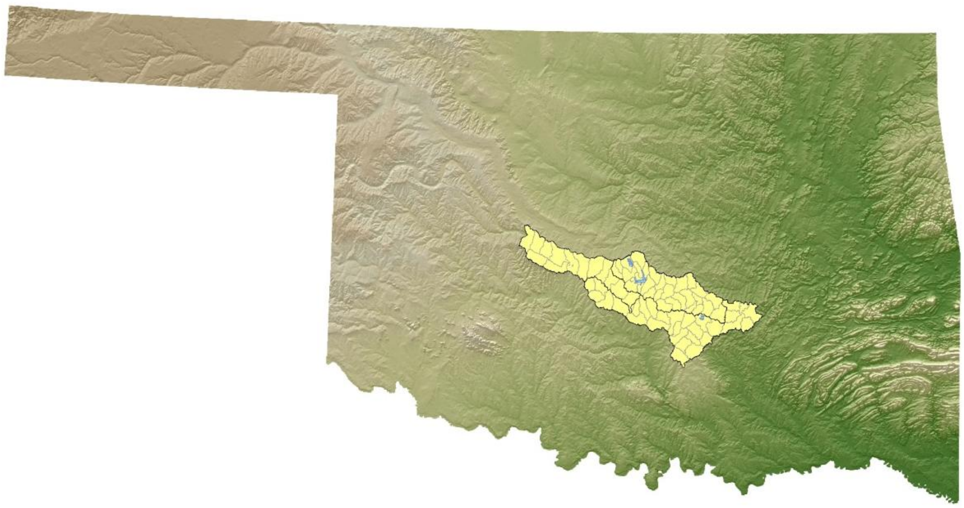
MIDDLE CANADIAN, LOWER CANADIAN, & LITTLE RIVER BASINS



HYDROLOGIC INVESTIGATION

TECHNICAL REPORT TR-2011-01

2011

OKLAHOMA WATER RESOURCES BOARD

Planning and Management Division

MIDDLE CANADIAN, LOWER CANADIAN & LITTLE RIVER BASINS

HYDROLOGIC INVESTIGATION

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State of Oklahoma

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MIDDLE CANADIAN, LOWER CANADIAN, & LITTLE RIVER BASINS

HYDROLOGIC INVESTIGATION

INTRODUCTION

The Oklahoma Water Resources Board (OWRB) 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 Middle Canadian, Lower Canadian, and Little River basins 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 Middle Canadian, Lower Canadian, and Little River basins lie in the counties of Caddo, Canadian, Grady, Cleveland, McClain, Pottawatomie, Seminole and Pontotoc and Hughes as shown in Figure 1. The Canadian River flows from the Upper Canadian River basin (OWRB System 2-6-3) into the Middle Canadian basin, and 194 miles downstream to the southeast to its confluence with the Little River at river mile 102.4. The Little River basin originates in Cleveland County and flows 120 miles to its confluence with the Canadian River.

The Middle Canadian and Lower Canadian basins have a drainage area of 710 mi^2, and 1,148 mi^2, respectively. Elevation in these basins ranges from 207 to 495 feet, while the Canadian River flows in these systems with an average slope of 0.08 %. The Little River basin has a drainage area of 889 mi^2, and flows with an average bed slope of 0.09%. The basins are part of the Canadian River interstate stream compact between New Mexico, Oklahoma, and Texas.

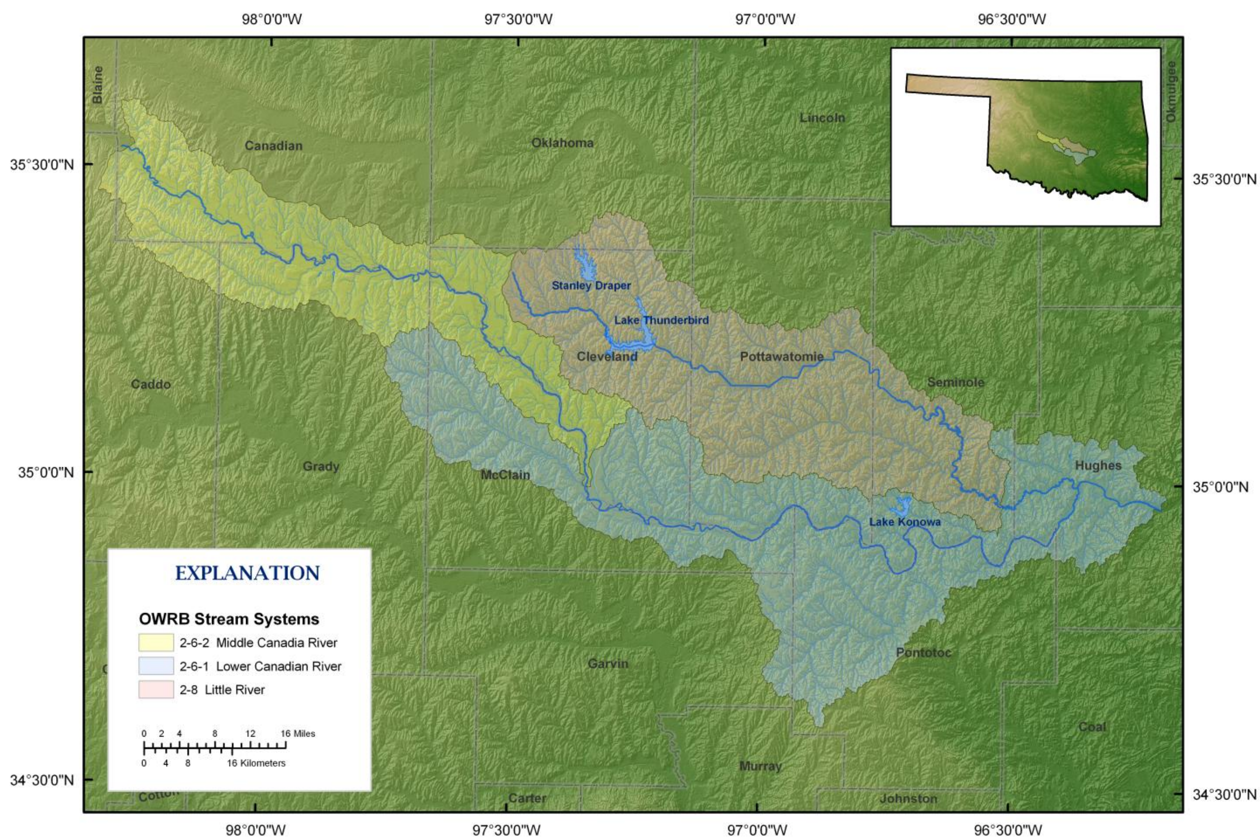


FIGURE 1 SHADED RELIEF OF THE MIDDLE CANADIAN (2-6-2), LOWER CANADIAN (2-6-1), AND THE LITTLE RIVER (2-8) BASINS

LAND COVER/USE

Irrigation and hydropower are the prevalent uses in the Middle Canadian, Lower Canadian, and Little River basins. The Middle Canadian and Little River basins are composed of Central Redbed Plains that transition into High Plains from alluvial sands in the Lower Canadian basin (McGaugh, 1986). The predominant deep loamy soils sustain crops of pasture, hay and small grains, and large areas of deciduous forest mainly in the Little River basin, as depicted in Figure 2.

