

The Delaware River Floods of 2004, 2005, and 2006: Causes and Lessons Learned

Daniel Kucz, Student Member
Civil Engineering Department, Lafayette College, Easton, PA

Abstract

The September 2004 flood, a product of the remnants of Hurricane Ivan, produced massive destruction along the Delaware River. Less than seven months later, in April 2005, the Delaware River rose to higher levels as a result of snow melt and unusually high amounts of rain. In June of 2006, the Delaware River was subject to severe flooding again as a result of a week-long rainfall event. The severity of suffering three floods within eighteen months of each other can only be known by those citizens who lived through it. Although these three floods provided for massive amounts of property damages, they also provide insight into why we must invest resources to further understand these events and become better at predicting them to lessen the damages suffered. This paper presents facts about the three floods, provides possible reasons for their occurrence, and offers suggestions to mitigate damages during future floods.

Background

In mid-September of 2004 a large portion of the Northeastern United States was subject to the wrath of Hurricane Ivan, a weather occurrence atypical for that portion of the country. Though the structural damages sustained from most hurricanes are due to wind, Hurricane Ivan's most prominent characteristic was its massive amounts of rainfalls unleashed during its path along the East coast. As a result of these high rainfalls, as well as unusually wet antecedent conditions in the Delaware River Basin, flooding was imminent. What resulted from Hurricane Ivan and the fall flood of 2004 was substantial flooding in the Delaware River Basin, and, consequently, considerable damage assessment and cleanup efforts in the months to follow (Figures 1 and 2).

Figure 1. September 2004 flood in Barryville, NY ("The Seasons of the Delaware River", 2004)

Figure 2. September 2004 flood in Easton, PA along PA Route 611. ("2004 Lehigh Valley Flood", 2004)

Seven months later, as most communities along the Delaware River were beginning to move on, another flood engulfed its banks (Figures 3 and 4). Between April 2 and April 4, 2005, up to five inches of rainfall fell in the upper portions of the Delaware River Basin. This rainfall, coupled with an unusually large amount of snow pack in the Pocono (Pennsylvania) and Catskill Mountain (New York) regions produced gage readings along the river that exceeded the 2004 event and were consistent with the worst flooding in fifty years.

Figure 3. April 2005 flood in Barryville, NY (Courtesy of Shohola Bridge Project, Shohola, PA)

Figure 4. April 2005 flood at Northampton St. bridge in Easton, PA. ("Easton flood 4/5/2005", 2005)

While researchers began analyzing the prior two floods, and citizens were in the midst of recovery efforts, yet another large magnitude flood event occurred in late June of 2006 (Figures 5 and 6). Similar to the prior two floods of 2004 and 2005, wet antecedent moisture conditions were prevalent in most parts of the Delaware River Basin. A tropical low stalled over eastern Pennsylvania extending from parts of Delaware to New York. Rain fell for a period of over a week, and the heaviest rainfalls occurred just before the low departed from the extents of the Delaware River Basin.

Figure 5. June 2006 flood in Lackawaxen, PA at the Roebling Bridge. ("Photo Gallery", 2006)

Figure 6. June 2006 flood in Easton, PA along PA Route 611. ("Flood 2006", 2006)

In analyzing and comparing the facts behind each of these floods, some possible explanations for the causes will become apparent. Furthermore, the mere issue of flooding is not the sole concern when determining the lessons learned. Rather, assessing lessons learned from one event and implementing possible solutions to lessen the damages caused by a subsequent event is of primary concern. In this case, the crux of the lessons learned will be to offer viable solutions for flood damage prevention which can limit destruction in the future.

Flood of September 2004

Prior to Hurricane Ivan, antecedent conditions in the Delaware River Basin were saturated due to rain from the remnants of Hurricane Frances (USGS, 2005). In addition, according to USGS, the reservoirs in the upper Delaware River Basin (Cannonsville, Neversink, Pepacton) in New York were reported to be functioning at about 99% of their capacities when Hurricane Ivan arrived (2005). The result was a situation highly susceptible to flooding for even a moderate rainfall event. Combined with the highly unusual rainfall totals produced by Ivan, flooding was imminent.

