Engineering Challenges for Rivers and Creeks in the St. Louis Region

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Abstract

In 2015 and 2016, record high water levels were set along the middle Mississippi River, the lower Illinois River, and the lower Meramec River. Some water levels on the Illinois bested records that had just been set in 2013. This succession of progressively higher water levels is largely due to human activities and rendered the regulatory FEMA "base flood" levels obsolete as they are typically underestimated by 3 to 6 ft. Rising floodwater levels along rivers are primarily due to constriction by in-channel structures, floodway encroachments, levees and floodplain developments, while problems along creeks are mostly due to channelization, stormwater diversions, and watershed urbanization. Constriction of the lower Meramec River has greatly elevated and flattened the floodwater surface near and above Valley Park and caused anomalously high water velocities downstream. Engineering and regulatory challenges for the region include zoning that recognizes immutable geologic hazards and preserves bottomlands, significant increases in "base flood" elevations and flood insurance rates, and implementation of construction standards that foster reduction and deceleration of runoff and the protection of riparian borders.

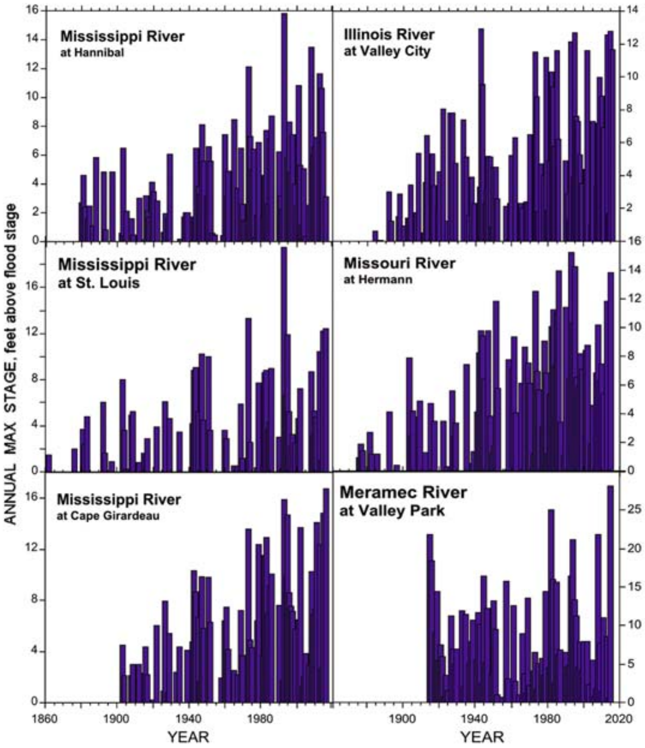

Fig. 1. *Graphs showing the progressive rise of peak annual water levels for several sites within about 100 miles of St. Louis, each in feet above its local flood stage (0 ft. on these graphs). All graphs depict the interval 1860-2020, but only St. Louis has data back to 1861; also, all data at Cape Girardeau from 1896 to 1902 were below flood stage and so are not shown. Vertical scales differ for each site; left plots, left scales; right plots, right scales.*

Introduction

Belt (1975) noted that the record high water level set in 1973 on the middle Mississippi River at St. Louis corresponded to a much smaller discharge than that calculated for prior record floods. Belt attributed this anomalously high river stage to constriction of the river by wing dikes and levees, and although his paper was attacked in several rebuttals, the much higher water level set during the 1993 flood provided stunning confirmation of his analysis. Criss and Shock (2001) analyzed multiple sites to establish that anomalously high river stages were occurring regionally along the upper and middle Mississippi, lower Missouri and Ohio Rivers, and showed that river constriction, not climate change, was the principal cause.

Subsequently, a succession of record and near record floods has afflicted the Midwest, in a broad zone roughly centered on St. Louis (Fig. 1). At various sites along the Missouri and Mississippi Rivers, the 1993 record water levels were nearly matched in 2008 and 2010, or topped during 2011 and 2015–16. The latter event caused great damage to the greater St. Louis region, set the third-highest water level on the Mississippi River at St. Louis, broke several records downstream, and demolished all previous records along the lower Meramec River in St. Louis County.

