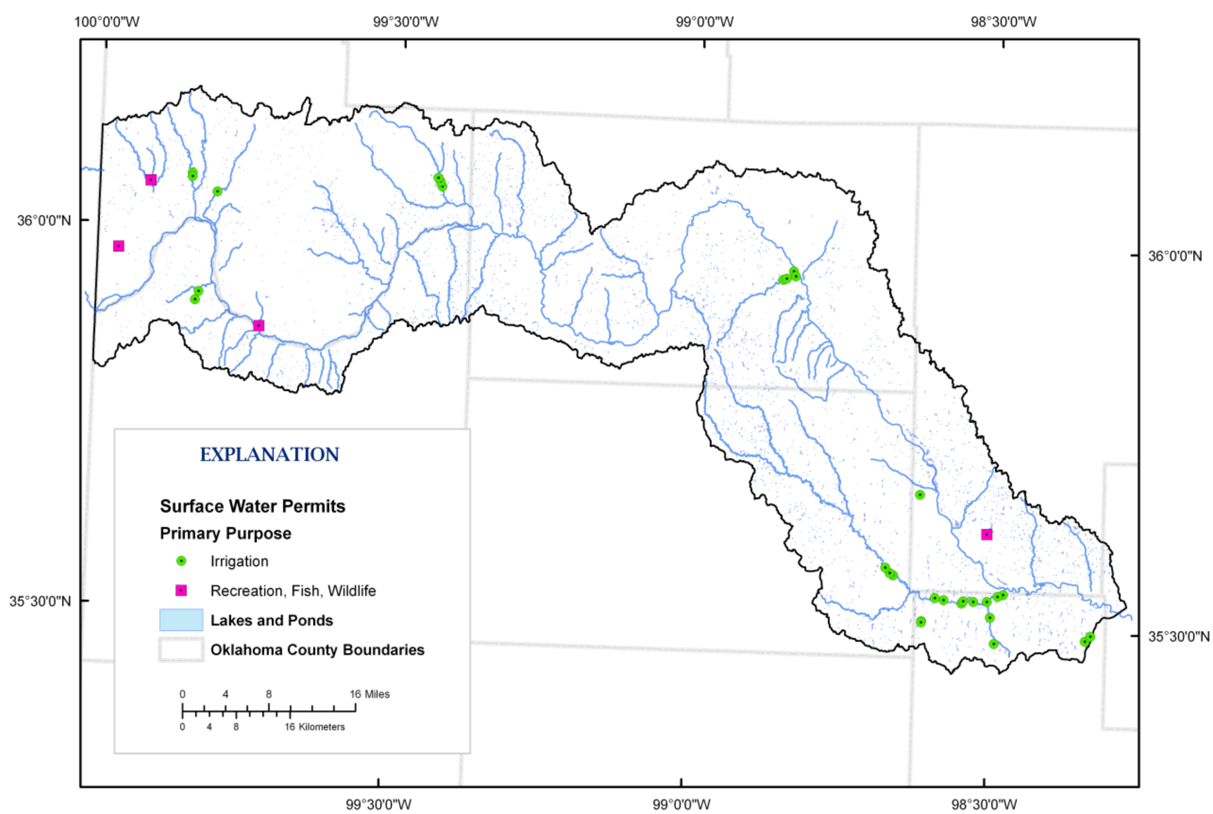


FIGURE 11: ACTIVE WATER RIGHTS IN THE UPPER CANADIAN RIVER BASIN, OK

The OWRB maintains a database of water use that is updated every year. Water use reports are filled out by water-right holders, who are required to report the amount of water used during each calendar year. The reported values are important for the OWRB to manage individual water rights concerning reductions and cancellations, and also to estimate water available in the basin after appropriation. Figure 10 shows the difference between the reported use (bars) and the permitted amounts (line) in the basin. An accentuated discrepancy between the permitted and reported amounts can be observed for the last 25 years, which is attributed to low reported uses received by the OWRB.

