

**Summary of 5.8 magnitude earthquake near Pawnee, Oklahoma
on September 3, 2016,
DamWatch Seismic Alerts, and impact on Watershed dams**

Larry Caldwell P.E.
Watershed Specialist
Oklahoma Conservation Commission

This is a brief summary of the Oklahoma 5.8 earthquake and aftershocks on September 3 and 4, how DamWatch reacted with revised USGS estimates of pga's* through the first day after the earthquake, and the impact on watershed dams near the epicenter.

The earthquake hit on a Saturday morning, September 3, 2016, at 7:02am CDT. The magnitude was 5.8; the largest ever recorded in Oklahoma and the largest recorded in the continental United States in the past two years (August 14, 2014). Oklahoma has recorded 2 of the 4 earthquakes greater than 5.0 in the US this year. The epicenter of the earthquake was approximately 8 miles NW of Pawnee, OK (about 20 miles NNE from Stillwater). The earthquake was quite shallow with a depth of about 4 miles. The earthquake was followed by 19 aftershocks registering between 2.7 and 3.6 magnitude within 36 hours following the earthquake. USGS anticipates that more aftershocks could occur for the next 2 to 3 week. For example, in February of this year when a 5.1 earthquake occurred near Fairview, Oklahoma, there was a 4.7 aftershock within the next couple of days.

USGS initially reported the magnitude of the earthquake as 5.6, but on September 7, after additional analysis of the seismic recordings, USGS upgraded the earthquake to a 5.8 magnitude. USGS reported that the 0.2 increase in the moment of magnitude resulted in a doubling of the estimated energy released during the earthquake.

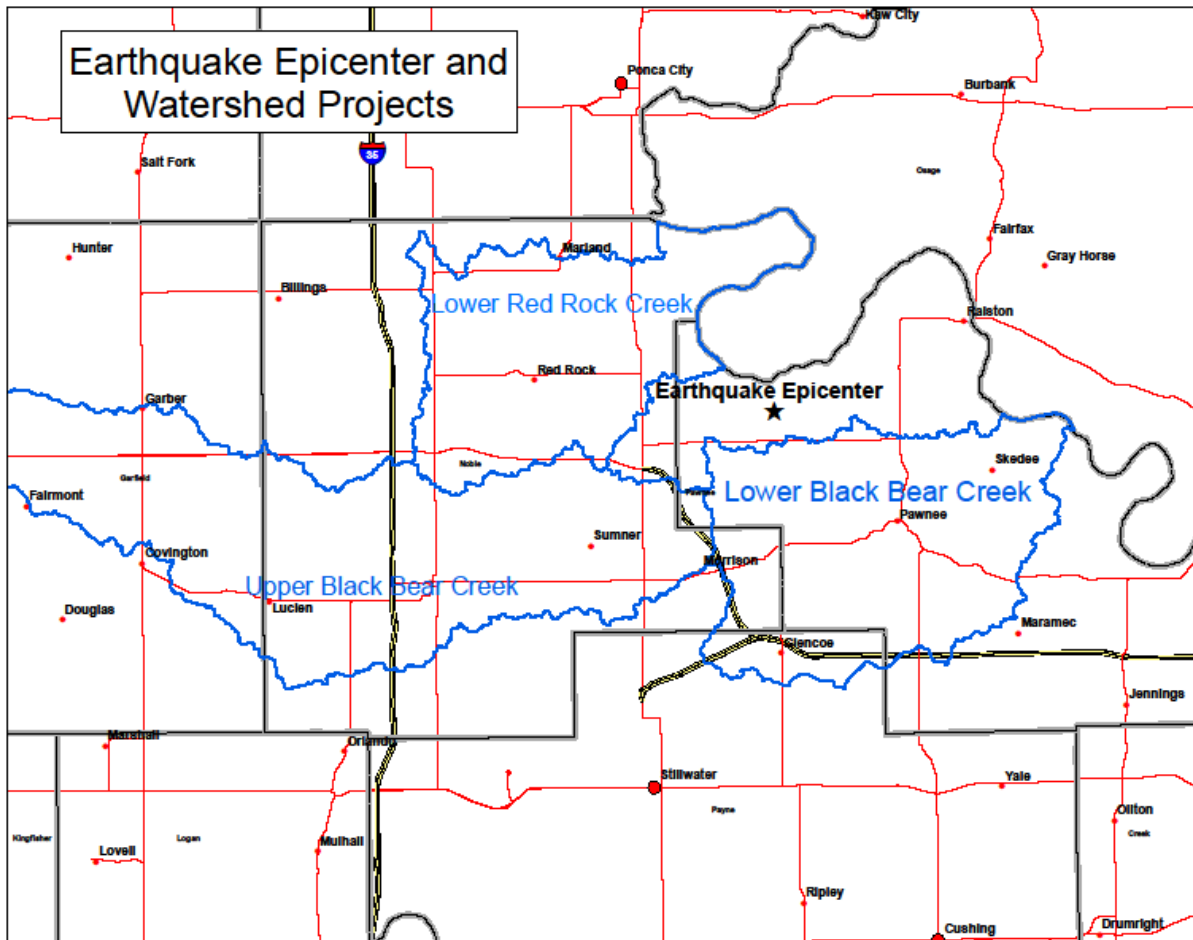
Extensive damage was reported to a few buildings in Pawnee and the surrounding area. Only one injury was reported. Damages were generally limited to rock facades falling off buildings, cracks in walls, items falling over shelves, etc., however there was at least one fire due to electrical issues or gas line break. The Oklahoma Geological Survey said that the hard bedrock beneath the surface in north-central Oklahoma is likely the reason for less damage than what would have occurred in other areas of the state with softer subsurface conditions.