Statistical methods easily establish that official estimates of flood risk cannot explain the rapid succession of severe Midwestern floods (Criss, 2008; Criss and Winston, 2008). A more difficult task undertaken by Criss (2016) was to develop a methodology to compute flood risk that accommodates the effects of progressive environmental changes on flood populations, while avoiding the use of discharge calculations. This new methodology shows that the regulatory "100-year" flood levels are underestimated by 3–6 feet at most sites in the St Louis region, and that Midwestern floodwater levels are rising at a rate that is 10 times faster than the rise of sea level.

This article provides estimates for "100-year" flood levels for numerous sites near St. Louis, using the Criss (2016) methodology and updated data, and compares these levels to regulatory values. We also demonstrate that floodwater levels have increased on the lower Meramec River at Valley Park by several feet relative to proximal sites, and link this increase to flattening of the water surface caused by floodway constriction, floodplain development and fill, and a new oversized levee. Floods on local creeks are also increasing because of urbanization, destruction of riparian borders, and acceleration of stormwater to stream channels by impervious surfaces and

Table 1. Record Water Elevations (NAVD 88) vs. "100-year" Flood Estimates by FEMA (2016), USACE (2004), and This Paper

Site Name,(River Mile)#	Data Since	FEMA Base Flood	USACE 100-yr	This Paper 100-yr flood	Record Level, year	∂S/∂t*, in/y
Mississippi R. at Hannibal (309.0)	1879	477	476.9	481.4	480.8, 1993	0.92
Mississippi R. at St. Louis (179.6)	1861	426	425.6	431.3	429.2, 1993	1.37
Mississippi R. at Cape Girardeau (52.1)	1896	352	351.7	358.3	353.1, 2016	1.28
Missouri R. at Hermann (97.9)	1873	519	518.5	523.5	518.5, 1993	1.43
Illinois R. at Valley City (61.3)	1883	445	445.3	449.0	444.7, 1943	0.77
Meramec R. at Valley Park (21.4)	1915	430		432.9	435.2, 2015	0.65

\# River Mile indicates miles above a variable confluence of reference.
* Rate of rise of the "100-year" flood, This Paper

storm sewers. Revised engineering practices and thoughtful land use could significantly ameliorate these effects.

Methods Long-term data (100 to 154 year) data are available from USACE (2016a, b) or NOAA (2016a) for several sites in the St Louis region, representing streams that drain basins that range from 4,000 to 710,000 square miles. Criss' (2016) new statistical method was applied to these sites to determine present-day values for the "100-year" flood, which is actually the flood with a 1 percent chance of occurrence in any given year. These values are compared to official values for such a flood, provided by USACE (2004) or by the "base flood" contours on flood insurance rate maps (FEMA, 2016); see Table 1.

Given the record flooding in the lower Meramec basin in St. Louis County in December 2015, a special comparative study was made of the largest floods at Eureka and Valley Park, using data from NOAA (2016a). For smaller creeks, long term data on water levels are not available, so our analysis is based on field observations and photographs.

Water elevations in this paper are all reported relative to the NAVD 88 datum. Literature data reported relative to local site datums or to the old NVGD 29 datum were all converted to the 1988 datum using VERTCON (NOAA 2016b) to establish gauge zero for each site. Differences between the 1929 and 1988 datums are mostly small (-0.11 to +0.39 feet), with 1929 elevations generally being higher. However, we found a large disparity between the FEMA and USACE datums at Hannibal, and the wildly incorrect value of 463 ft. reported for gauge zero by USGS (2016), that probably instead represent normal pool level; we assumed a value of 449.0 ft. for gauge zero to report the Hannibal results in Table 1. As an aside, we also note that the oft reported "gauge zero" of 392.92 ft. (NVGD29) for the Valley Park gauging station is too high by 1.4 ft. to be consistent with newer data and with the accurate NAVD 88 value of 391.1 ft. for this site.

Regional Rivers and Streams

Middle Mississippi River

Just 15 miles above St. Louis, the Mississippi and Missouri rivers merge to form the middle Mississippi River, which at St. Louis drains a 697,000 square mile basin and has an average flow of 195 kcfs. Only 42% of this mean flow is derived from the huge but predominantly semiarid Missouri River basin, even though it represents more than 75% of the drainage area above St. Louis. However, for major floods (>750 kcfs) at St. Louis, an average of 65% of the water originates in the Missouri basin. In other words, large floods at St. Louis are Missouri River floods.