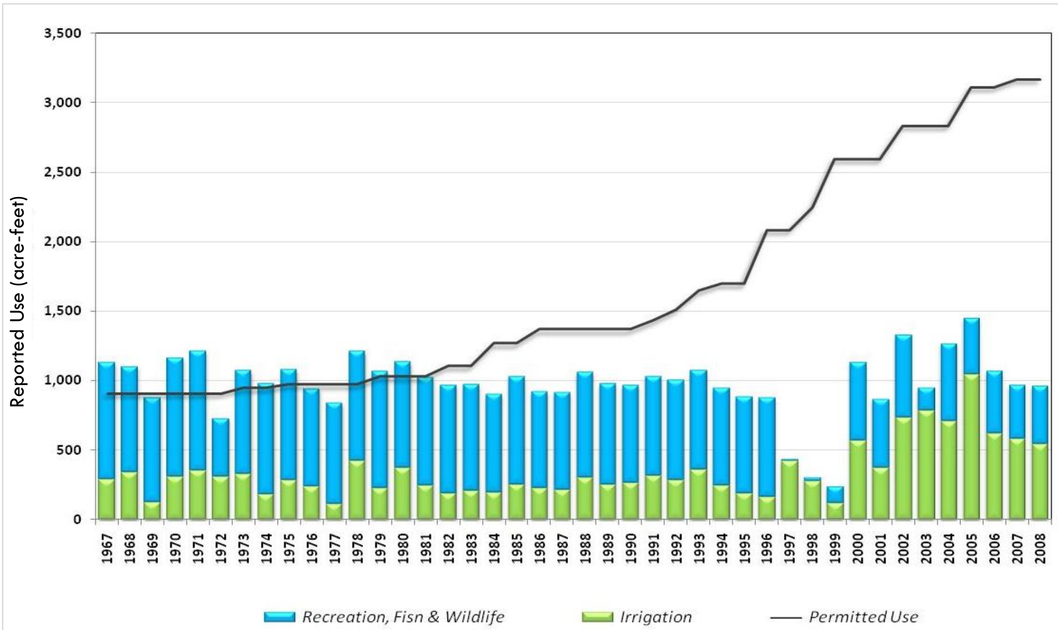


FIGURE 12: ANNUAL REPORTED AND PERMITTED WATER USE IN THE UPPER CANADIAN RIVER BASIN, OK

The number of permits issued for irrigation represents 85% of all permits, which according to the Land Cover/Use dataset (USDA) are mostly pasture and winter wheat. The amount of appropriated water for irrigation is 2,170 acre-feet/year (AFY), which constitutes 73% of the total amount authorized for use. There are five permits for recreation, fish & wildlife, which appropriate 1,000 AF of water. Table 5 presents a summary of the average permitted and reported water use on currently active permits as of 2009. The water appropriated for irrigation almost doubled during the 1990s, and is currently ten times larger than the appropriated amounts in the 60s, while the permitted amounts for recreation have remained relatively steady in the last 5 decades.

TABLE 5: PERMITTED AND REPORTED WATER USE FOR ACTIVE PERMITS, IN ACRE-FEET PER YEAR (AFY)

Permitted and Reported Water Use per Decade in the Upper Canadian River Basin, OK				
Decade	Recreation, Fish & Wildlife		Irrigation	
	Permitted	Reported Use*	Permitted	Reported Use*
1967-1970	680	701	230	268
1971-1980	680	639	285	283
1981-1990	680	680	580	237
1991-2000	728	476	1,230	295
2001-2008	840	413	2,119	685

**Data gathered from the OWRB Water Rights Database*

STREAM WATER ALLOCATION MODELING

The OWRB Stream Allocation Program is a comprehensive water administrative tool for the evaluation and effective management of stream water rights in the state. In Oklahoma, stream water is considered to be publicly owned and subject to appropriation by the OWRB. Current Oklahoma water law and OWRB regulations require that a permit application be filed prior to the diversion of water. A permit would be senior to other permits issued on the stream at a later time, which is referred to as the Doctrine of Prior Appropriation ("first in time, first in right") that is used by many states in the west to administer water rights (OWRB, 2009).

Oklahoma's water law requires the OWRB to evaluate three conditions before an application for the use of water is approved: 1) A present or future need for the water must exist and the intended use must be beneficial; 2) the applied for amount of unappropriated water must be available; 3) the use of water must not interfere with domestic or existing appropriative uses, and the needs of the area's water users if the application is for the transportation of water for use outside the area where the water originates.

The OWRB's allocation modeling program aims to address the need for a more accurate determination of both availability and possible interference (conditions 2 and 3 above). By using data from 1950 to present, the models can provide better estimates of water availability after appropriation at any location of a basin, showing areas sensitive to water shortages, and taking into consideration inter-and intra-basin transfers.