Although there was not a Watershed project directly above the epicenter, there are many watershed dams near the epicenter. The epicenter was between the boundaries of Lower Red Rock, Lower Black Bear, and Upper Black Bear Watershed projects. See map below.

Jim Henley prepared a listing of the dams near the epicenter. The closest watershed dam was within 4 miles from the epicenter. There were 105 watershed dams in 3 counties including 18 high hazard dams within 25 from the epicenter (271 dams in 8 counties including 27 high

hazard dams within a 50 mile radius). The following is a summary of Jim’s GIS analysis showing the number of watershed dams including significant and high hazard dams within various radius’s of the epicenter:

Radius from Epicenter	Total No. of W'shed dams	No. of Significant Hazard dams	No. of High Hazard dams	No. of Counties
5 miles	2 dams	0	0	1
10 miles	12 dams	2	3	2
15 miles	36 dams	5	5	2
20 miles	68 dams	9	9	3
25 miles	105 dams	14	18	3
30 miles	138 dams	19	22	4
40 miles	187 dams	25	22	7
50 miles	271 dams	27	27	8



USGS first reported the earthquake magnitude at about 7:30am. The Oklahoma DamWatch initially did not issue seismic alerts. USEngineering was contacted and they quickly diagnosed and corrected the problem and a little later, DamWatch issued 31 seismic alerts.

The Oklahoma pilot DamWatch seismic threshold is set at 0.25 pga. USGS initially had a pga of 0.42 on the dams closest to the epicenter, but then later that afternoon made two revisions. The first revision was at 12:26pm when they revised the pga's upward to as much as 0.52 on some dams. But then at 1:32pm, USGS lowered most of the pga's at specific dams to below the 0.25 threshold, except for Lower Black Bear Watershed dams no. 6 and 7 that were revised to 0.28 and 0.32 which were the largest pga's reported for any watershed dam in the area from this earthquake. The alerts for the dams that USGS lowered the pga's below the .25 threshold were automatically terminated by DamWatch. USGS reported the final pga at the epicenter as 0.40. The epicenter was a few miles north of the north boundary of Lower Black Bear Watershed that was the closet watershed project to the epicenter.