Flooding is a serious and growing problem at St. Louis. As pointed out by Belt (1975), water levels have greatly increased for the same flows due to channel constriction and levees. For example, the flows of the 1903 and 1993 floods were very similar at just above 1Mcfs, yet the peak water elevation was only 417.6 ft. in 1903 but 429.2 feet in 1993 (Criss and Shock, 2001). Progressively higher water levels for moderate flows have been demonstrated at many sites by the "specific gauge" technique (e.g., Pinter, 2001; USACE 2012), and for low, moderate and very high annual flows by Criss and Shock (2001). Progressively higher floodwater levels have rendered the regulatory "base flood" levels obsolete at many sites (Criss 2016; Table 1). Data for Cape Girardeau (Table 1) confirm that rising flood levels are severe along the Middle Mississippi River, and are smaller yet serious in the lock and dam reaches of the Upper Mississippi River (e.g., Hannibal, Table 1). Whether our predicted heights for "100-year" levels will soon be realized is questionable, because before such levels would be attained, all flood defenses would be overwhelmed and the river would spread out everywhere to recapture its natural floodplain.

Lower Missouri River

The Lower Missouri River is managed much like the Middle Mississippi River, with a combination of thousands of wing dams and dredging. Problems of rising flood water levels are also similar. Long term data for river stages on the lower Missouri River were evaluated for Hermann, the closest site to St. Louis where a lengthy record is available. Calculations based on the Criss (2016) methodology show that the base flood levels are underestimated by >4 ft. at this site. A similar underestimation was found for Boonville (not shown). Specific gauge data (USACE, 2012) show that rising water levels for moderate floods are ubiquitous from Omaha to St. Louis, along the entire, >600-mile-long channelized reach.

Lower Illinois River

Incredibly, at several sites along the lower Illinois River, all-time record high stages were set in 2013, only to be nearly matched or bested by those set in July 2015. Even those levels were almost matched by stages in January 2016. Long term data are available for the lower Illinois River at Valley City. Here the 1943 flood is still highest, but listed in descending order, the next highest floods at Valley City occurred in 2015, 2013, 1995, 1993 and 2016, all of which had peak water levels within 2 to 16 inches of the 1943 level (Fig. 1). Calculations using the Criss (2016) methodology show that the base flood level is underestimated by > 3 ft. at this site.

Lower Meramec River

The 3,980-sq mile Meramec basin is one of the very few remaining, unimpounded river basins in the USA. Upstream of St. Louis, the basin has a low population density. These conditions explain the extraordinary diverse aquatic fauna in this spring fed river. Because of its relatively small size, the river has a short time constant, so flood peaks in the lower basin arrive only ~2 days after heavy rainfall, and within a day upstream.

The unusual storm of late December 2015 caused record stages all along the lower Meramec River, from Pacific MO to the Mississippi confluence nearly 50 miles downstream. Criss and Luo (2016) showed that, relative to previous high floods, water levels were highest at Valley Park, where they exceeded the prior record flood of 1982 by 4.4 feet. Criss and Luo attributed this relative magnification to floodway constriction, floodplain developments and fill, the construction of a large levee in 2005, and to continued development of proximal suburban watersheds.

The impact of these developments on the flooding in the lower Meramec Valley can be quantified with the historical records at Eureka and Valley Park. Since 1945, eight large floods at Eureka attained water levels above 439.6 ft.; these were also the eight largest floods at Valley Park. However, the difference between the water levels at Eureka and at Valley Park have become greatly reduced over time, indicating that the slope of the water surface between these sites has become much flatter (Fig. 2). In fact, this slope has become much flatter than suggested by the FEMA (1995) calculations and diagrams, which depict the expected slope of the water surface for 10, 50, 100 and 500 year floods. Clearly, progressive constriction of the river at Valley Park has caused this profound flattening, and this effect extends far upstream. The base flood level is underestimated by nearly 3 ft. at Valley Park (Table 1).