Models are constructed using a network-flow algorithm in Microsoft Excel® called Central Resource Allocation Model (CRAM), which is numeric algorithm was first developed by the *Texas Department of Environmental Quality* in the 1970s (Wurbs, 2004), and later incorporated into Excel and commercialized by the Consulting firm *AMEC Earth and Environmental*. The model simulates management of the water resources under a priority-based water allocation system. Historic water-use reports and streamflow at selected USGS gaging stations are used to assemble and calibrate the models on a monthly time-step. Simulations consist of naturalized flows that are distributed throughout the basin with water being allocated to each water right (Wurbs, 2006). Calibration of the model is performed until the simulated flows match the observed flows at the gages and ensures the model is representative of the hydrology of the basin. After calibration, simulations are run to estimate the amount of unappropriated water at ungaged locations, evaporation and content at reservoirs, and amount and frequency of shortages at permitted locations due to overuse by other permits or low streamflow conditions, among other analyses.

MODEL DEVELOPMENT

The OWRB compiles water-use data reported by permit holders on an annual basis. The data is stored in the OWRB Water Rights Administration database and used to conduct hydrologic studies and allocation models. The first step involves naturalizing the observed gaged streamflow. Naturalization consists of removing the effects of permitted water uses to compute the flow that would have occurred at the gage under natural conditions (Wurbs, 2006).

The National Hydrography Dataset (NHD) is used to characterize areas of a basin of intermittent and perennial flow (U.S. Geological Survey, 2006). Groundwater discharge supports the perennial flow of streams, particularly during low-flow periods. Streams lacking groundwater discharge are dependent on surface runoff and may flow only part of the year, thus are referred to as intermittent. Digital information on perennial and intermittent streams is retrieved from the digital dataset and plotted to identify the predominant types of streams at each sub-watershed (HUC-12). Units where perennial streams are dominant in most of the stream network or in the main stream are considered to be supported by a combination of baseflow and surface runoff, and therefore called perennial. The remaining sub-watersheds where flow is mainly intermittent are assigned direct runoff only. The classification of perennial and intermittent streams for the basin is depicted in Figure 13, and gathered from the National Hydrography Dataset. The classification is taken into consideration in the allocation models during the flow naturalization process, where perennial areas contain a mixture of runoff and baseflow discharge and intermittent streams are composed of runoff only. Once naturalized flows are added as input of the model, along with information about water rights, several simulations are run to calibrate the simulated flows to recorded flows at the USGS gage at Bridgeport.