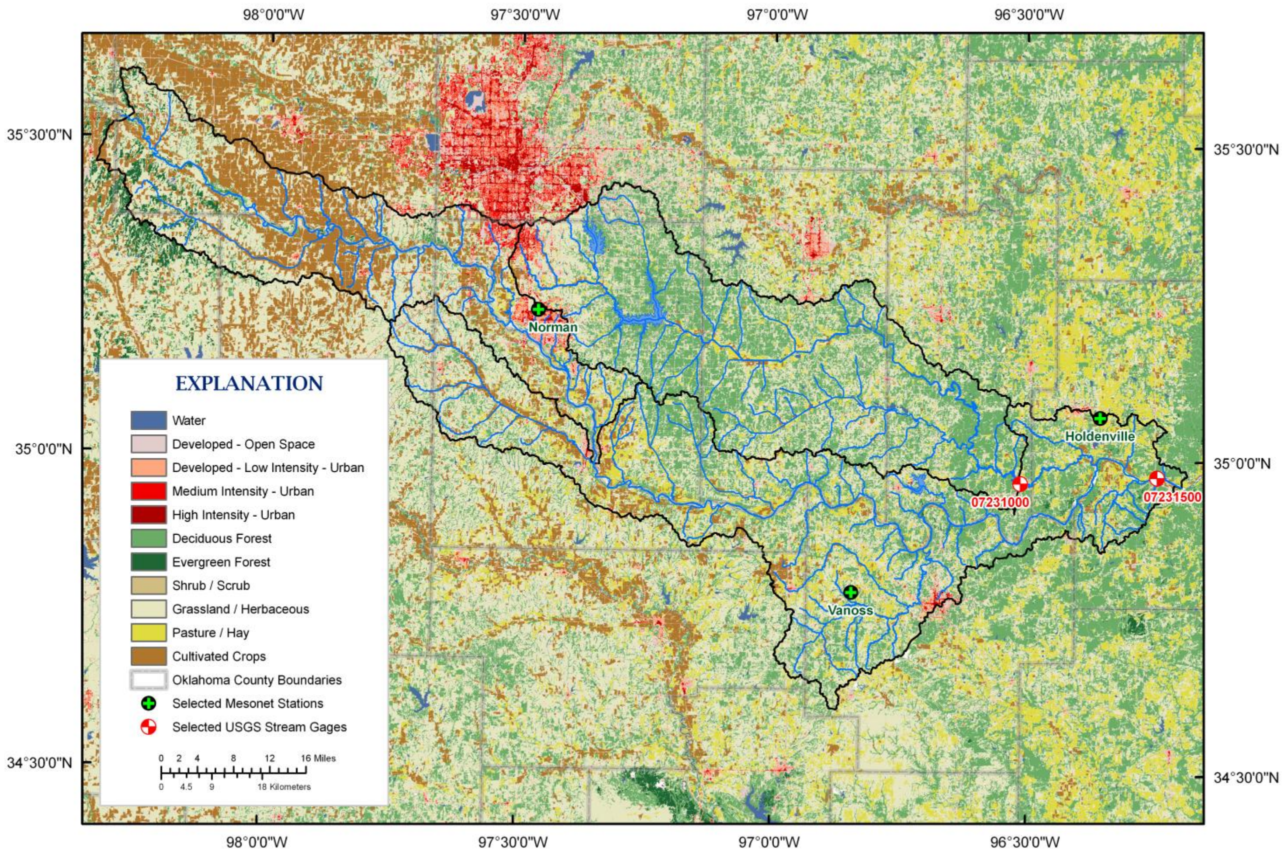


FIGURE 2 NATIONAL LAND COVER CLASSIFICATION FOR OWRB SYSTEMS 2-6-1, 2-6-2 AND 2-8

WATER BALANCE

A water balance was constructed for the Middle Canadian, Lower Canadian, and Little River basins for the period 2003-2010 using available hydro-meteorological data. Mean monthly precipitation data is estimated using the Mesonet stations at Norman and Holdenville, while streamflow is retrieved from the active USGS streamflow gages Little River near Sasakwa, OK (USGS 07231000) and Canadian River at Calvin, OK (USGS 07231500). Daily streamflow is used as input of the PART program (Rutledge, 1998) to obtain baseflow and runoff, while actual evapotranspiration is computed as a residual of the water budget. The seasonal variation of the components in the water budget for each basin is presented in Tables 1 and 2 for Little River basin, and the Canadian River basins, respectively. The overall budget for the area is depicted in Figure 3, where the mean annual rainfall is 34 inches, and actual evapotranspiration is the main output of the system and accounts for 83% of the available water. About 90 percent of the streams in the area are ephemeral and carry water during wet periods of the year when runoff is abundant and water table rises above the base of the stream channels.

TABLE 1 SEASONAL WATER BALANCE FOR THE LITTLE RIVER BASIN (2003-2010), IN ACRE-FEET (AF)

Little River Basin, OK (2003-2010)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	56,211	82,499	119,376	140,870	189,706	239,769	167,274	201,033	147,740	161,585	54,810	67,090	**1,627,923**
R	6,045	6,1464	13,335	14,817	30,167	42,909	18,017	9,779	3,675	10,490	7,705	4,919	**237,322**
BF	4,682	5,986	7,586	8,120	13,276	9,660	14,224	6,875	5,038	2,134	3,200	4,089	**84,870**
aET	45,484	70,350	98,455	117,934	146,264	187,200	135,033	184,379	139,028	148,961	43,905	58,081	**1,375,074**

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

TABLE 2 SEASONAL WATER BALANCE FOR THE MIDDLE AND LOWER CANADIAN RIVER BASINS (2003-2010), IN ACRE-FEET (AF)

Middle Canadian and Lower Canadian River Basins, OK (2003-2010)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	117,550	172,524	249,643	294,592	396,718	501,412	349,808	42,404	308,958	337,910	114,620	140,300	**3,404,439**
R	18,782	12,443	30,979	41,405	42,068	63,763	40,741	19,208	12,214	19,431	16,848	9,990	**327,872**
BF	21,871	21,458	27,501	31,167	22,247	22,149	15,944	4,511	9,392	8,092	13,071	14,667	**212,070**
aET	76,898	138,623	191,162	222,019	332,404	415,500	293,123	396,686	287,351	310,387	84,701	115,643	**2,864,497**

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

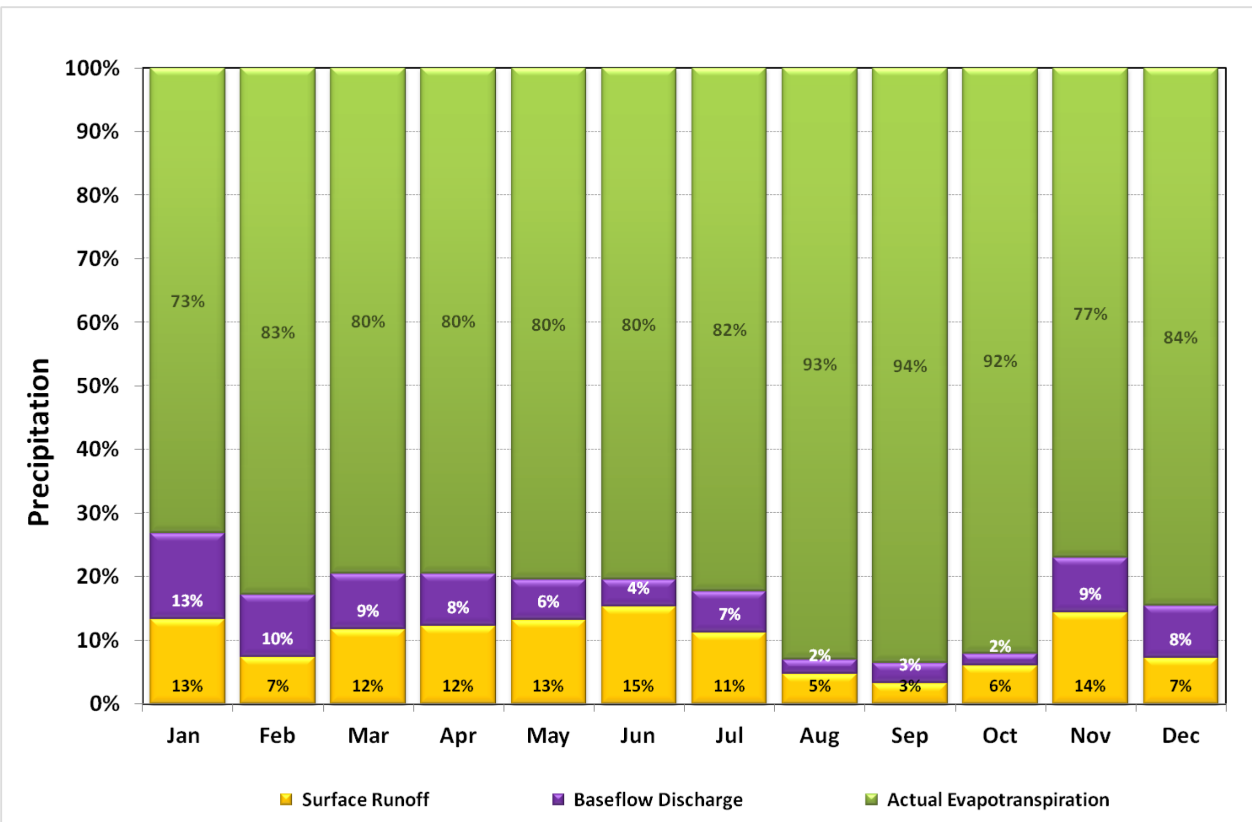


FIGURE 3 OVERALL WATER BUDGET FOR THE STUDY AREA, EXPRESSED AS A PERCENTAGE OF PRECIPITATION (2003-2010) MIDDLE CANADIAN, LOWER CANADIAN, AND LITTLE RIVER BASINS