As forecasters began to report that Hurricane Ivan was on its way to the Delaware River Basin, the situation was eerily familiar to the flooding along the Delaware in August of 1955 when two hurricanes hit within one week. Beginning in the early morning hours of September 17th, 2004 and continuing at least a period of 24-hours, the remnants of Hurricane Ivan (which had been degraded to a tropical storm) dropped roughly 4-6 inches of rainfall across most of the portions of the upper Delaware River Basin (DRBC, 2005). Much of this rainfall occurred in the upper portions of the Delaware River Basin, including the Pocono and Catskill mountain regions. As a result of the saturated antecedent conditions and high reservoir levels, the additional rainfall could not be absorbed by the ground or reservoirs, transforming it almost completely into runoff. Because the storm produced such phenomenal volumes of runoff, flood stage was reported North and South along the Delaware River sequentially.

After the flood, it was determined that, at Riegelsville, NJ, the peak flow of 216,000cfs was equal to about a 70-year recurrence interval (USGS, 2005). Nevertheless, the September 2004 flood had a flow 124,000cfs short of the 1955 peak flow and had a gage height of about 7.9 feet less than the 1955 mark (USGS, 2005).

Flood of April 2005

Not more than seven months later, between April 2 and April 4, 2005, the Delaware rose again…but higher. A week before the April 2005 flood, nearly two inches of rain fell in widespread areas across the Delaware River basin. This rainfall, combined with warm temperatures, forced accumulated snow falls (Figure 7) to begin melting across the Pocono and Catskill Mountains. As a result, antecedent conditions were extremely moist, if not saturated throughout the upper Delaware River basin. In addition, the reservoirs that serve New York City were again at nearly 100% capacity

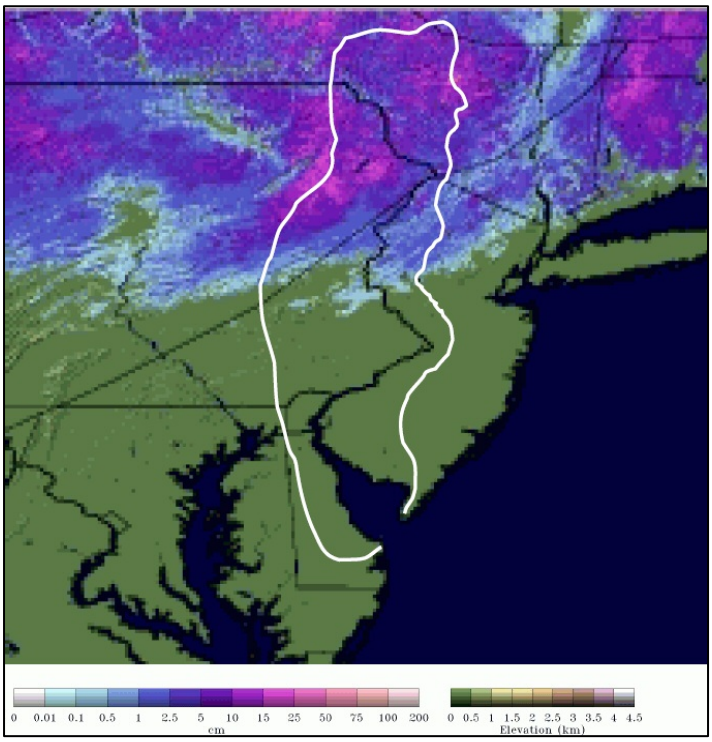

Figure 7. Snow pack water equivalent April, 2005 ("Spring Flood of April 2-4, 2005" 2005)

in preparation for the coming dry summer season (New Hope, PA, 2005). These factors set the stage for a situation susceptible to flooding again.

During April 2nd and 3rd, a potential flood situation turned into an actual flood situation. As 3-5 inches fell in the upper Delaware River basin, concurrent with locations of the extremely wet antecedent conditions, the Delaware was forced over its banks, and water levels exceeded those experienced during the September 2004 flood. Prior to the storm, reservoirs in upstate New York were already spilling water over their banks (USGS, 2005). In addition, during the rain event of April 2nd -3rd, Lake Wallenpaupack (a dammed reservoir used for hydroelectricity) began emptying water into the Lackawaxen River, a tributary to the Delaware River (USGS, 2005).

After the event, the estimated recurrence interval, according to USGS (2005) varied from the 80-year to the 100-year flood flow event, depending on the location along the main stem of the Delaware River.

Flood of June 2006

In the last week of June, 2006, a front stalled over the Delaware River basin as a result of a tropical low that had previously threatened to become a tropical depression before arriving in the northeast (NWS, 2006). The front made its presence felt initially on June 22nd (Figure 8) and continued to remain in the area for the next six days. Between June 22nd and June 28th, rain fell in amounts of 0.5-1.5 inches per day over widespread areas of the Delaware River basin (NWS, 2006). On June 28th, the heaviest rainfall was experienced with one-day totals of 3-6 inches in widespread locations (Figure 8) (NWS, 2006). With such event sequencing, the watershed was "primed" with unusually wet conditions prior to the June 28th rainfall event. As the June 28th event occurred, the rainfall was unable to infiltrate into the ground due to extremely wet, if not saturated, antecedent conditions. In addition, with the largest rainfall totals on the final day, the worst-case scenario was occurring.