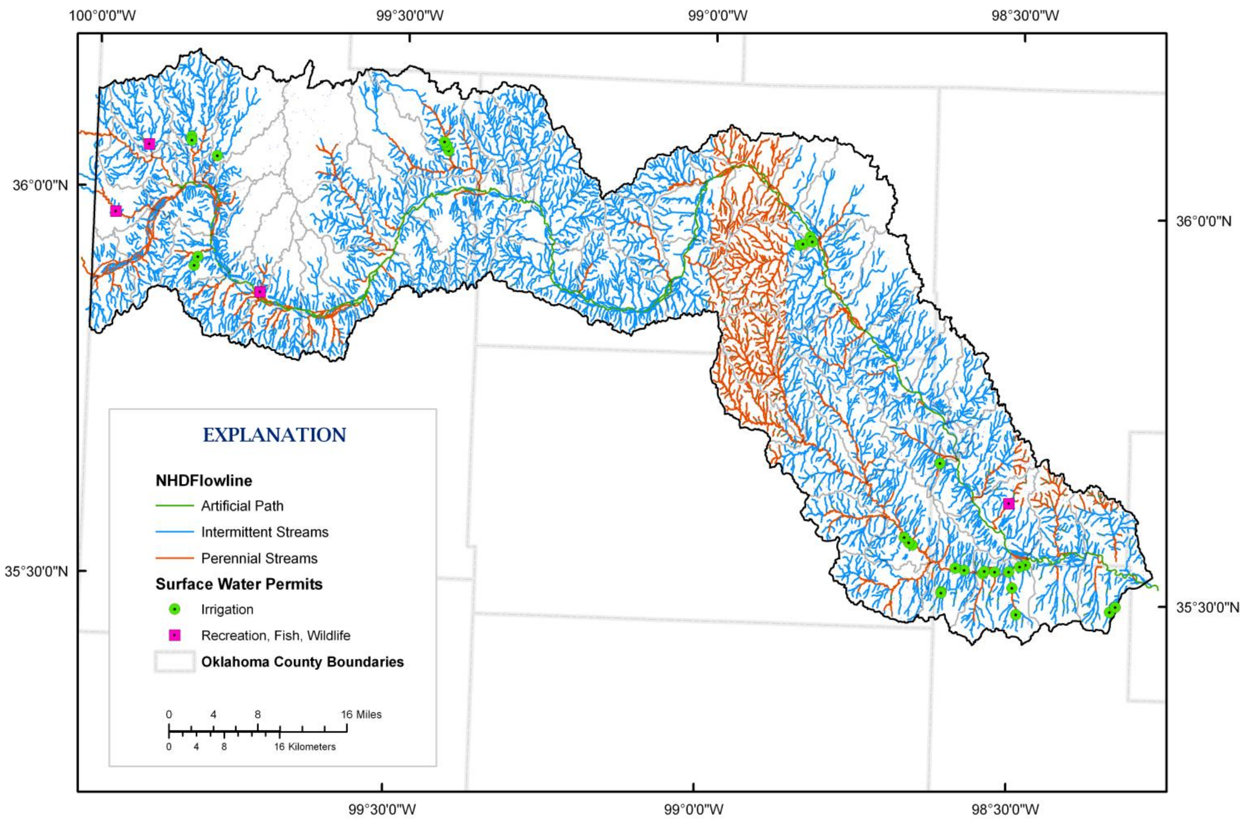


FIGURE 13: PERENNIAL AND INTERMITTENT STREAMS FROM THE USGS NATIONAL HYDROGRAPHY DATASET

Allocation models in ExcelCRAM are composed of two types of objects that are inter-connected to represent the network: nodes, which are points at which water conveys, and links that carry water from one node to another. Construction of the model includes incorporating these objects in the model, and attributing hydrologic and water-rights data to each object. Hydrologic data includes inflows at each sub-watershed, reservoir/lake operations, environmental flows, and inter/intra-basin transfers, while water-rights information is entered to specify details about the permit, appropriated amounts, schedules of use, reported water use, and other details. Figure 14 shows the network schematic built within ExcelCRAM for the Upper Canadian basin. The model includes 56 inflows which represent the water entering the sub-basins, 30 demands that represent the existing water rights, and 6 reservoirs or lakes. The demand patterns of the model, or monthly distribution of the water use demands, is summarized in table 6, and is subject to change subject to changes in demand schedules and climate conditions.