GROUNDWATER

The surface geology of the Middle Canadian and Lower Canadian basins includes the Rush Springs, Duncan, and Dog Creek Shale Formations, which are part of the El Reno group (Figure 4). The Little River runs through the Garber Sandstone, Wellington and Vanoss Formation. The lower part of the area where the Little River joins the Canadian River is part of the Wewoka formation. Perennial streams are related geologic formations that continuously provide baseflow discharge to streams throughout the year. The permanent flows are supported by the Rush Springs and Marlow Formations in the Middle Canadian and by the Garber Sandstone and alluvium deposits in the Lower Canadian and Little River basins.

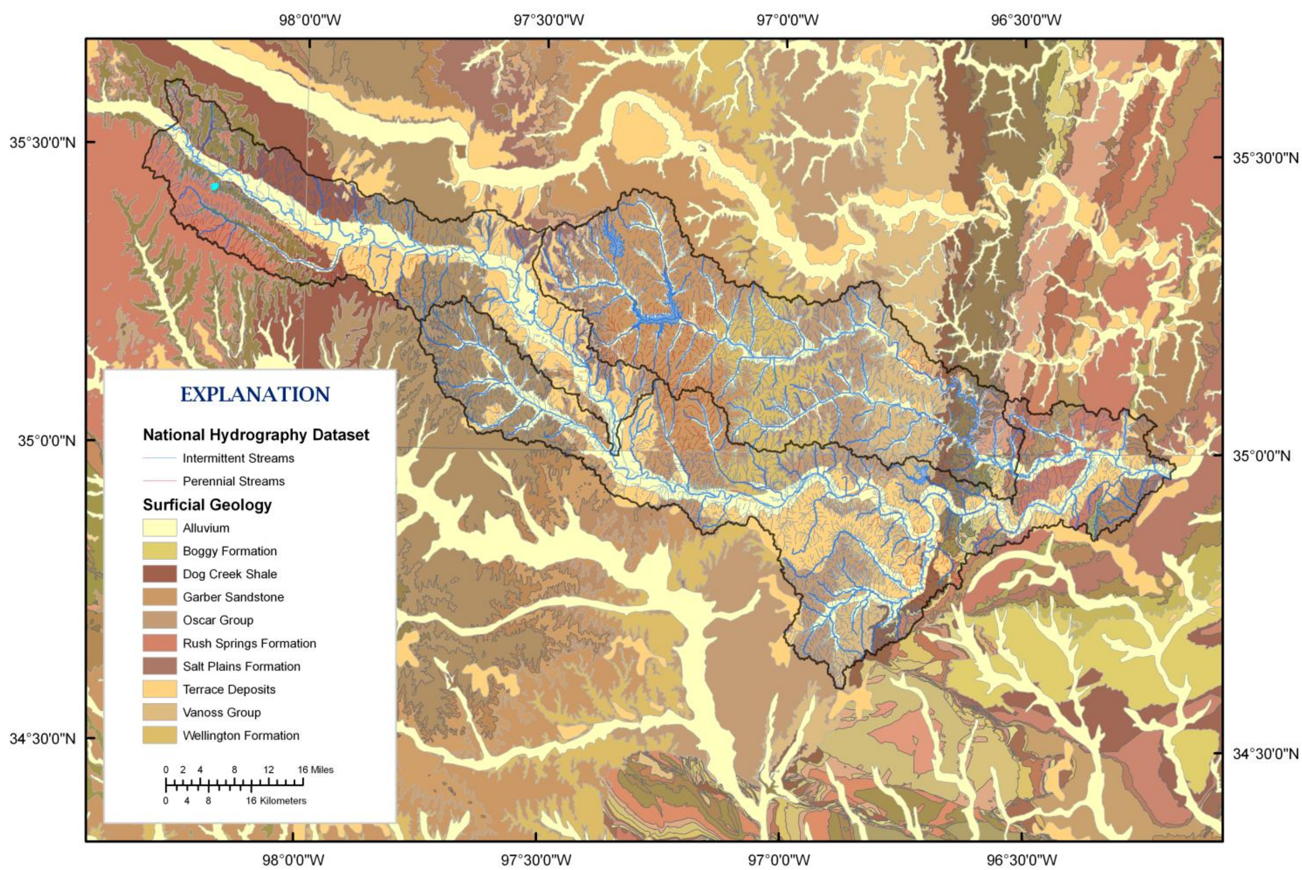


FIGURE 4 GEOLOGIC FORMATIONS IN THE MIDDLE CANADIAN, LOWER CANADIAN, AND LITTLE RIVER BASINS

RESERVOIRS IN THE BASIN

The largest reservoirs in the Little River basin are Lake Thunderbird and Stanley Draper in the Little River basin. Table 4 shows a summary of the largest reservoirs in the Middle Canadian, Lower Canadian, and Little River basins registered in the OWRB Dam Safety database, as of 2011.