Small Basins

More than 40 different sites along small streams with watersheds of <83 sq. miles are monitored in the St. Louis area. Analysis of hydrographs shows that the associated time constants are very short for these streams, generally ranging from 0.5 to 4 hours, so flood peaks arrive very soon after rainfall. Flood flows on many of these small creeks are >1000 times greater than mean flows, so flash floods are a serious problem in the metro area. High flows on small streams in St. Louis County have had many unfortunate consequences in our region (Fig. 3). These include channel widening and incision that has isolated the channel from the floodplain, while causing erosion that has destroyed bridges, damaged roads and consumed lawns. High water velocities have removed all fine sediments from the channels of many local streams, leaving their bottoms choked with coarse gravel. Many streams have lost their perennial flow, so they are now dry gulches that contain water only during flash floods. As a result, area streams have very low species diversity. Hasenmueller et al. (2016) document correlations in local creeks between reduced base flow, increased peak flows, and poor water quality including high dissolved solids, high chloride (from road salt), low dissolved oxygen, and high E. coli counts. Monitoring of small rural streams in advance of development should be prioritized, so that problematical changes caused by urbanization can be better understood and documented.

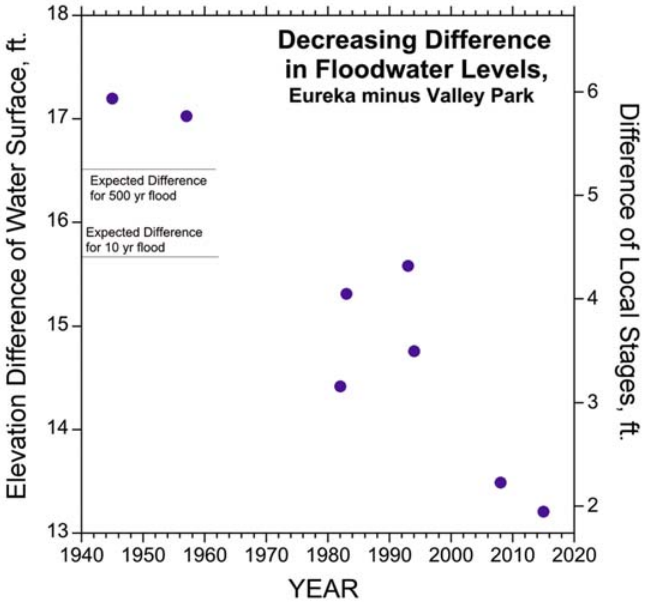

Fig. 2. *Progressive flattening of the water surface for large floods in the lower Meramec basin is indicated by the decreasing difference in peak water levels at Eureka and Valley Park. Left vertical axis shows the difference in elevation of the water surface relative to NAVD 88; as shown by FEMA, the expected difference should be ~ 16 ft., or a drop of 1.3 ft. per mile. The right scale depicts the difference between the stages as reported relative to their arbitrary, local site datums.*

Conclusions

Flooding is a serious and growing threat in the St. Louis region. Floodwater levels are progressively rising in this area, primarily because of mismanagement of lands and rivers, causing regional flood risk to be underestimated by 3 to 6 feet. Understated flood risk and faulty tax schemes have promoted the development of low lying areas, perversely magnifying potential damages while further increasing water levels. Constriction of our rivers has continued as new levees and navigation structures have been added. Inadequate management of stormwater has caused damaging, high peak flows in local creeks. “Flood control” by massive constructed works is a demonstrable failure- what is needed is flood prevention. Environmental and engineering geologists have unique skills that are desperately needed, as their training

Fig. 3. *Effects of urban sprawl on streams. Top: Lower Fox Creek in southwestern St. Louis County, May 8, 2007 near Business 44 east of Pacific. This small, ~15 sq. mi. watershed is in an early stage of suburban development, but in 2007 the creek had high base flow, vegetated banks, and high wildlife diversity. Middle: Lower Fox Creek on Sept. 4, 2016. Increased flash flooding is indicated by bending of vegetation and debris, and by the growth of gravel bars. Large gravel bars and channel widening are far more obvious upstream, where much perennial flow has been lost, and the stream bottom contains abundant algae due to increased sunlight and nutrient loads. Bottom. Lower: Fishpot Creek near Valley Park in October 2008. Dense suburban development of this 9.6 sq. mi. basin has greatly magnified stormwater runoff, causing frequent, destructive flash floods. The associated erosion has greatly deepened and widened the channel and completely removed fine sediments. Perennial flow is gone. Note the huge dune forms in coarse gravel, and the tons of riprap dumped to save properties. This is the end result of irresponsible development.*

enables them to recognize geologic processes and their associated hazards. Geologists can greatly aid our region by advocating thoughtful zoning that preserves bottomlands, promoting construction standards that prioritize stormwater reduction and deceleration, and providing realistic risk assessment.

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