4.3.6. Hailstorm

4.3.6.1. Location and Extent

Hailstorm events can occur in all areas of Pennsylvania. Hail precipitation is often produced at the front of a severe thunderstorm system or in conjunction with a tornado event. Hailstorms occur when ice crystals form within a low pressure front due to the rapid rise of warm air into the upper atmosphere and the subsequent cooling of the air mass. Frozen droplets gradually accumulate on the ice crystals until, having developed sufficient weight, they fall as precipitation in the form of balls or irregularly shaped masses of ice. Hailstones are formed most commonly in thunderstorms with intense updraft, high liquid water content, large vertical extent, large water droplets, and cloud layers below freezing.

4.3.6.2. Range of Magnitude

Hail is described qualitatively and quantitatively by its size and can range from 0.2 inches to 4.5 inches; as shown in table 4.3.6-1.

Table 4.3.6-1 Hailstone size and relationship to updraft speed (NOAA, 2 May 2013).

HAILSTONE SIZE	MEASUREMENT (INCHES)	UPDRAFT SPEED (MPH)
BB	< 0.25	< 24
Pea	0.25	24
Marble	0.50	35
Dime	0.70	38
Penny	0.75	40
Nickel	0.88	46
Quarter	1.00	49
Half Dollar	1.25	54
Walnut	1.50	60
Golf Ball	1.75	64
Hen Egg	2.00	69
Tennis Ball	2.50	77
Baseball	2.75	81
Tea Cup	3.00	84
Grapefruit	4.00	98
Softball	4.50	103

The size of hail is dependent on the strength of the upward air movement along the front of a thunderstorm, called the updraft. Hailstone nuclei are buoyed or lifted by the updraft and grow in size the longer the stone is held aloft. Weaker updrafts create smaller hailstones while strong updrafts provide a longer amount of time for hailstone nuclei to grow in diameter.

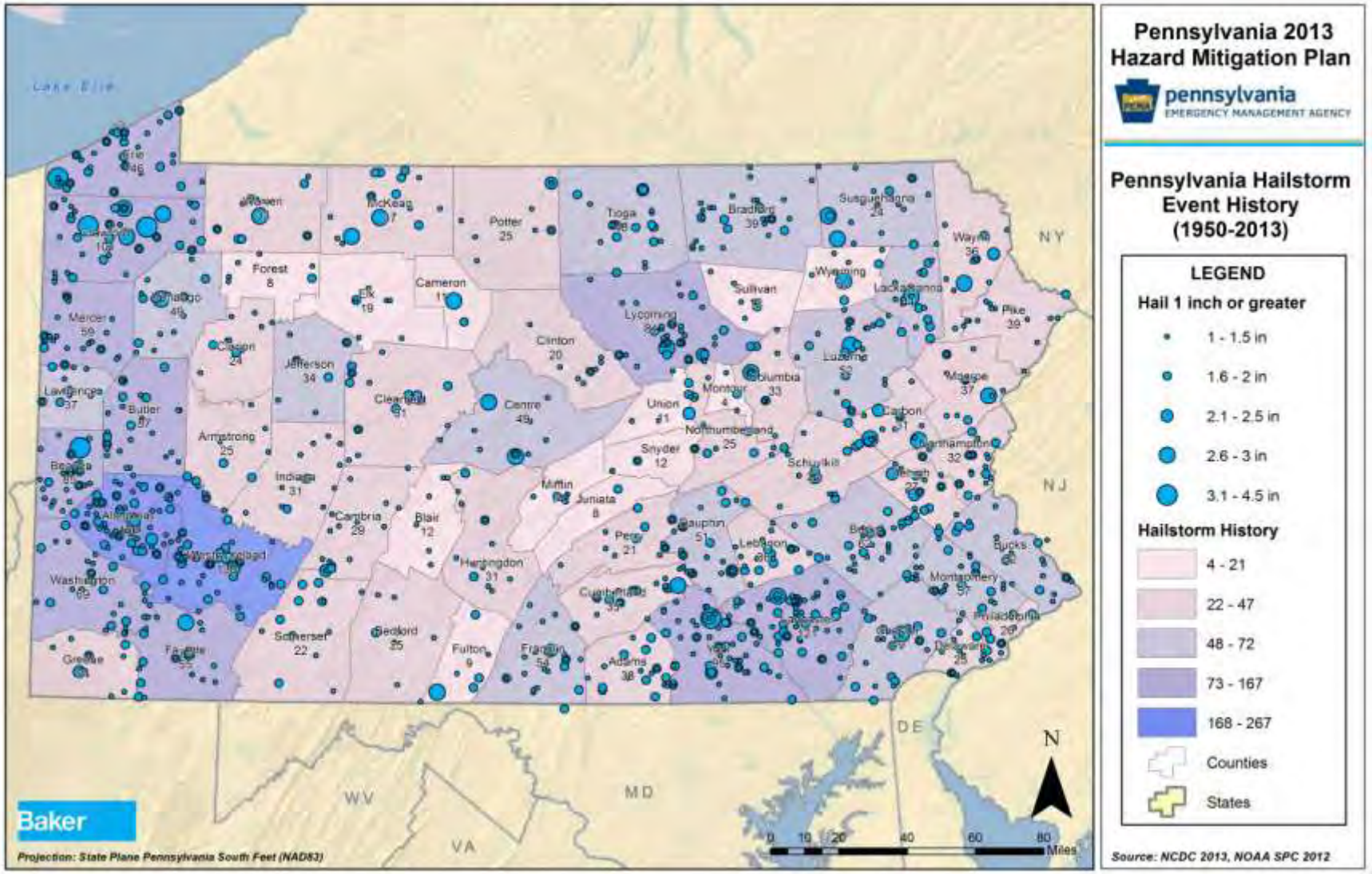
Hailstorms can cause significant damage to crops, livestock and property. Damage is dependent on the size, duration, and intensity of hail precipitation. Those who do not seek shelter could face serious injury. Automobiles and aircraft are particularly susceptible to damage. Since hail precipitation usually occurs during thunderstorm events, the impacts of other hazards associated with thunderstorms (i.e. strong winds, intense precipitation, etc…) often occur simultaneously.