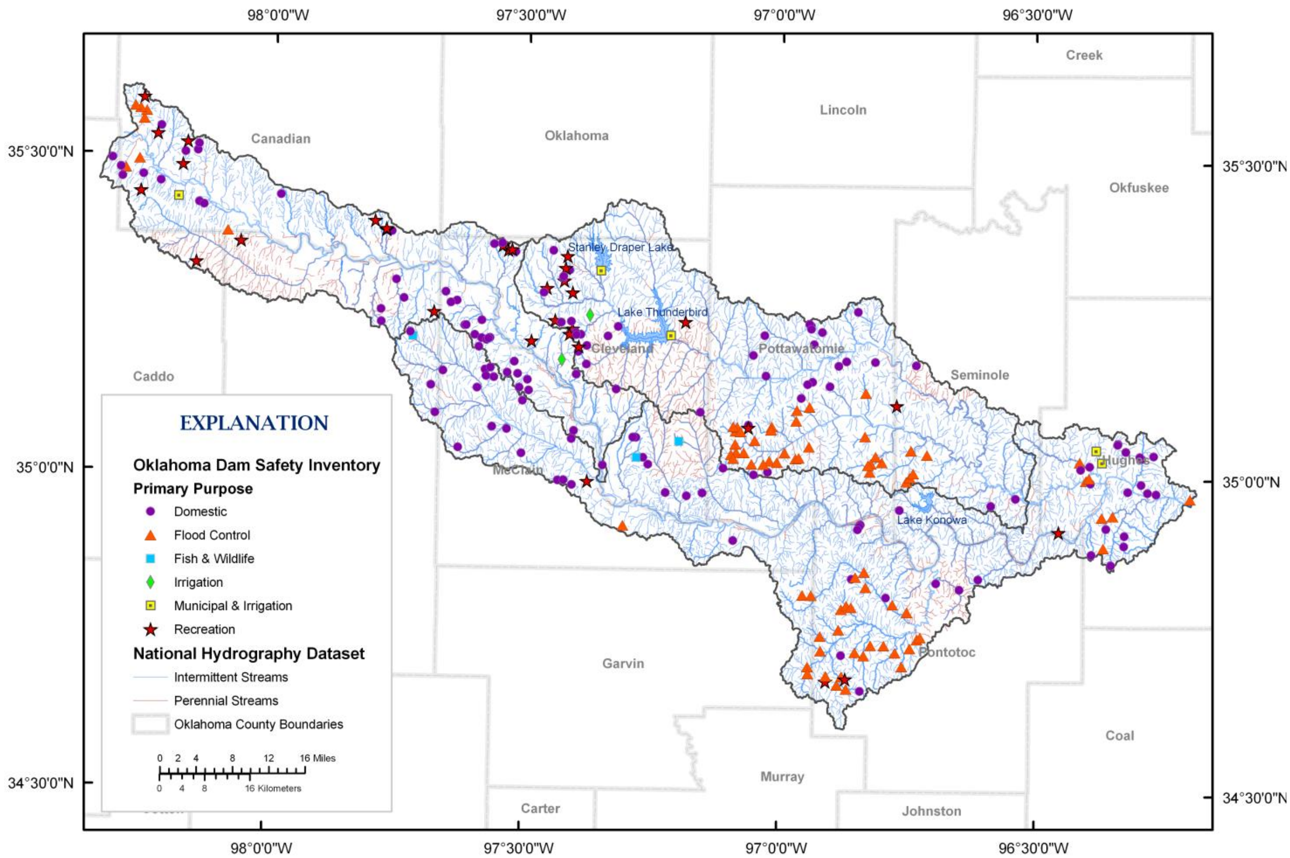


FIGURE 5 RESERVOIRS IN THE MIDDLE CANADIAN, LOWER CANADIAN, AND LITTLE RIVER BASINS, ACTIVE ON THE DAM SAFETY INVENTORY

TABLE 4 RESERVOIR STORAGE IN THE MIDDLE CANADIAN, LOWER CANADIAN, AND LITTLE RIVER BASINS

Reservoir Storage in Acre Feet (AF)					
Criteria	**Number of Structures**	**Name**	**Construction Date**	**Basin**	**Normal Storage (AF)**
> 1,000 AF	6	Lake Thunderbird	1965	Little River	119,600
		Stanley Draper Lake	1962	Little River	100,000
		Konawa Lake	1964	Lower Canadian	23,000
		Holdenville City Lake	1931	Lower Canadian	11,000
		Purcell City Lake	1930	Lower Canadian	2,600
		Cedar Lake Dam	1937	Middle Canadian	1,125
100 – 1,000 AF	+ 46	-	-	-	7,680

ANNUAL FLOWS, PEAKS, AND FLOW DURATION

Streamflow data is available for the USGS gages at Calvin and near Sasawka for the period 1950 to 2010. The annual flows at USGS gages are presented in Figure 6. The gage at Sasawka shows a slight streamflow trend upwards and a mean annual discharge of 21,051 acre-feet. The downstream gauge at Calvin, which collects the waters flowing from the Canadian River and the Little River, shows a higher mean annual discharge of 57,494 acre-feet and a stronger upper trend. The growing streamflow upper trends might reflect an increase in return flows from irrigation practices and other uses in the area.

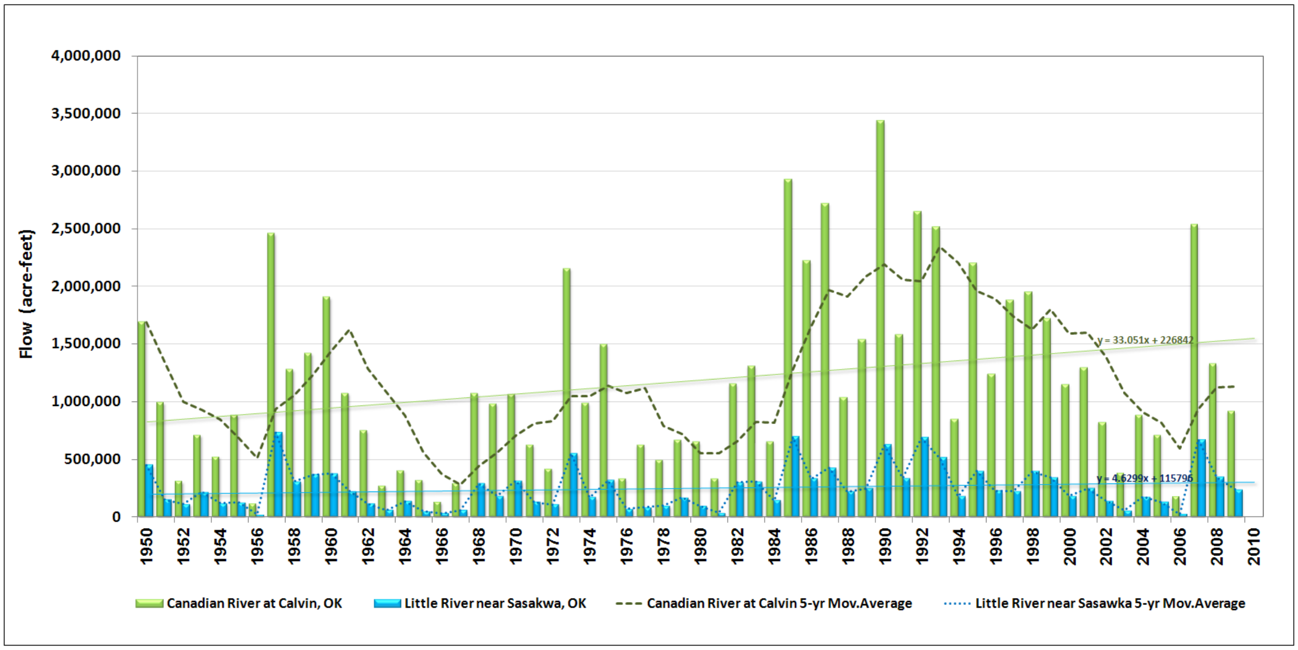


FIGURE 6 ANNUAL STREAMFLOW AT USGS GAGES IN THE MIDDLE CANADIAN, LOWER CANADIAN, AND LITTLE RIVER BASINS (1950-2010)

Analysis of the streamflow records from 1950 to 2010 shows that the largest discharge measured at the gage near Sasawka was 31,600 cfs in January 1950, while the maximum flow at the gage near Calvin was 140,000 cfs in January 1987 (Figure 7). Peak flows at the gages show a slight trend downwards that reflects the attenuating effect of the flood control structures in the streams.