The following summaries are provided at the end of this report:

1. Table summarizing the times & magnitude of the initial earthquake and aftershocks
2. The initial and revised USGS pga's for the dams with DamWatch alerts
3. USGS shakecast maps from DamWatch
4. Photos of damages in Pawnee (taken from area newspaper websites)
5. A listing of the 271 dams within a 50 mile radius from the earthquake epicenter

The initial DamWatch alerts were for 31 dams in Lower Black Bear, Upper Black Bear, and a couple in Long Branch and Lower Red Rock Watersheds. All of the dams with DamWatch seismic alerts were located within 15 miles from the epicenter. Conservation district employees in Noble and Payne Counties inspected several dams in the field on Saturday immediately following the earthquake. They are going back and doing a more detailed review on some dams. Everything looked normal on the dams they have inspected so far. The heavy vegetation on the dams makes it difficult to notice any deformation of the crest or slopes of the embankments. Some of the dams will be mowed soon so they can take a closer look. The remote pipe camera will be used to video the principal spillways of some of the high hazard dams closet to the epicenter to see if there has ben any displacement of the conduit.

In an unprecedented action, the Oklahoma Corporation Commission is requiring 37 injection wells in a 514 square-mile area around the epicenter of the earthquake to shut down within seven to 10 days because of previous connections between the injection of wastewater and earthquakes. EPA has shutdown 17 injection wells in nearby Osage County.

* Peak ground acceleration (pga) is equal to the maximum ground acceleration that occurs during earthquake shaking at a location. Unlike the Richter scale, pga is not a measure of the total energy (magnitude, or size) of an earthquake, but rather an intensity measure of how hard the earth shakes at a given geographic point. In an earthquake, damage to buildings and infrastructure is related more closely to ground motion, of which pga is a measure, rather than the magnitude of the earthquake itself.

Summary of OK Earthquakes and
aftershocks following 5.6 mag earthquake
at 7:02 am
September 3, 2016

Mag	KM from	Direction from Pawnee	Time CDT	
5.6*	15	NW	7:02	am
3.4	9	NW	7:16	am
2.7	10	NW	7:32	am
2.9	12	NW	7:57	am
3.6	15	WNW	7:58	am
2.6	11	NW	9:05	am
3.2	11	NW	9:47	am
2.6	10	NW	9:56	am
3.1	11	NW	10:25	am
3.2	12	NW	10:31	am
2.7	11	NW	6:56	pm
3.1	13	NW	10:15	pm
3.5	15	WNW	11:20	pm