A potential worst-case scenario of a hailstorm would be if a storm carrying hail of over 2 inches were to occur over a prolonged period in an agricultural area of one of the Commonwealth's predominantly agricultural counties such as Lancaster or Franklin. Because hail can cause significant crop damage, a storm of this magnitude would potentially destroy agricultural yields and result in significant lost revenue, as well as anticipated property damage or injuries.

4.3.6.3. Past Occurrence

Figure 4.3.6.1 shows a map of the number of recorded hailstorm events by county between 1950 and 2013. An *event* is that which produces hail of ¾ inches or greater in diameter. Previous versions of the SSAHMP found that approximately 96% of hailstorm events occurred during the months of April, May, June, July, August, and September. In addition, approximately 87% of historic events occurred during the afternoon (noon to 5pm) or evening (5pm to 9pm) hours. Both of these results are consistent with the relationship between hail and thunderstorms, which most often occur during late spring, summer, and early fall months.

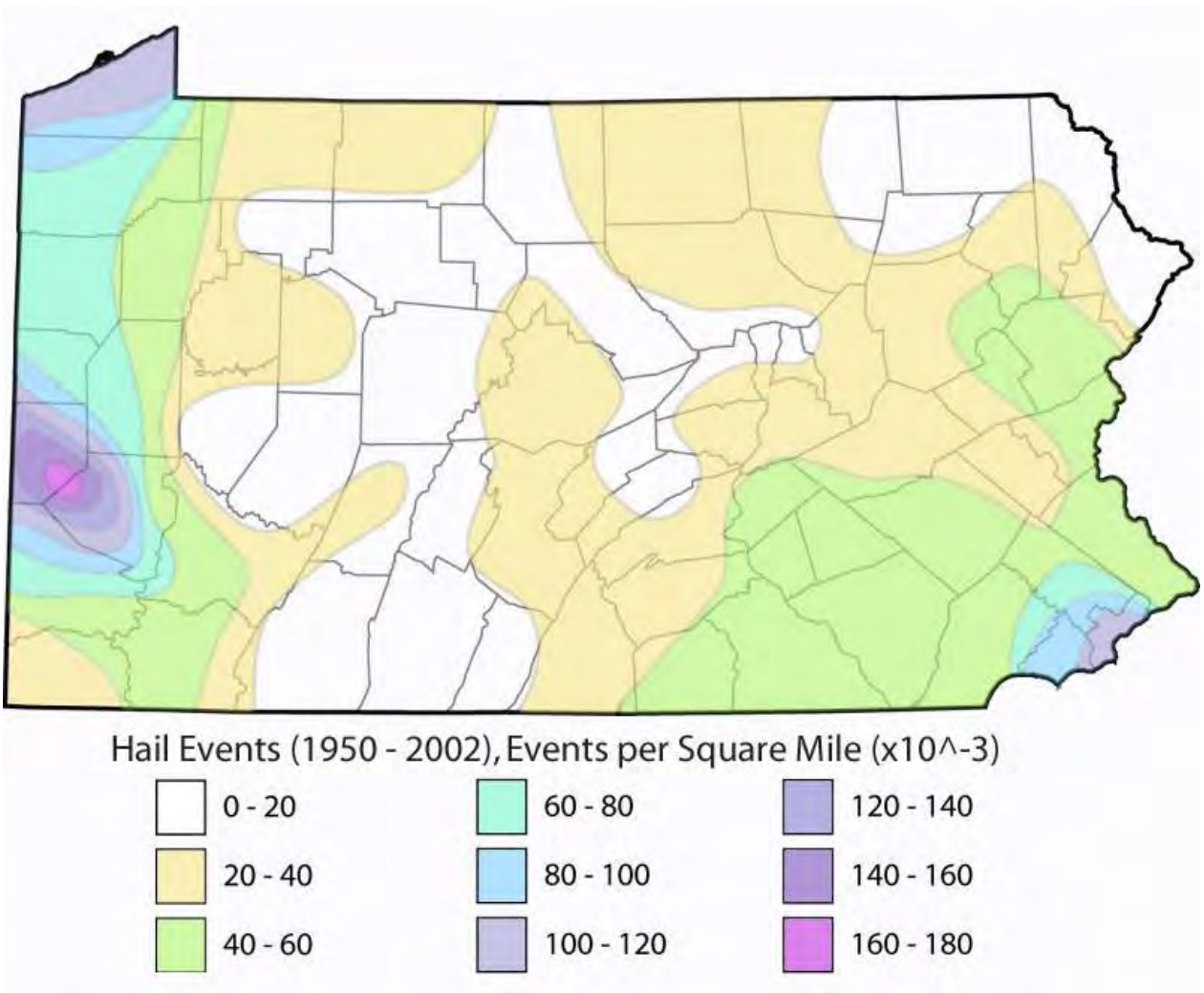
Figure 4.3.6-1 Number of hailstorm events by county between 1950 and 2013 (NCDC, 2013).



4.3.6.4. Future Occurrence

Hailstorm events will occur annually, primarily between April and August, throughout Pennsylvania. Using events collected between 1950 and 2002, Figure 4.3.6-2 shows the number of hail events per square mile across Pennsylvania. It is clear that the southeast and extreme west sections of the Commonwealth can expect to experience a higher number of hailstorm events compared to other areas of Pennsylvania. On the whole, though, the probability of future hail events can be considered *likely* according to the Risk Factor Methodology (see Section 4.1).

Figure 4.3.6-2 Hail events per square mile in Pennsylvania (Pennsylvania State Climatologist).



4.3.6.5. Environmental Impacts

Damage to trees, shrubbery, and other vegetation may occur during hailstorm events through defoliation. Unless there are compounding stresses, natural vegetation can typically recover over time following the event. However, crops such as corn and soybeans can be damaged to the point of total loss, particularly if an event occurs later in the growing season.