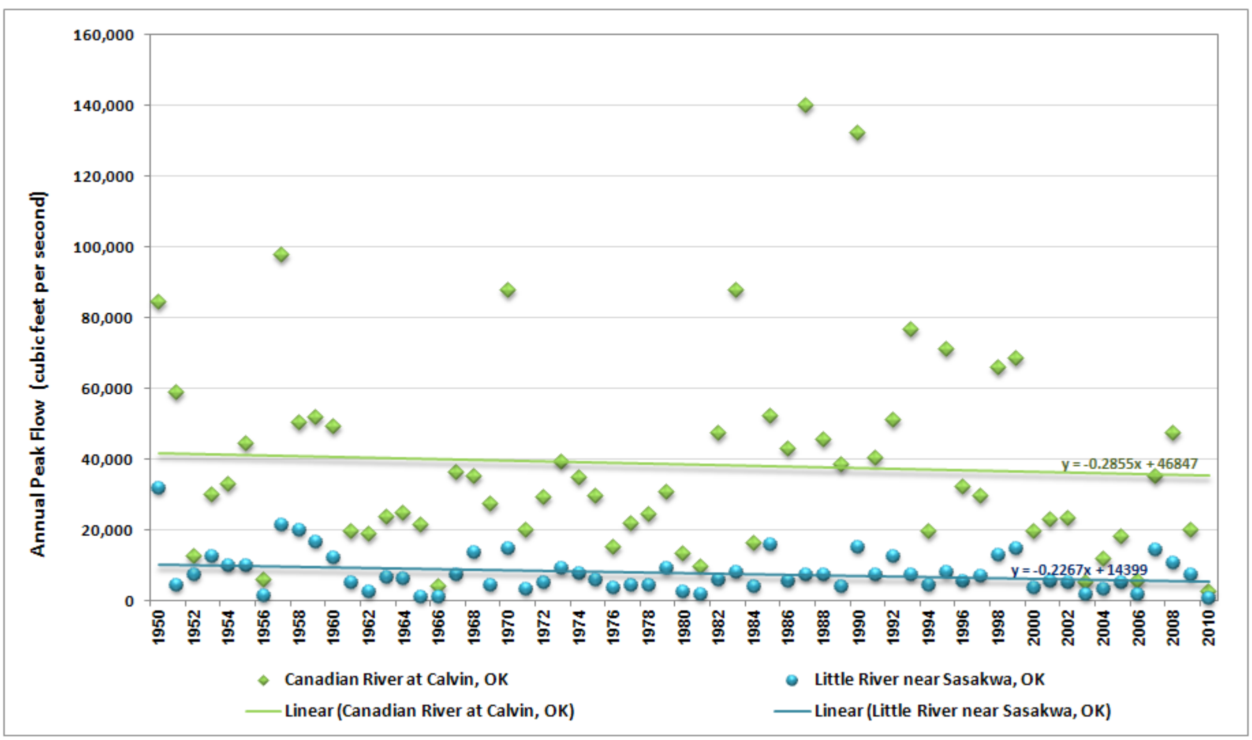


FIGURE 7 PEAK FLOWS MEASURED A THE USGS GAGES CANADIAN RIVER AT CALVIN, AND CANADIAN RIVER NEAR SASAKWA, OK

From the continuous daily streamflow data recorded at the gage from January 1st, 1950 to December 31st, 2010, there are 240 days of zero flow near Calvin, which corresponds to 1% of the records, and 678 days of zero flow near Sasakwa, which represents 3% of the records. The Canadian and Little River are considered perennial streams because flows at the gages are above zero flow more than 90 percent of the time. Streams with zero flows more than 10% of the time are intermittent (U.S. Forest Service, 2005).

TABLE 3 MONTHLY PERCENT EXCEEDANCE AT THE USGS GAUGES CANADIAN RIVER AT CALVIN AND LITTLE RIVER NEAR SASAKWA, IN ACRE-FEET (AF)

Percent Exceedance in Acre-Feet (AF)						
Flow		**Mean**	**Exceedance**			
			90%	**80%**	**50%**	**20%**
January	Sasakwa	5,884	474	948	3,319	24,181
	Calvin	36,572	163	1,374	4,730	18,885
February	Sasakwa	16,867	948	948	4,741	23,233
	Calvin	49,695	10,442	16,065	42,834	150,238
March	Sasakwa	21,712	948	2,371	8,534	23,233
	Calvin	71,070	13,132	21,319	84,907	178,976
April	Sasakwa	17,261	2,371	4,267	13,276	37,457
	Calvin	91,740	22,473	30,750	103,292	234,668
May	Sasakwa	37,806	3,793	7,112	26,077	60,215
	Calvin	137,051	31,648	45,851	36,206	409,836
June	Sasakwa	23,676	948	1,897	10,905	46,465
	Calvin	93,918	29,143	43,512	36,206	409,836
July	Sasakwa	10,602	497	948	6,638	25,603
	Calvin	33,977	3,332	7,670	27,453	135,958
August	Sasakwa	5,643	474	474	2,371	21,810
	Calvin	16,902	1,035	3,392	14,209	76,993
September	Sasakwa	7,415	474	948	4,741	23,233
	Calvin	31,231	1,482	5,742	32,023	113,943
October	Sasakwa	12,055	948	1,422	8,534	28,448
	Calvin	46,627	1,136	46,166	46,166	120,369
November	Sasakwa	10,446	474	948	8,534	28,448
	Calvin	42,667	2,779	4,962	34,010	130,424
December	Sasakwa	7,578	474	474	5,690	18,017
	Calvin	38,471	2,779	4,990	34,010	130,424
MEAN ANNUAL	Sasakwa	**14,746**	**12,823**	**22,757**	**100,990**	**360,343**
	Calvin	**57,494**	**9,962**	**231,765**	**583,065**	**1,970,606**

WATER RIGHTS AND WATER USE

As of 2010, there are 11 surface water rights (permits) in the Little River basin that total 24,466 ac-ft appropriated, 20 permits in the Middle Canadian River basin that add up to 29,262 ac-ft appropriated, and 37 permits in the Lower Canadian River basin that equal 14,103 ac-ft. A list of active water rights for each basin is presented in Table 4, and a map showing all active water rights is presented in Figure 8.

TABLE 4 APPROPRIATED WATER IN THE MIDDLE CANADIAN, LOWER CANADIAN AND LITTLE RIVER BASINS IN ACRE-FEET (AF)

Appropriated Water in Acre-feet (AF)				
	Primary Purpose			
	Irrigation	Rec Fish & Wildlife	Municipal & Industrial	Total
Middle Canadian River (2-6-2)	27,891	203	584	28,678
Lower Canadian River (2-6-1)	9,323	127	39,665	49,107
Little River (2-8)	326	180	23,960	24,466

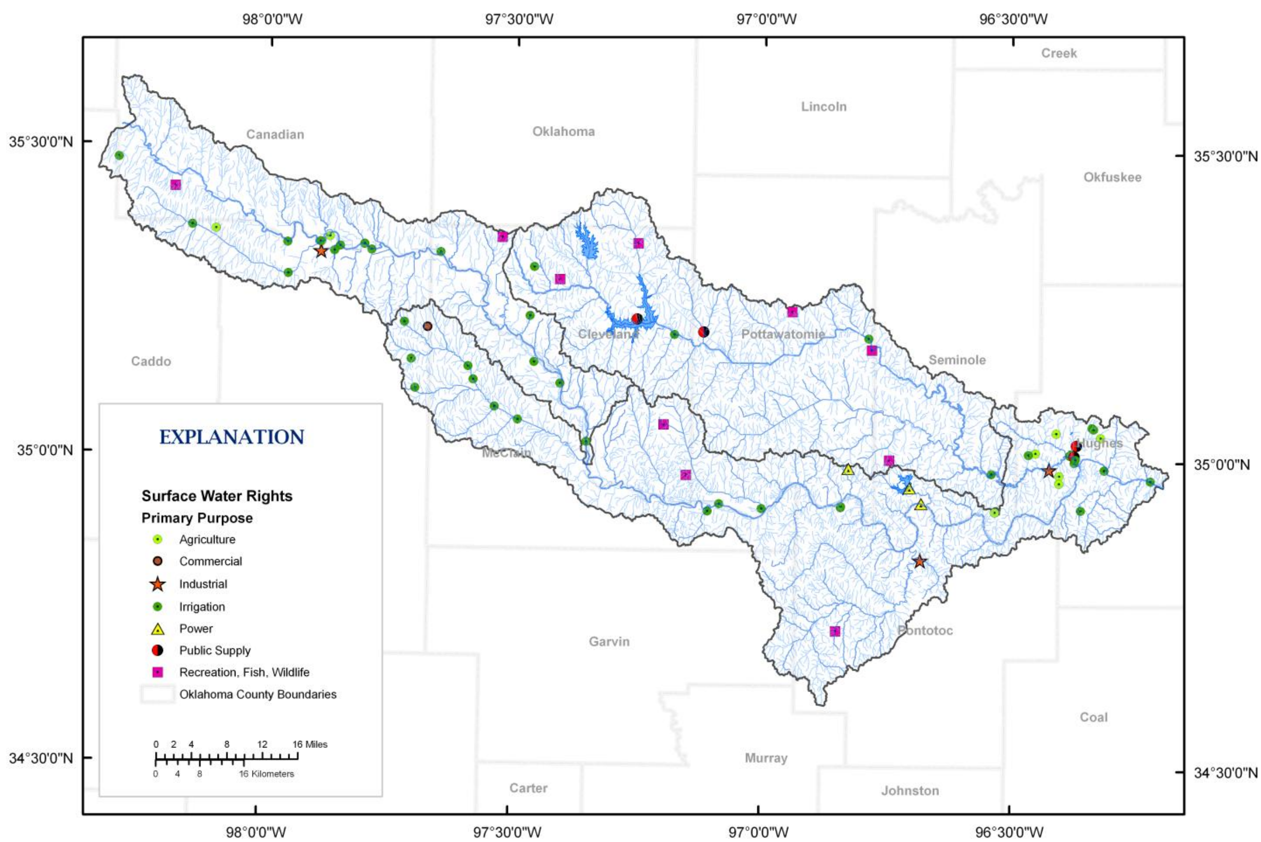


FIGURE 8 ACTIVE WATER RIGHTS IN THE MIDDLE CANADIAN, LOWER CANADIAN AND LITTLE RIVER BASINS

The OWRB maintains a database of water use that is updated every year from use reports submitted by water-right holders to the OWRB. The reported values are important for the agency to manage individual water rights and also to estimate water available in the basin after appropriation. Figure 8 shows the reported use (bars) and the permitted amounts (line) in the stream systems, as available on the OWRB Water Rights Database.