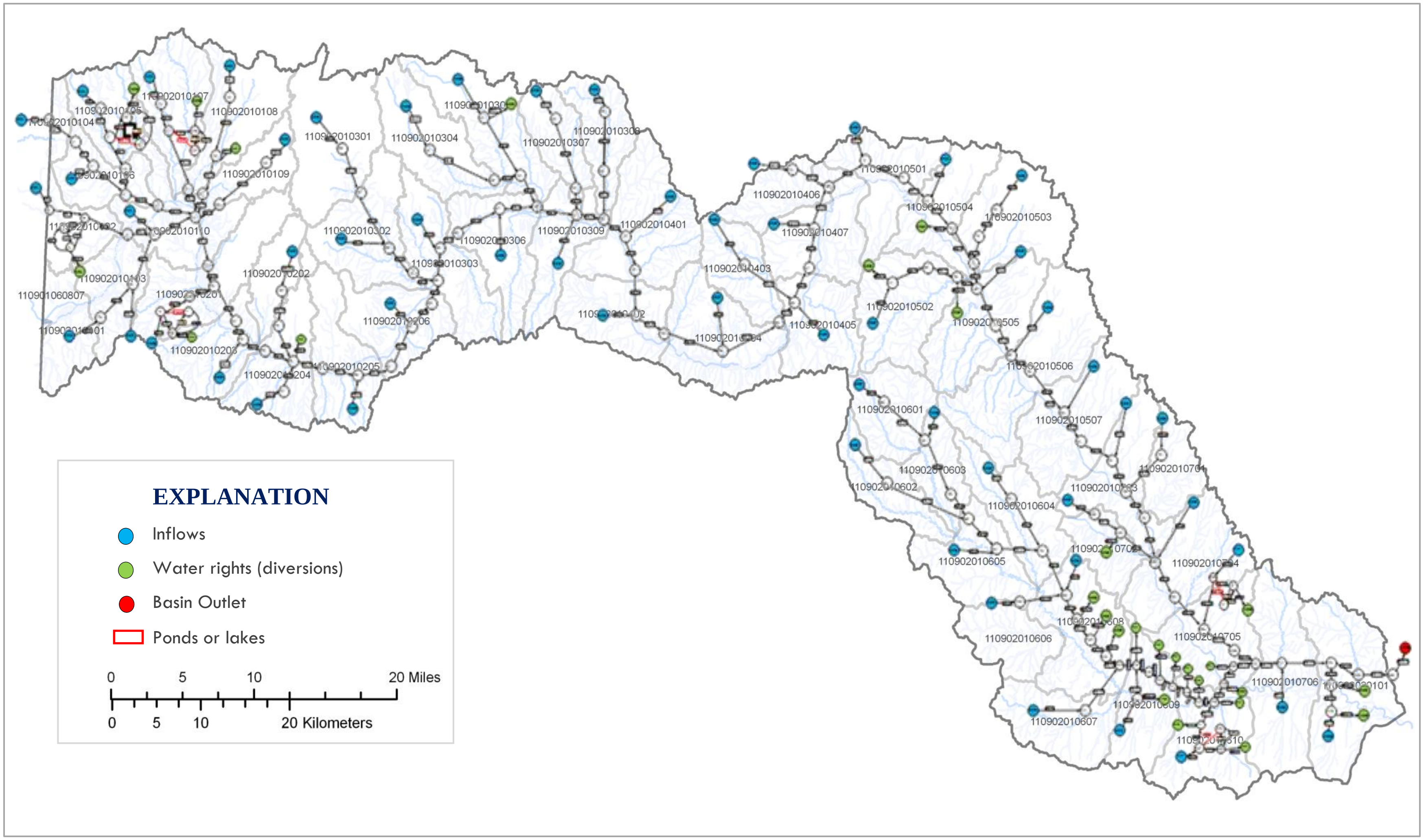


FIGURE 14: SCREENSHOT OF THE NETWORK SCHEMATIC FROM THE ALLOCATION MODEL FOR THE UPPER CANADIAN RIVER BASIN, OK

TABLE 6: DEMAND PATTERNS FOR THE UPPER CANADIAN RIVER BASIN, OK IN ACRE-FEET (AF)

Demand Patterns* for the Upper Canadian River Basin, OK												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Irrigation	0.0%	0.0%	0.0%	0.0%	0.0%	24.7%	33.0%	29.4%	13.0%	0.0%	0.0%	0.0%
Evaporation**	3.0%	3.9%	8.7%	8.4%	13.1%	15.4%	7.2%	12.8%	8.8%	11.2%	4.4%	3.3%

**Data gathered from CDM as preliminary for the 2012 Oklahoma Comprehensive Water Plan (OWRB, 2012).*

***Evaporation estimated from the water budget for the basin. Applied to reservoirs with recreation, fish and wildlife uses (non-consumptive).*

Water is distributed in the system on a monthly basis and demands are supplied based upon the selected management scenario:

- **Scenario 1: Historic Use**
  Simulations under this scenario deliver water to currently active demands using reported water use values. Unreported values are replaced with the appropriated amount and there are no demands prior to date of permit issue. This scenario is mainly used for calibration, and ensures that the model is representative of the hydrology of the basin, and able to reproduce the recorded streamflow of USGS gages with less than a 5 % error.
- **Scenario 2: Full Use--Priority based**
  Water is delivered to all currently active permits using the full appropriated amounts for all years. Distribution of water to demands is based on their priority in time, where senior water rights are first in obtaining water before junior rights. This scenario is mainly used by the OWRB to identify interference of water rights from a legal prospective.
- **Scenario 3: Average Reported Use**
  This scenario delivers water to currently active demands using the average of the reported use, for all years and unreported values, based on their priority in time. The resulting information is useful to determine shortages and interference based on average use.
- **Scenario 4: Full Use--No priority**
  This scenario delivers water from upstream to downstream in the basin, using the permitted amounts for active demands, for all years with no priority of use. This scenario is the most used by the OWRB to perform drought analyses, identify over-appropriated areas, and anticipate water shortages and interference of water rights based on use instead of priority.

Simulations are run, and the model presents tables with details about shortages, water availability and valuable hydrologic information. Results from the model are archived in a database and plotted using ArcGIS®, which allows the user to see the spatial distribution of water shortages in the basin.

WATER AVAILABILITY

The allocation model has been used to evaluate various management scenarios and hydrologic conditions in the basin. Availability and reliability are estimated from simulations at the sub-basin scale. Table 7 presents the mean annual unappropriated water as of 2009 at each sub-basin computed by the model. The spatial distribution of potential water shortages (i.e. anticipated shortages based on the hydrologic conditions of the simulation) is depicted Figure 15.

TABLE 7: UNAPPROPRIATED WATER FOR SUB-BASINS IN THE UPPER CANADIAN RIVER BASIN, IN ACRE-FEET (AF)
Estimates from the ExcelCRAM stream water allocation model. Simulation Scenario 4, from 1950 to 2008.