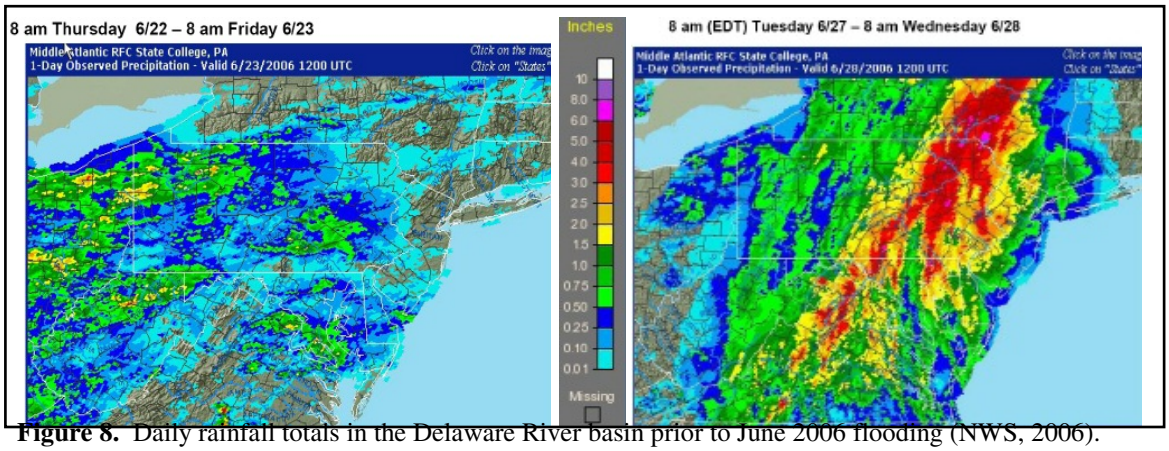

Figure 8. Daily rainfall totals in the Delaware River basin prior to June 2006 flooding (NWS, 2006).

Aside from the week-long rainfall event, locations along eastern Pennsylvania and western New Jersey had experienced unusually wet weather for the period from mid-May to the end of June. Such unusually wet weather tends to create a watershed that is susceptible to flooding on two different fronts. Firstly, such weather tends to raise groundwater levels. Secondly, wetter weather leading up to a major rainfall event is concurrent with less water infiltrating to the ground and worse antecedent moisture conditions. Each of these factors likely contributed to the flooding that occurred in 2006.

The recurrence interval for the 2006 even exceeded that of the prior 2004 and 2005 flooding events, in some cases. According to USGS (2006), it was estimated that the recurrence interval ranged from a 70- to 100-year flood, depending on location.

General causes of the most recent flooding

The common theme among the previously described floods of 2004, 2005, and 2006 are unusually wet antecedent moisture conditions combined with event sequencing. Prior to each event, there were distinct links between excess moisture being released unto the ground and subsequent floods from precipitation. However, the causes of the wet antecedent moisture conditions varied. In the September 2004 flood, wet antecedent moisture conditions were the result of Hurricane Frances one week prior to Hurricane Ivan. In April 2005, wet antecedent moisture conditions were the result of excessive snowmelt combined with moderate rainfall. In June 2006, wet conditions were the result of a month of above-average rainfall combined with a tropical low stalling over the Delaware River basin for a week. The varying causes of wet conditions are representations of the varying causes of flooding along the Delaware River, throughout history. Table 1 shows the top ten ranked flood events at Riegelsville, NJ.

Table 1 – Historic quantified flood events of the Delaware River at Riegelsville, NJ

Rank	Date	Stage (ft)	Flow (cfs)	Cause(s)
1	August 19, 1955	38.85	340000	Hurricane Diane (Aug 18-19) preceded by Hurricane Connie (Aug 11-15)
2	October 10, 1903	35.9	275000	Heavy rains
3	April 4, 2005	34.07	262000	2"-5" Rainfall preceded by abnormal snowpack/snowmelt from a rainfall event on March 28/29, 2005
4	June 29, 2006	33.62	254000	Tropical disturbance with extremely heavy rainfall (3"-10") preceded by June 24-26 heavy rainfall event
5	January 8, 1841	33.3*	250000	Snowmelt and Ice choked floodwaters combined with heavy rains
6	March 19, 1936	32.45	237000	Excessive rain and snowmelt
7	September 19, 2004	30.95	216000	Tropical Storm Ivan preceded by Tropical storm Frances one week earlier
8	January 20, 1996	28.72	187000	Excessive rain and warm temperatures coupled with excessive snowpack/snowmelt/ice jams
9	May 24, 1942	27.5	164000	Severe rainfall
10	April 1, 1940	26.47	154000	Moderate to heavy rainfall combined with moderately heavy snowmelt