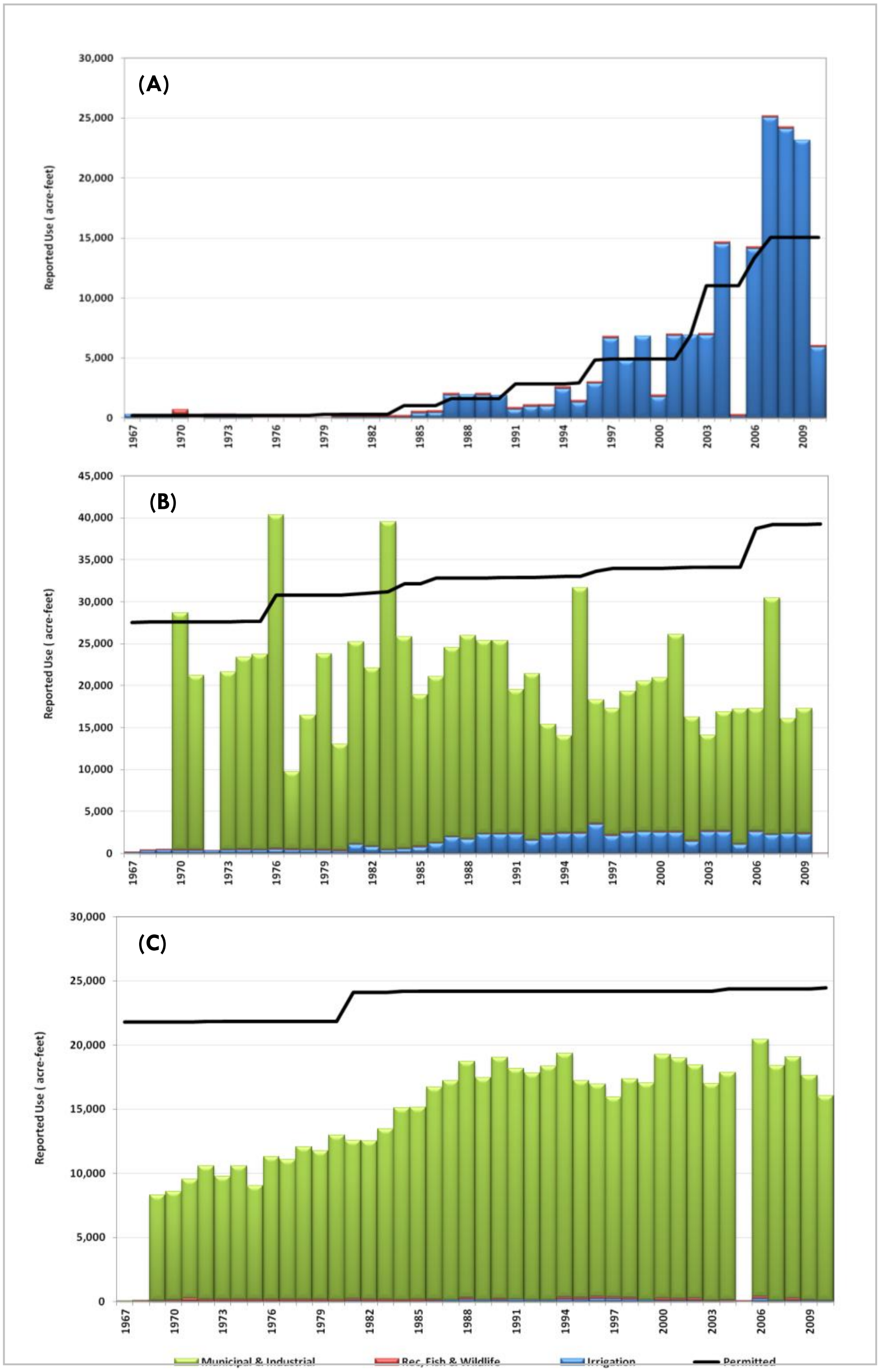


FIGURE 9 REPORTED WATER USE AND APPROPRIATED AMOUNTS: (A) MIDDLE CANADIAN RIVER BASIN; (B) LOWER CANADIAN RIVER BASIN; AND (C) LITTLE RIVER BASIN

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 (OWRB, 2009).

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 a numeric algorithm 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 or ephemeral are assigned direct runoff only. This stream classification is taken into consideration during the flow naturalization process, where perennial sub-basins are assigned with a mixture of runoff and baseflow discharge, while intermittent streams are assigned 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 gages Canadian River at Calvin and Little River near Sasakwa.

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 10 shows the network schematic built within ExcelCRAM for the Middle Canadian River, Lower Canadian River and Little River basins. The model includes 74 inflows which represent the water entering the sub-basins, 69 demands that represent the existing diversion points/water rights, and 12 reservoirs or lakes. 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.