Mean Monthly Unappropriated Water in Sub-basins of the Upper Canadian River Basin, OK

12-HUC	Acres	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
110902010101	16,713	86	101	154	132	298	238	119	110	88	99	77	76	**1,578**
110902010102	12,990	62	72	109	94	218	166	77	73	58	64	53	53	**1,099**
110902010103	17,309	316	369	565	484	1,092	872	436	403	324	364	281	277	**5,783**
110902010104	5,111	61	72	111	101	299	229	167	125	94	101	58	62	**1,480**
110902010105	17,823	66	85	125	118	380	274	203	150	112	107	60	70	**1,750**
110902010106	16,071	341	406	619	546	1,418	1,093	665	547	425	455	308	319	**7,142**
110902010108	25,998	132	155	240	218	646	483	347	258	198	219	125	133	**3,154**
110902010109	14,215	70	83	128	116	345	264	192	144	108	117	67	71	**1,705**
110902010110	22,848	1,158	1,364	2,094	1,850	4,883	3,747	2,343	1,888	1,464	1,608	1,057	1,093	**24,549**
110902010201	31,247	1,305	1,538	2,363	2,095	5,609	4,281	2,724	2,169	1,679	1,850	1,196	1,241	**28,050**
110902010202	12,378	61	72	111	101	300	230	167	125	94	102	58	62	**1,483**
110902010203	20,305	1,578	1,857	2,852	2,514	6,553	5,035	3,101	2,518	1,959	2,165	1,439	1,481	**33,052**
110902010204	25,656	1,981	2,328	3,575	3,138	8,035	6,208	3,741	3,079	2,403	2,649	1,744	1,798	**40,679**
110902010205	23,788	2,297	2,699	4,142	3,624	9,130	7,082	4,178	3,482	2,728	3,014	2,027	2,076	**46,479**
110902010206	22,501	2,408	2,830	4,345	3,808	9,675	7,499	4,483	3,710	2,899	3,199	2,132	2,189	**49,177**
110902010301	36,251	482	564	864	740	1,669	1,332	667	616	495	556	430	424	**8,839**
110902010302	27,526	848	993	1,520	1,301	2,936	2,344	1,173	1,083	870	979	757	746	**15,550**
110902010303	27,052	3,391	3,980	6,108	5,330	13,268	10,345	6,022	5,066	3,976	4,400	3,015	3,070	**67,971**
110902010304	27,599	367	430	658	563	1,271	1,014	508	469	376	424	327	323	**6,730**
110902010305	30,428	772	903	1,383	1,184	2,671	2,127	1,061	980	788	891	688	678	**14,126**
110902010306	24,909	4,286	5,028	7,715	6,717	16,543	12,934	7,419	6,299	4,955	5,495	3,820	3,872	**85,083**
110902010307	15,141	75	88	136	124	367	281	205	153	116	124	71	76	**1,816**
110902010308	18,023	89	105	162	147	437	334	244	182	138	148	84	90	**2,160**
110902010309	19,147	4,545	5,332	8,186	7,145	17,811	13,905	8,127	6,827	5,354	5,925	4,065	4,134	**91,356**
110902010401	35,253	4,720	5,537	8,503	7,433	18,666	14,558	8,603	7,184	5,623	6,215	4,230	4,311	**95,583**
110902010402	23,406	4,836	5,673	8,714	7,625	19,233	14,993	8,920	7,420	5,801	6,407	4,339	4,428	**98,389**
110902010403	17,750	88	103	160	145	430	329	240	179	135	146	83	89	**2,127**
110902010404	32,699	4,998	5,864	9,008	7,892	20,026	15,599	9,362	7,751	6,051	6,675	4,492	4,591	**102,309**
110902010405	22,700	5,387	6,320	9,709	8,500	21,501	16,762	10,019	8,316	6,496	7,170	4,845	4,946	**109,971**
110902010406	13,900	69	81	125	114	337	258	188	141	106	114	65	70	**1,668**
110902010407	25,749	5,584	6,551	10,066	8,824	22,462	17,498	10,556	8,717	6,799	7,495	5,030	5,144	**114,726**
110902010501	23,499	5,896	6,917	10,626	9,304	23,544	18,362	10,988	9,116	7,119	7,856	5,309	5,419	**120,456**
110902010503	29,311	145	170	264	240	711	544	396	296	224	241	137	147	**3,515**
110902010504	21,943	6,188	7,258	11,149	9,752	24,555	19,140	11,354	9,455	7,404	8,193	5,569	5,675	**125,692**
110902010505	31,209	6,874	8,062	12,386	10,839	27,358	21,272	12,643	10,506	8,233	9,135	6,197	6,317	**139,822**
110902010506	42,504	7,440	8,724	13,399	11,706	29,315	22,834	13,425	11,227	8,813	9,788	6,701	6,814	**150,186**
110902010507	32,116	7,599	8,911	13,688	11,968	30,094	23,430	13,859	11,552	9,058	10,051	6,851	6,975	**154,036**
110902010601	19,855	264	309	473	405	914	730	365	337	271	305	236	232	**4,841**
110902010602	17,294	230	269	412	353	796	636	318	294	236	265	205	202	**4,216**
110902010603	13,885	449	525	804	688	1,553	1,240	621	573	460	518	400	394	**8,225**
110902010604	24,127	1,318	1,543	2,362	2,022	4,563	3,642	1,823	1,683	1,352	1,521	1,176	1,158	**24,163**
110902010605	23,942	997	1,167	1,787	1,530	3,452	2,755	1,379	1,273	1,023	1,151	889	876	**18,279**
110902010606	17,335	231	270	413	354	798	637	319	294	237	266	206	203	**4,228**
110902010607	23,027	306	359	549	470	1,060	846	424	391	314	353	273	269	**5,614**
110902010608	31,001	1,961	2,295	3,514	3,008	6,788	5,330	2,598	2,408	1,964	2,263	1,749	1,724	**35,602**