*estimated stage based on rating curve (Q, cfs vs. h, ft)
(Sources: Dale (1996), NOAA (1940), USGS (2006))

From Table 1, Ranked events #1, #4, and #7 have causes related to tropical disturbances. Events ranked #3, #6, and #10 were the result of heavy spring rainfall coupled with snowmelt. Events ranked #5 and #8 were the result of unusual winter rain and high temperatures. Overall, the major causes of floods stem from a wide range of reasons which include tropical activity, spring rain/snowmelt, and rare winter temperatures/rain. There is no single dominant cause, which leads to the deduction that the Delaware River is vulnerable to major flooding of several different forms. Such vulnerability increases the difficulty of mitigating flood damages in the future.

Additional blame for the most recent flooding was placed on upstream development and poor reservoir regulation. In all of the floods, the reservoirs that act as the source for NYC drinking water were at maximum capacity and spilled millions of additional gallons of runoff into the upper Delaware River. Although reservoirs were targeted as causes by downstream citizens, it should be noted that these reservoirs produce so little additional flow during flood events that the height increase in the Delaware is negligible (USGS, 2005). The outflow of such reservoirs, though they are relatively high in magnitude at their points of release, is smaller than the natural inflow into the reservoirs, relieving blame from reservoir releases upstream (Buterbaugh, 2005).

Another reaction to the most recent flooding was to blame the occurrence on increased runoff as a result of upstream development. Some residents tended to point their fingers at the increased development occurring in Monroe, Pike, and Wayne

counties in the Pocono Mountains. Some of these counties have experienced as much as a 150% population increase over a period of two decades (1970-1990) (Pennsylvania Pocono Mountains, 2005).

Although these areas upstream have undoubtedly experienced increased development, the majority of the Pocono Mountain region contained within the Delaware River Basin remains wooded areas. To provide evidence to support the preceding statement, the annual peak flows (1907-2006) at Riegelsville, NJ were plotted (Figure 9). After plotting this best-fit line, no clear upward trend was observed. This implies that the annual peak flows at Riegelsville have not increased with magnitude over time as would be expected with the increase in land development.

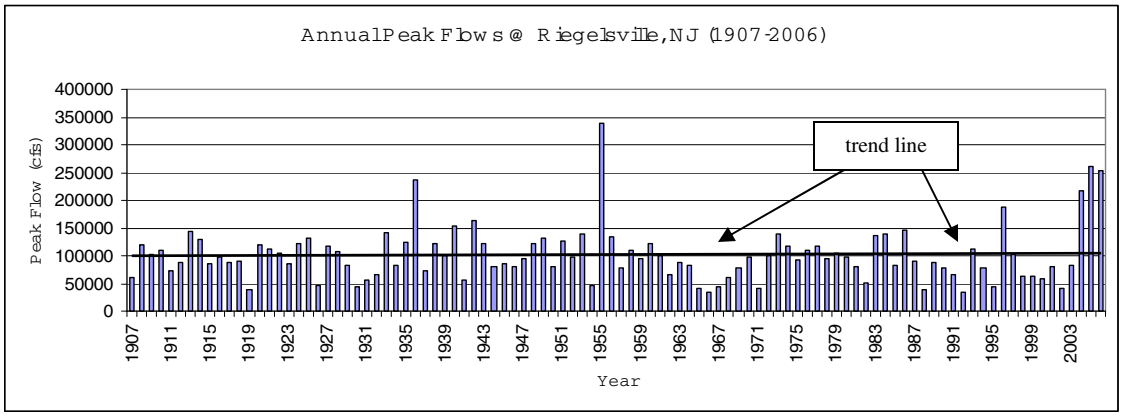

Figure 9. Annual peak flows at Riegelsville, NJ (data obtained from USGS, 2006)

Conclusion/ Lessons Learned

Although it is impossible to prevent floods from occurring, it is possible to lessen the damages suffered by the floods. As a result, the Delaware River Basin Commission (DRBC) has outlined its plan for reducing damages. Ultimately, the causes of the most recent flooding were related to antecedent moisture conditions and event sequencing. Considering this, DRBC's plan includes recognizing event sequencing through implementing flood warning improvements, increasing federal funding for USGS stream and rain gages, complying with requirements for state and local hazard mitigation plans, updating flood plain maps in areas where development has occurred recently, strengthening flood plain regulations, maintaining flood control structures, and enforcing local storm water management regulations (DRBC 2005).