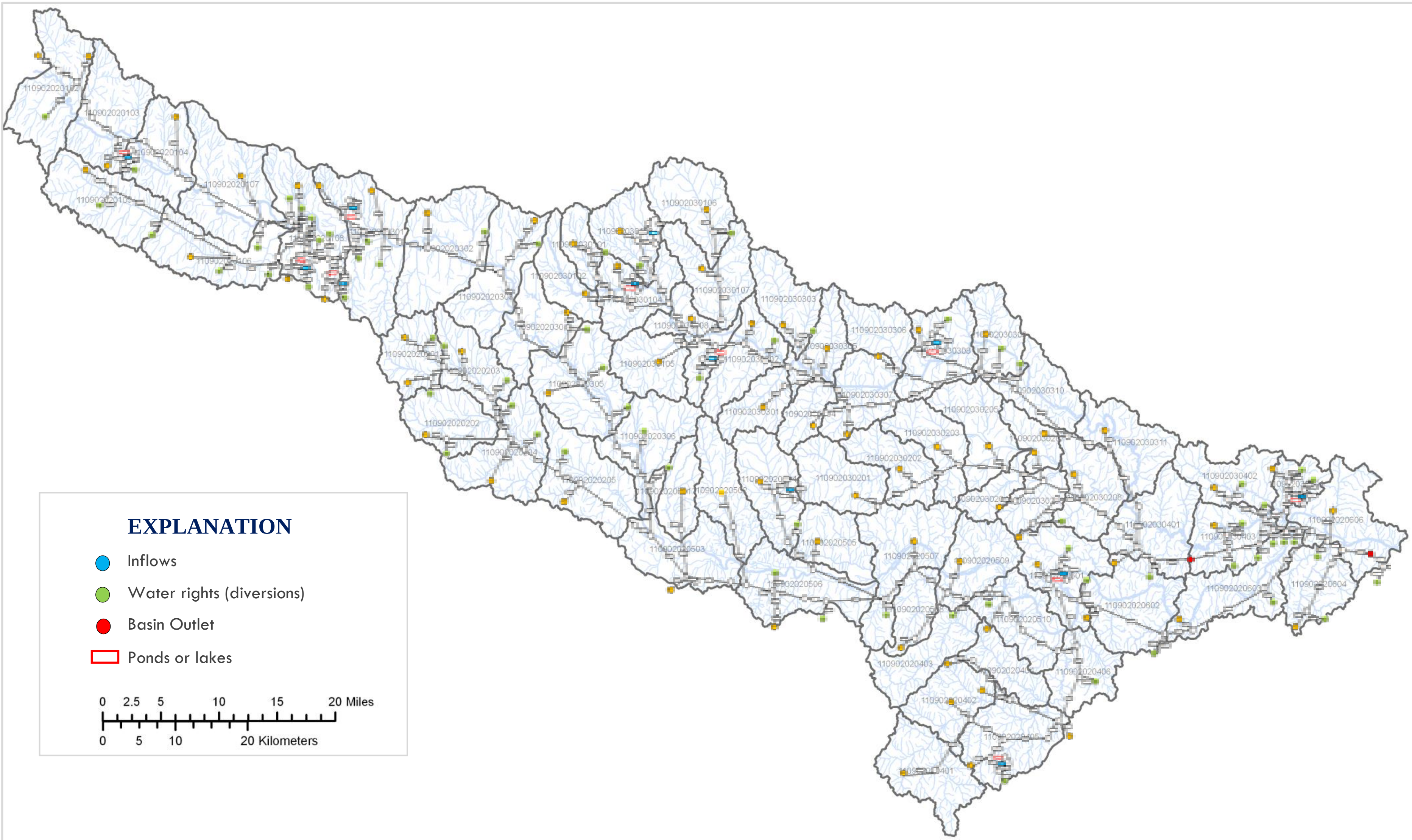


FIGURE 10 SCREENSHOT OF THE NETWORK SCHEMATIC FROM THE ALLOCATION MODEL FOR THE MIDDLE CANADIAN RIVER, LOWER CANADIAN RIVER, AND LITTLE RIVER BASINS

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 5 presents the mean annual unappropriated water as of 2009 at each sub-basin computed by the model. The spatial distribution of potential water shortages for scenario 4 (i.e. anticipated shortages based on the hydrologic conditions of the simulation) is depicted Figure 11.

TABLE 5 ESTIMATED MEAN MONTHLY WATER AVAILABILITY AT EACH SUB-BASIN IN THE AREA IN ACRE-FEET (AC-FT)

Mean monthly Unappropriated Water in systems 2-6-1, 2-6-2, and 2-8													
HUC-12*	Area (Ac)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
110309020102	55	13,353	16,130	24,010	21,900	50,303	38,769	1,495	17,962	14,661	16,927	12,261	12,259
110902020103	49	14,350	17,337	25,976	24,328	54,123	41,263	22,438	18,465	5,494	18,237	13,397	13,326
110902020104	40	15,184	18,335	27,601	26,335	57,272	43,361	23,278	18,933	16,207	19,324	14,338	14,208
110902020105	49	1,024	1,226	1,994	2,465	3,866	2,537	954	504	835	1,336	1,156	1,083
110902020106	49	2,050	2,453	3,990	4,926	7,736	4,812	1,540	705	1,449	2,673	2,312	2,168
110902020107	64	6,514	19,926	30,191	29,534	62,293	46,541	24,300	19,364	17,164	21,059	15,838	15,615
110902020108	57	19,684	23,736	36,389	37,166	74,361	52,968	24,847	18,757	18,286	25,130	19,417	18,981
110902020201	30	629	753	1,223	1,512	2,373	1,567	603	325	521	821	710	665
110902020202	35	726	869	1,414	1,747	2,741	1,822	722	398	616	947	819	768
110902020203	34	1,326	1,587	2,579	3,188	5,004	3,247	1,174	600	1,046	1,730	1,496	1,403
110902020204	51	3,102	3,712	6,038	7,463	11,709	7,690	2,912	1,547	2,537	4,046	3,500	3,281
110902020205	53	4,204	5,030	8,184	10,115	15,868	10,455	4,007	2,152	3,471	5,483	4,743	4,446
110902020301	93	21,601	26,038	40,134	41,789	81,626	57,468	6,216	19,335	19,599	27,635	21,586	21,015
110902020302	66	22,975	27,682	42,810	45,095	86,812	60,914	27,579	20,085	20,761	29,426	23,135	22,467
110902020303	50	24,004	28,912	44,814	47,572	90,698	63,493	28,601	20,650	21,636	30,768	24,296	23,556
110902020304	38	24,792	29,855	46,349	49,469	93,674	65,458	29,357	21,057	22,290	31,796	25,186	24,389
110902020401	47	972	1,163	1,894	2,341	3,670	2,446	978	545	831	1,268	1,097	1,028
110902020402	36	1,719	2,057	3,350	4,140	6,493	4,327	1,731	965	1,470	2,242	1,940	1,818
110902020403	37	764	914	1,489	1,840	2,886	1,923	769	429	653	997	862	808
110902020404	25	1,292	1,546	2,518	3,111	4,879	3,252	1,301	725	1,105	1,685	1,458	1,366
110902020405	50	2,743	3,282	5,346	6,606	10,364	6,899	2,752	1,530	2,342	3,578	3,096	2,902
110902020501	24	489	585	952	1,177	1,846	1,230	492	274	418	638	551	517
110902020502	38	793	949	1,546	1,910	2,996	1,997	799	445	678	1,035	895	839
110902020503	50	32,590	39,185	61,532	68,234	123,111	84,912	36,906	25,153	28,796	41,967	33,983	32,636
110902020504	41	847	1,018	1,655	2,046	3,215	2,128	834	455	717	1,108	959	900
110902020505	32	1,508	1,809	2,943	3,637	5,711	3,791	1,500	826	1,282	1,970	1,704	1,599
110902020506	51	34,446	41,405	65,146	72,688	130,114	88,938	37,626	25,170	29,741	44,388	36,076	34,599
110902020507	57	37,137	44,628	70,392	79,171	40,289	95,630	40,182	26,540	31,961	47,900	39,114	37,448
110902020508	23	473	566	921	1,139	1,786	1,190	476	265	404	617	533	500
110902020510	40	39,219	47,119	74,447	84,181	148,148	00,831	42,205	27,637	33,700	50,615	41,463	39,650
110902020601	44	42,590	51,513	82,875	95,037	65,934	112,251	5,661	29,028	36,413	55,482	45,453	43,199
110902020602	53	43,686	52,825	85,009	97,675	170,073	115,008	46,759	29,637	37,348	56,912	46,690	44,359
110902020603	51	44,733	54,077	87,048	00,194	174,024	117,640	47,808	30,220	38,241	58,277	47,871	45,466
110902020604	35	724	866	1,409	1,742	2,732	1,804	695	374	600	944	816	765
110902020606	51	58,840	2,286	116,197	136,657	232,521	157,817	64,168	39,652	48,349	75,108	64,772	60,897
110902030101	17	243	315	489	631	1,030	697	316	184	195	301	304	271
110902030102	25	361	468	729	939	1,532	1,041	478	282	295	448	451	402
110902030103	33	114	229	327	383	409	224	103	42	15	-	80	166
110902030104	36	1,240	1,688	2,604	3,318	5,209	3,444	1,548	871	911	1,400	1,491	1,424
110902030105	32	471	610	950	1,225	1,998	1,358	623	367	385	584	588	524
110902030106	42	617	800	1,246	1,605	2,619	1,780	817	481	504	765	771	687