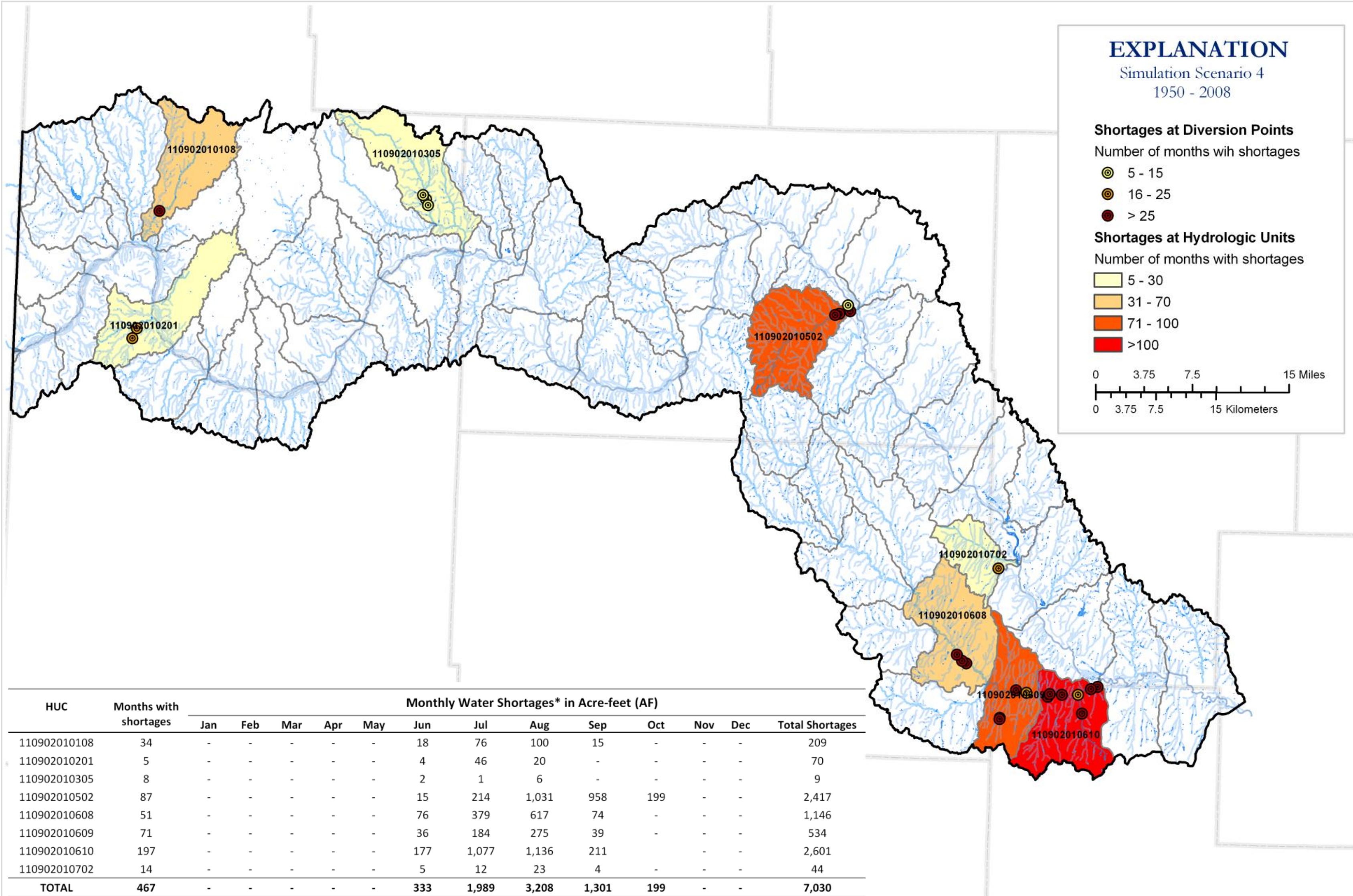
Mean Monthly Unappropriated Water in Sub-basins of the Upper Canadian River Basin, OK														
12-HUC	Acres	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
110902010609	21,389	2,552	2,987	4,572	3,914	8,833	6,929	3,373	3,127	2,551	2,945	2,276	2,243	**46,302**
110902010610	26,894	2,907	3,404	5,211	4,460	10,067	7,818	3,753	3,483	2,864	3,354	2,593	2,557	**52,471**
110902010701	14,769	73	86	133	121	358	274	200	149	113	121	69	74	**1,771**
110902010702	13,281	177	207	316	271	611	482	237	220	178	204	158	155	**3,216**
110902010703	26,225	7,802	9,149	14,057	12,304	31,088	24,190	14,413	11,967	9,371	10,388	7,043	7,180	**158,952**
110902010704	29,714	8,126	9,528	14,641	12,817	32,419	25,223	15,052	12,487	9,776	10,836	7,340	7,484	**165,729**
110902010705	25,635	8,453	9,912	15,221	13,312	33,556	26,114	15,456	12,886	10,097	11,192	7,626	7,768	**171,593**
110902010706	35,369	11,830	13,867	21,276	18,494	45,252	35,232	19,859	16,970	13,444	15,089	10,638	10,738	**232,689**
Basin Outlet	36,640	12,317	14,437	22,149	19,241	46,939	36,554	20,502	17,565	13,930	15,652	11,073	11,167	**241,526**
Monthly Average		**2,715**	**3,184**	**4,888**	**4,265**	**10,614**	**8,269**	**4,808**	**4,045**	**3,180**	**3,536**	**2,444**	**2,477**	**54,420**