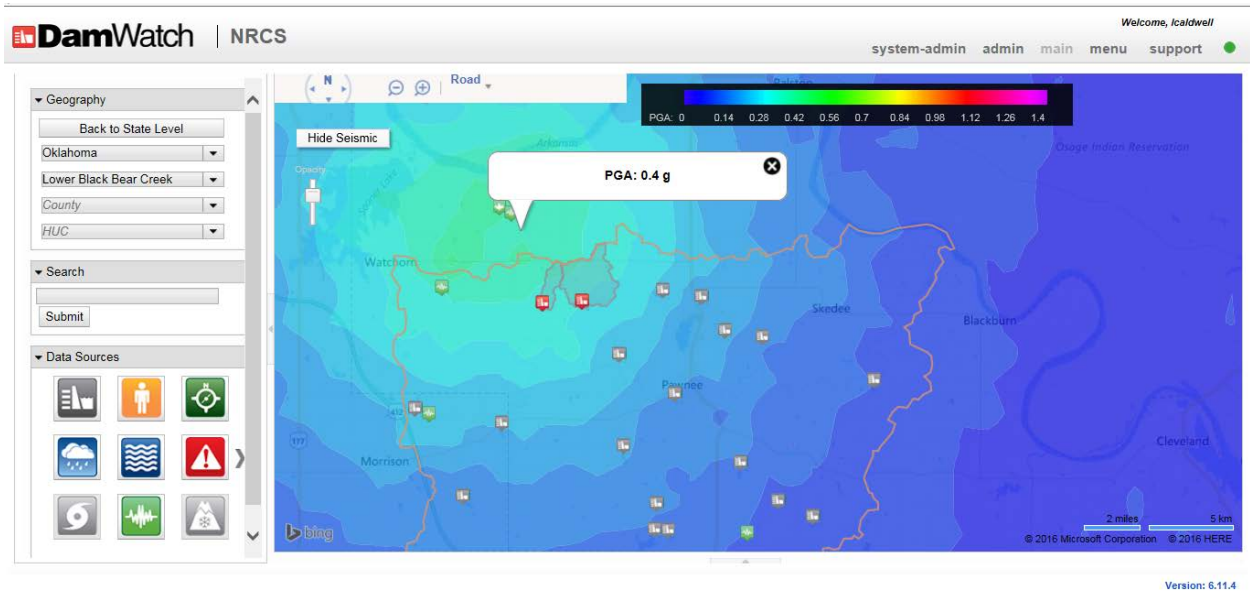
September 4, 2016

2.5	13	NW	7:16	am
2.7	12	NW	7:56	am
2.6	15	NW	9:29	am
2.8	12	NW	11:37	am
2.5	19	N Perry	1:08	pm
2.6	19	N Perry	1:28	pm
3.2	7	NW Cushing	3:03	pm

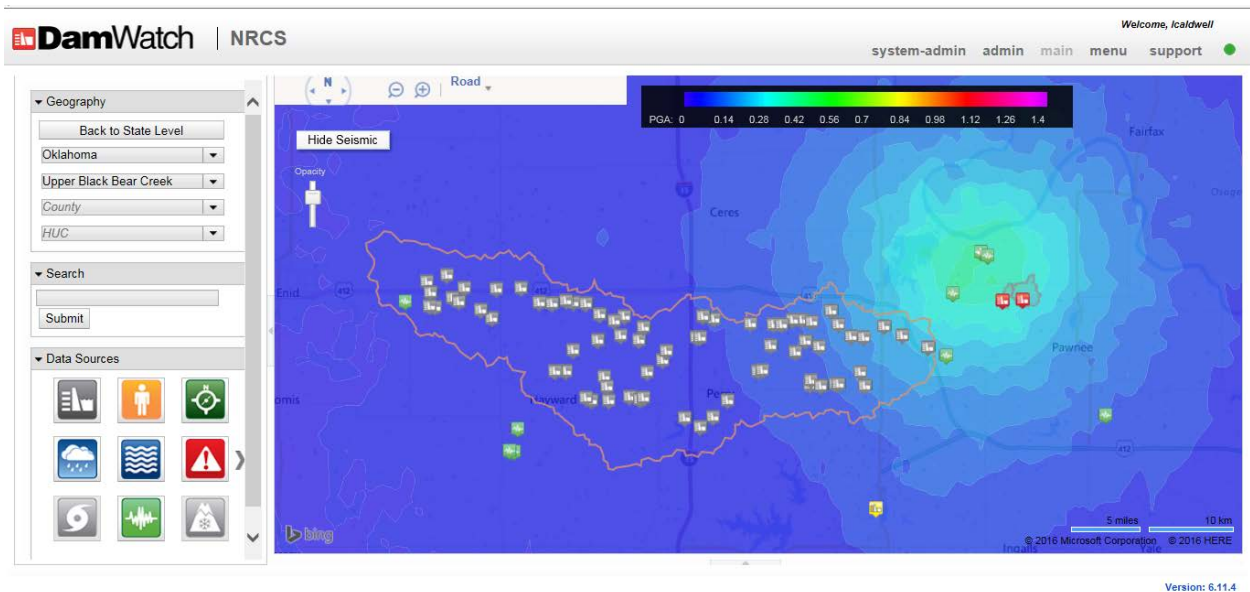
* USGS upgraded the earthquake to 5.8 on September 7