Unfortunately, the extra monitoring devices required to measure snow pack equivalents, the extra personnel required to frequent these gages, and the additional lines of communication to carry out advanced warnings of possible floods comes at a high cost. In addition, the product of such systems may be summed up as a few additional hours of preparation prior to the onset of a flood. Ultimately, the only flawless flood mitigation plan is to refrain from encroaching upon the floodplain. Stricter land use regulations and ordinances to prevent construction in floodplains would limit such encroachment.

References

"2004 Lehigh Valley Flood". (2004). Retrieved on March 28, 2006 from http://home.moravian.edu/users/phys/mejjg01/geology/Flood%20images/flood_of_2004/Lehigh_Valley_Flood_2004.htm

Buterbaugh, C. (2005). "April 2 rainstorm breaks all high water records!" The River Reporter, April 7-13, 2005. Retrieved February 20, 2006, from http://www.riverreporter.com/issues/05-04-07/news-lackawaxen.html.

Dale, F. (1996). *Delaware Diary Episodes in the Life of a River*. Rutgers University Press, New Brunswick, New Jersey.

"Delaware River Flooding from Tropical Storm Ivan" (2004). United States Geological Survey, New Jersey. Retrieved on February 20, 2006 from http://www.state.nj.us/drbc/Flood_Website/Ivan2004.pdf.

Delaware River Basin Commission (2005). *Message from the Delaware River Basin Commission concerning the recent flooding*. Retrieved February 20, 2006, from http://www.state.nj.us/drbc/Flood_Website/message.htm.

"Easton flood 4/5/2005" (2005). Retrieved on March 28, 2006 from http://www.state.nj.us/drbc/Flood_Website/reporteddamages.htmhttp://www.mbensel.com/flood/easton_flood_452005.htm

"Flood 2006". (2006). Retrieved on September 29, 2006 from Webshots user dah59 from http://community.webshots.com/album/551824075NzDusq.

National Oceanic and Atmospheric Administration. (1940). "Monthly weather review." Accessed 9/13/2006 from http://docs.lib.noaa.gov/rescue/mwr/068/mwr-068-03-0083.pdf.

Natinoal Weather Service. (2006). *Major Delaware River Flood of June 2006*. Accessed 8/28/2006 from http://www.state.nj.us/drbc/Flood_Website/2006/NWS-07-19-06.pdf.

New Hope, PA (2005). *Delaware River – flooding information*. Retrieved February 20, 2006, from http://www.newhopepa.com/Flood/flood_index.htm.

"Overview – Pennsylvania's Pocono Mountains" (2005). Retrieved on May 4, 2006 from http://www.insiders.com/poconos/main-overview.htm.

"Photo Gallery – Flood 2006". (2006). Retrieved on January 7, 2007 from http://www.riverreporter.com/ .

"Spring Flood of April 2-4, 2005" (2005). United States Geological Survey, New Jersey. Retrieved on February 20, 2006 from http://www.state.nj.us/drbc/Flood_Website/Spring2005.pdf

"The Seasons of the Delaware". (2004). Retrieved on March 28, 2006 from http://www.upperdelawarescenicbyway.org/seasons.htm

United States Geological Survey (2004). *County-wide reported flood damages in the Delaware River Basin*. Retrieved February 20, 2006, from http://nj.usgs.gov/special/flood0405/

United States Geological Survey (2005). *County-wide reported flood damages in the Delaware River Basin*. Retrieved February 20, 2006, from http://nj.usgs.gov/special/flood0405/

United States Geological Survey (2005). *Summary of April 2-4, 2005, flooding in New Jersey*. Retrieved February 20, 2006, from http://nj.usgs.gov/special/flood0405/

United States Geological Survey (2005). *Summary of September 17-23, 2004, flooding on the Delaware River and its tributaries in New Jersey*. Retrieved February 20, 2006, from http://nj.usgs.gov/special/flood0904/

United States Geological Survey. (2006). *Summary of June 28-29, 2006 flooding in the New Jersey part of the Delaware River Basin*. Retrieved on December 28th, 2006 from http://nj.usgs.gov/special/flood0606/.