Explanation of Figure 15

Conditions: Scenario 4 and historic flows from 1950 to 2008. Water is delivered to permits from upstream to downstream users with no restrictions of priority, and all water rights use the full amounts authorized by their permits each year of the simulation period.

Calibration: Simulated streamflow was previously calibrated to the USGS gage on the Canadian River at Bridgeport (± 5% Error).

Results: The simulation uses almost 60 years of historic data, which captures the statistical characteristics of the basin hydrology and accounts for the probable range of future hydrology. The model in ExcelCRAM presents tables with valuable hydrologic data, including estimates of unappropriated available water at the sub-basin scale (Table 7), and at ungaged locations (nodes). It also has the capability of estimating water shortages in the system, representing supply failures where available flows do not meet the demands (full permitted amounts in Scenario 4) of water rights. Results from the model are linked to geographic information systems, where the spatial distribution of shortages can be visualized by the user. A threshold was set in the model to display only permits with four or more shortages. The shortages are color-coded according to their frequency of occurrence, and listed for each sub-basin. More specific information about flow availability, reliability, and potential shortages in this basin can be provided by the OWRB upon request.



HUC	Months with shortages	Monthly Water Shortages* in Acre-feet (AF)												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total Shortages
110902010108	34	-	-	-	-	-	18	76	100	15	-	-	-	209
110902010201	5	-	-	-	-	-	4	46	20	-	-	-	-	70
110902010305	8	-	-	-	-	-	2	1	6	-	-	-	-	9
110902010502	87	-	-	-	-	-	15	214	1,031	958	199	-	-	2,417
110902010608	51	-	-	-	-	-	76	379	617	74	-	-	-	1,146
110902010609	71	-	-	-	-	-	36	184	275	39	-	-	-	534
110902010610	197	-	-	-	-	-	177	1,077	1,136	211		-	-	2,601
110902010702	14	-	-	-	-	-	5	12	23	4	-	-	-	44
TOTAL	**467**	**-**	**-**	**-**	**-**	**-**	**333**	**1,989**	**3,208**	**1,301**	**199**	**-**	**-**	**7,030**

FIGURE 15: WATER SHORTAGES ESTIMATED BY THE ALLOCATION MODEL BASED ON HISTORIC FLOWS (1950 TO 2008) AND CONDITIONS OF SCENARIO 4

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