Summary of pga's (initial & revised)
for specific dams
September 3, 2016

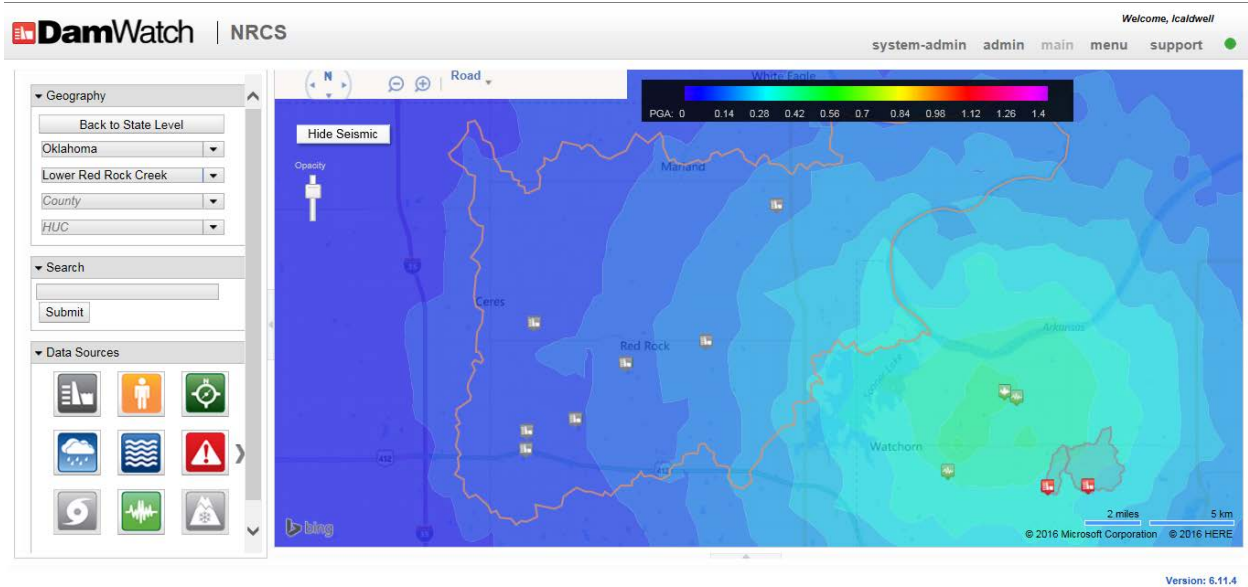
Dam		Distance from epicenter (miles)	pga			
W'shed	Dam No.		Orig 7:02am	Revised 12:26pm	Revised 1:32pm	Revised 2:20pm
LBB	1	11.1	0.32	0.36	0.16	
LBB	2	9.7	0.40	0.44	0.20	
LBB	3	8.4	0.40		0.20	
LBB	4	6.9	0.48	0.52	0.24	
LBB	5	7.1	0.44	0.52	0.24	
LBB	6	4.7	0.28	0.60	0.56	0.28
LBB	7	3.9	0.32	0.64	0.56	0.32
LBB	11	8.2	0.44	0.48	0.24	
LBB	13	10.9	0.32	0.40		
LBB	14	8.1	0.44	0.48	0.20	
LBB	17	9.7	0.36	0.40	0.16	
LBB	18	12.6	0.28	0.36	0.16	
LLB	19	13.5	0.28	0.32	0.12	
LBB	21	13.8	0.28	0.24		
LBB	23	13,3	0.32	0.36	0.16	
Long Branch	7A	10.4	0.32	0.36	0.16	
Long Branch	11	11.6	0.32	0.40	0.16	
LRR	3	11.2	0.32	0.40	0.16	
LRR	13	18.1	0.32		0.16	
UBB	1	8.1	0.44	0.48	0.24	
UBB	2	8.6	0.40	0.48	0.24	
UBB	5	9.2	0.40	0.44	0.20	
UBB	6	10.9	0.32	0.40	0.16	
UBB	7	11.7	0.32	0.36	0.16	
UBB	8	12.1	0.32	0.36		
UBB	9	12.2	0.28	0.36	0.16	
UBB	10	13.9	0.28	0.24		
UBB	16	20.9	0.36	0.40	0.20	
UBB	75	12.8	0.32	0.32	0.16	
UBB	76	13.4	0.28	0.32	0.12	



Lower Black Bear Watershed
 showing maximum pga near the watershed boundary
 and the two remaining active DamWatch alert
 s after USGS finished revising the pga estimates



Upper Black Bear Watershed



Lower Red Rock Watershed

Photos of Damage in Pawnee, Oklahoma; September 3, 2016



