Review of Delaware River FIS and FIRMs for Falls Township, Bucks County, PA
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In my professional opinion, the revised Flood Insurance Rate Maps (FIRMs) issued on March 16, 2016 by the Federal Emergency Management Agency (FEMA) for the Falls Township area of Bucks County, Pennsylvania, significantly underestimate the flood hazards faced by that community and neighboring areas in the County. Therefore, the concerns about those flood hazards of the Delaware Riverkeeper and the Delaware Riverkeeper Network and other parties with respect to the proposed siting the Elcon Recycling Services, LLC commercial chemical hazardous waste treatment and storage facility at 100 Dean Sievers Place, Morrisville, PA are thoroughly justified. The discussion below summarizes the reasons for these concerns.

Precipitation-frequency estimates from the 1961 U.S. Weather Bureau's Technical Paper 40 (TP 40) are still widely used throughout the U.S. Many municipal stormwater management design ordinances still codify its figures (often without citation). However, the National Oceanic and Atmospheric Administration (NOAA) and the six NOAA-funded Regional Climate Centers (RCCs) in the U.S. have long realized that TP-40 systematically underestimated extreme precipitation events, such as the so-called 25-, 50-, 100-, and 500-year events--"so-called" because these represent **average** recurrence intervals. The "100-year" storm is actually that which has a 1% chance of being equaled or exceeded in any given year. And in fact, if such a 1% storm occurred in one year, the probability of an event of the same magnitude (or greater) in the very next year would still be 1%. The shortcomings of TP-40 are due to a number of factors: the short average duration of the precipitation records analyzed; the relatively small number of weather stations for which data were available; the statistical distribution used to analyze the data; and climate change.

Therefore, NOAA undertook production of a new Precipitation-Frequency Atlas of the United States, NOAA Atlas 14. Volume 2 of Atlas 14, covering much of the Midwest and all of the Middle Atlantic States, including New York, New Jersey, Pennsylvania and Delaware, was published in June 2004, and was based on precipitation data through 1999. However, Volume 2 has not been updated in the ensuing 11.5 years. Thus, it is based on data that does not include 16 years that have seen increasingly extreme weather in the mid-Atlantic region and across the U.S. and the entire world.

Examination of the FIood Insurance Study (FIS) for Bucks County, Pennsylvania (FIS No.42017CV001C, revised March 16, 2015) that provides the documentation for the methods used to produce the latest revised FIRMs for the county shows that a wide variety of hydrologic methods were used to estimate the runoff for most of the streams in the region. However, very few streams were analyzed using more accurate methods, such as were used in Temple University's 2003 to 2006 study of the Pennypack Creek Watershed (see FIS, Volume 1, page 40) (https://www.temple.edu/ambler/csc/research/projects/PennypackCreekWatershed.htm) where the watershed was modeled as comprising ten sub-basins. Curve numbers were calculated for each sub-basin based on land use, land cover and soil types. Precipitation-Frequency data were taken from NOAA Atlas 14. Runoff was then computed using USACE's HEC_HMS. The resulting flows were then entered into the Corps HEC_RAS model system to determine the hydraulic characteristics and responses of the stream; i.e., the flooding that results from the different runoff events. (The use of the most accurate precipitation values is obviously of paramount importance in such flood modeling.)

The design storm that drove the Pennypack Creek modeling effort was the Atlas 14 100-year, 2-day precipitation mean value of 8.75 inches (with a 90% confidence interval of 7.87 to 9.51 inches) in the headwaters of the watershed. This value was used to produce the floodplain maps for the watershed in 2006. FIRMs based on those Temple maps were finalized in 2010, and were issued on March 16, 2015 as part of the abovementioned "Revised FIS." However, it is interesting to note that in the 2-day period of June 16-17, 2001, 9.99 inches of rain actually fell at the location of the Willow Grove Naval Air Station, the location of the Atlas 14-predicted 8.75 inches event (Lat. 40.1942^{O} N, Long. 75.1458^{O} W). The recurrence interval of such an event obviously would now be calculated as much less than 100 years.

In assessment of the proposed 100 Dean Sievers Place site, it will be instructive to examine daily precipitation data from two representative sites in the upper portions of the Delaware River Basin. Therefore, such data were downloaded from the website of the Northeast Regional Climate Center (NRCC), one of the abovementioned six supported by NOAA. One site is Walton, New York, which is located in Delaware County, just north of and approximately

equidistant from two of New York City's reservoirs – Cannonsville and Pepacton reservoirs. The other site is the Lehigh Valley International Airport, located approximately four miles northeast of the center of Allentown, Pennsylvania. (A telephone conversation with a staff climatologist at the NRCC guided the selection of the two sites.)