Mean monthly Unappropriated Water in systems 2-6-1, 2-6-2, and 2-8													
HUC-12*	**Area (Ac)**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
110902030107	41	1,212	1,571	2,447	3,153	5,145	3,497	1,606	946	991	1,504	1,515	1,351
110902030108	31	2,062	2,702	4,780	5,280	7,916	6,357	1,628	1,022	636	1,824	2,051	2,076
110902030201	38	555	719	1,120	1,444	2,355	1,601	735	433	454	688	694	618
110902030202	33	1,039	1,347	2,098	2,703	4,410	2,997	1,376	811	849	1,289	1,299	1,158
110902030203	33	1,527	1,980	3,083	3,973	6,482	4,405	2,023	1,192	1,249	1,894	1,909	1,702
110902030204	16	237	307	479	617	1,007	684	314	185	194	294	296	264
110902030205	40	2,105	2,729	4,250	5,476	8,935	6,072	2,788	1,643	1,721	2,611	2,631	2,345
110902030206	22	321	415	647	834	1,362	921	420	246	260	398	401	357
110902030207	17	2,596	3,366	5,242	6,755	11,021	7,490	3,439	2,026	2,123	3,221	3,245	2,893
110902030208	39	3,482	4,514	7,031	9,060	14,784	10,043	4,609	2,713	2,846	4,320	4,353	3,881
110902030301	24	354	459	715	921	1,504	1,022	469	276	290	439	443	395
110902030302	36	2,594	3,391	5,852	6,663	10,173	7,871	2,298	1,401	1,051	2,483	2,716	2,669
110902030304	18	273	347	543	688	1,138	781	337	205	218	338	336	299
110902030305	26	3,805	4,961	8,297	9,808	15,313	11,138	3,634	2,155	1,870	3,986	4,230	4,018
110902030306	26	372	483	752	969	1,581	1,074	493	291	305	462	466	415
110902030307	35	4,595	5,979	9,884	11,842	18,646	13,410	4,656	2,763	2,511	4,966	5,212	4,894
110902030308	41	5,570	7,244	11,855	14,382	22,794	16,227	5,947	3,522	3,308	6,178	6,433	5,983
110902030310	33	6,487	8,433	13,705	16,766	26,684	18,856	7,133	4,209	4,041	7,315	7,580	7,005
110902030311	41	7,078	9,200	14,899	18,305	29,195	20,562	7,917	4,671	4,525	8,049	8,319	7,664
110902030402	35	11,812	15,337	24,456	30,622	49,298	34,194	14,135	8,311	8,365	13,922	14,238	12,939
110902030403	37	506	656	1,020	1,315	2,146	1,458	668	393	413	627	632	563
110902030404	19	12,322	16,073	25,674	32,167	51,760	35,746	14,677	8,545	8,645	14,502	14,888	13,544
Monthly Average		**9.445**	**10,598**	**18,501**	**19,513**	**33,932**	**24,524**	**9,823**	**7,475**	**8,108**	**12,401**	**10,176**	**9,705**

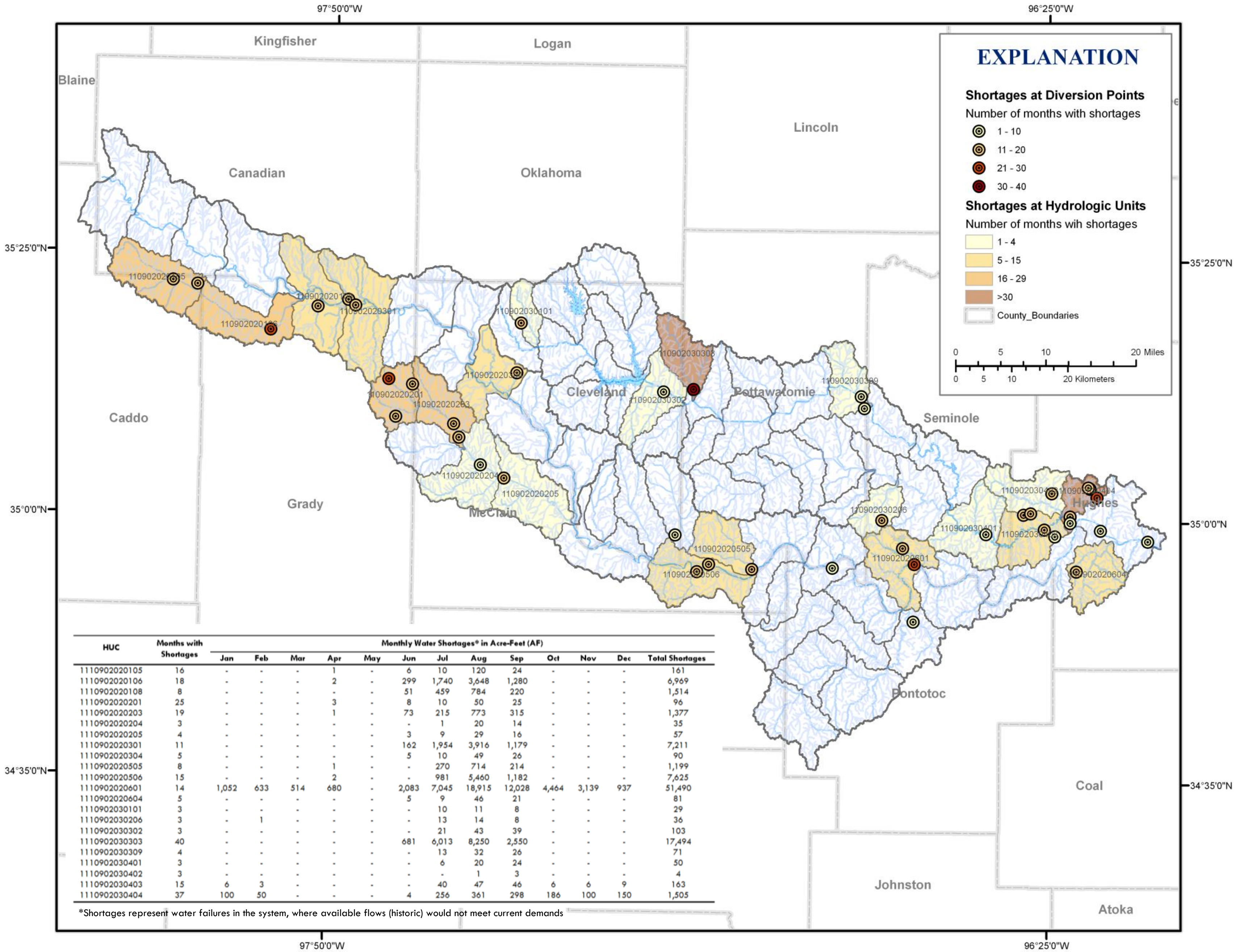
**HUC-12 refers to the 12-unit hydrologic unit codes of the National Hydrography Dataset*

Explanation of Figure 1s

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 Calvin and on the Little River near Sasakwa (± 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 5), 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
1110902020105	16	-	-	-	1	-	6	10	120	24	-	-	-	161
1110902020106	18	-	-	-	2	-	299	1,740	3,648	1,280	-	-	-	6,969
1110902020108	8	-	-	-	-	-	51	459	784	220	-	-	-	1,514
1110902020201	25	-	-	-	3	-	8	10	50	25	-	-	-	96
1110902020203	19	-	-	-	1	-	73	215	773	315	-	-	-	1,377
1110902020204	3	-	-	-	-	-	-	1	20	14	-	-	-	35
1110902020205	4	-	-	-	-	-	3	9	29	16	-	-	-	57
1110902020301	11	-	-	-	-	-	162	1,954	3,916	1,179	-	-	-	7,211
1110902020304	5	-	-	-	-	-	5	10	49	26	-	-	-	90
1110902020505	8	-	-	-	1	-	-	270	714	214	-	-	-	1,199
1110902020506	15	-	-	-	2	-	-	981	5,460	1,182	-	-	-	7,625
1110902020601	14	1,052	633	514	680	-	2,083	7,045	18,915	12,028	4,464	3,139	937	51,490
1110902020604	5	-	-	-	-	-	5	9	46	21	-	-	-	81
1110902030101	3	-	-	-	-	-	-	10	11	8	-	-	-	29
1110902030206	3	-	1	-	-	-	-	13	14	8	-	-	-	36
1110902030302	3	-	-	-	-	-	-	21	43	39	-	-	-	103
1110902030303	40	-	-	-	-	-	681	6,013	8,250	2,550	-	-	-	17,494
1110902030309	4	-	-	-	-	-	-	13	32	26	-	-	-	71
1110902030401	3	-	-	-	-	-	-	6	20	24	-	-	-	50
1110902030402	3	-	-	-	-	-	-	-	1	3	-	-	-	4
1110902030403	15	6	3	-	-	-	-	40	47	46	6	6	9	163
1110902030404	37	100	50	-	-	-	4	256	361	298	186	100	150	1,505

*Shortages represent water failures in the system, where available flows (historic) would not meet current demands

FIGURE 11 WATER SHORTAGES ESTIMATED BY THE ALLOCATION MODEL BASED ON HISTORIC FLOWS (1950 – 2008) AND CONDITIONS OF SCENARIO 4

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