The daily data for both sites spanned the period from January 1, 1960 through December 31, 2015; i.e., 40,908 daily precipitation amounts were reviewed. I then calculated an *annual-maximum event series* for each site. (The basic data for intensity-duration-frequency analyses of rainfall comprise the largest events of each year-- in this case, the largest 24-hour rainfall of each year.) In order to extrapolate to the magnitude of rare events, a frequency curve, known as the *extreme-value distribution*, is fitted to the observed frequency distribution of annual maxima on special probability paper, which is sometimes called "Gumbel paper" or "extreme-value paper." Obviously, the longer the period covered by the data, the more accurate will be the extrapolation. Thus, the 56 years of data analyzed for these two representative sites suggest a high degree of confidence in the resulting extrapolations. For both sites the magnitude of the 1% ("100-year") rainfall event arrived at by the above method was eleven (11.0) inches. The TP-40 value for the 100-year, 24-hour event at Walton, New York was approximately 6.8 inches, and the value for Allentown, Pennsylvania was about the same. In other words, I estimate an approximately 60% increase in the 100-year event, which is supposed to be the event anticipated by the FIRMs.

The mean value of the precipitation-frequency estimate in NOAA Atlas 14 for Walton, NY for the 100-year event was 6.71 inches, but the upper bound of the 90% confidence interval, which prudent engineering practice would advise, was estimated at 9.23 inches. (9.63 inches fell on Walton on June 27, 2006, and the abovementioned analysis estimated that event to have a recurrence interval of only 57 years.) The Atlas 14 100-year event at Allentown was 7.29 inches (mean value), and the upper bound of the 90% confidence interval was 7.82 inches. (8.71 inches were recorded at the Allentown airport on October 8, 2005, with again an estimated recurrence interval of 57 years.)

I should underscore here that the largest daily rainfall of the past 56 years recorded at Walton was the above 9.63 inches, and that it fell after 1999 (the last year analyzed by Atlas 14), as did five other yearly maxima of the greatest 10 of the past 56 maxima (from greatest to least- 2010, 2003, 2011, 2009, 2002). For Allentown, similarly the 8.71 inches maximum in 2005, and four others (2010, 2004, 2008, 2011) were in the top 10 of the past 56. Need the evidence for climate change be any clearer?

I have also noted that much attention has understandably been focused on the extent and elevations of the Delaware River's historic flood of record that occurred August 18-20, 1955 because of Hurricanes Connie and Dianne, which struck eastern Pennsylvania and southern New York between August 11 and 18. However, upon examination of the daily precipitation amounts recorded at Walton, NY and Allentown, PA in July and August of 1955, we can observe an interesting pattern related to that historic flood.

At Walton, a total of 1.98 inches of rain fell in the entire month of July 1955, 1.20 inches of which fell on July 1st and 2nd. The remaining 0.78 inch fell in eight separate events over the last 29 days of July. Then, a total of only 0.64 inches fell in five separate events from August 1 through August 10. However, from August 11 through August 18, a total of 8.20 inches fell in 8 days, the largest rainfall of which was 3.12 inches. This obviously helped to produce the historic flood. To reiterate: the maximum 24-hour rainfall at Walton in the past 56 years was the abovementioned 9.63 inches on June 27, 2006 (estimated recurrence interval of 57 years), which single day accounted for 0.76 inch more than the above 10-day total. And, the expected 100-year event from the above analysis is 11.0 inches.

At Allentown, a similar picture is seen. In the entire month of July 1955, a total of only 0.42 inch of rain fell, on four days. Then in the first 10 days of August, a total of 0.69 inch fell. But from August 11 through August 18, a total of 10.23 inches fell in six of the eight days. This is indeed more than the 8.71 inches daily/annual maximum recorded on October 8, 2005, but still less than the single-day 100-year event of 11.0 inches expected from the annual-maximum series calculations described above.

I believe a further note is necessary to put the hurricane-induced Delaware River Flood of Record (1955) in its proper perspective. Most climate researchers now realize that hurricanes have grown significantly more powerful and destructive over the past four decades. One of the most prominent of these researchers is Kerry A. Emmanuel, Professor of Atmospheric Science at the Massachusetts Institute of Technology. Much, indeed most, of the research of Emmanuel and his coauthors over the past three decades (more than 160 scientific papers since 1995 alone) has focused on the role of global/ocean warming on the increased frequency and intensity of cyclones and the risks associated with them. The conclusions are definitive. Such storms will produce higher wind velocities and greater precipitation in the 21st century than in the 20th. (A few representative examples of his research writings are cited below.)

Therefore, dramatic climate change already has made the most recent FIRMs obsolete and unreliable. And yet, Presidential Executive Order 13690 of January 30, 2015 (Federal Register, February 4, 2014, Vol.80, No.23, pp.6425-6428) apparently sought to address such issues. The Executive Order, in part, requires that "The floodplain shall be established using……the elevation and flood hazard area that result from using a climate-informed science approach that uses the best-available, actionable hydrologic and hydraulic data and methods that integrate current and future changes in flooding based on climate science." [Sec. 2. (i)(1)(i)] It seems that the Executive Order 13690 has been ignored.

In conclusion, the "Revised" FIRMs issued by FEMA on March 16, 2015 and utilized by the Bucks County Planning Commission do not adequately represent the true risks of flooding along the Delaware River in Bucks County, based as they are on badly outdated climate and stream flow data in the region. Furthermore, they do not take into account the effects of climate change on the steadily increasing frequency, intensity and precipitation of hurricanes and tropical storms. Therefore, regulatory reliance on the historic flood of August 1955 and even the most recently revised flood plain maps seriously underestimates the dangers posed to the environmental health of the Delaware River and to the more than two million people who withdraw their drinking water downstream.

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