4.3.6.6. Jurisdictional Vulnerability Assessment

As a hazard, damage to crops and vehicles are typically the most significant impacts of hailstorms. Areas in eastern and central Pennsylvania typically experience less than 2 hailstorms per year while areas in western Pennsylvania experience 2-3 annually. (FEMA, 1997). All jurisdictions are vulnerable to the effects of hailstorms, but jurisdictions with large amounts of farmland and high agricultural yields are more likely to be affected by hailstorm hazards. According to the 2007 US Department of Agriculture Agricultural Census, in Pennsylvania, the top ten jurisdictions for agricultural production are as follows:

1. Lancaster County (18.5% of state total sales)
2. Chester County (9.5% of state total sales)
3. Berks County (6.3% of state total sales)
4. Franklin County (5.2% of state total sales)
5. Lebanon County (4.4% of state total sales)
6. Adams County (3.7% of state total sales)
7. York County (3.7% of state total sales)
8. Cumberland County (2.3% of state total sales)
9. Schuylkill (2.1% of state total sales)
10. Bradford County (2.1% of state total sales)

Beyond these agricultural counties, Table 4.3.6-2 lists which counties profiled hailstorm in their most recent hazard mitigation plan or plan update. As stated in Section 4.1, the decision by a county to profile a hazard is one indicator of the presence of risk from that hazard. This indicator should be viewed complementary to other analysis in this section. Together this analysis from reputable sources addresses different aspects of risk for a full risk profile.

Currently, eight counties have a calculated risk factor value for hailstorms. The State Risk Factor for hailstorms is 1.9, and the THIRA ranking is 6 of 10. For more details on the State Risk Factor and THIRA prioritization, please see Section 4.1.

Table 4.3.6-2 Counties profiling hailstorm hazards with hazard ranking and risk factor (if available).

COUNTY	Profiled Hazard	Did Not Profile Hazard	Ranking (if available)	Risk Factor (If available)
Adams		X		
Allegheny		X		
Armstrong		X		
Beaver		X		
Bedford	X		Medium	2.4
Berks		X		

Table 4.3.6-2 Counties profiling hailstorm hazards with hazard ranking and risk factor (if available).				
COUNTY	**Profiled Hazard**	**Did Not Profile Hazard**	**Ranking (if available)**	**Risk Factor (If available)**
Blair		X		
Bradford		X		
Bucks	X		Low	1.6
Butler		X		
Cambria	X		High	2.7
Cameron		X		
Carbon		X		
Centre		X		
Chester		X		
Clarion		X		
Clearfield		X		
Clinton		X		
Columbia		X		
Crawford		X		
Cumberland		X		
Dauphin		X		
Delaware		X		
Elk		X		
Erie		X		
Fayette	X		Medium	2.4
Forest		X		
Franklin		X		
Fulton		X		
Greene		X		
Huntingdon		X		
Indiana		X		
Jefferson		X		
Juniata		X		
Lackawanna		X		
Lancaster		X		
Lawrence		X		
Lebanon*		X		
Lehigh	X		Medium	2.1

Table 4.3.6-2 Counties profiling hailstorm hazards with hazard ranking and risk factor (if available).

COUNTY	Profiled Hazard	Did Not Profile Hazard	Ranking (if available)	Risk Factor (If available)
Luzerne		X		
Lycoming	X		High	3.1
McKean		X		
Mercer		X		
Mifflin		X		
Monroe		X		
Montgomery	X		Medium	2.1
Montour*		X		
Northampton	X		Medium	2.1
Northumberland		X		
Perry*		X		
Philadelphia**		X		
Pike		X		
Potter		X		
Schuylkill		X		
Snyder		X		
Somerset		X		
Sullivan		X		
Susquehanna	X		Low	1.8
Tioga		X		
Union		X		
Venango		X		
Warren		X		
Washington		X		
Wayne		X		
Westmoreland		X		
Wyoming		X		
York	X		Medium	2.0

* Lebanon, Montour, and Perry use an alternate weighted ranking where Risk Factor = Frequency x [(0.25 x Critical facilities) + (0.40 x Social) + (0.25 x Economic) + (0.10 x Environmental)]. While this risk factor was used to comparatively rank hazards, the number does not correspond to a high-medium-low rating.

**Philadelphia uses an A, B, C rating system where A is high, B is medium, and C is low.

4.3.6.7. State Facility Vulnerability Assessment

Hail does not pose a direct threat to state critical facility buildings. Although property damage could result from a hailstorm, the real damage is on agricultural land and its crops. Because hailstorms primarily affect agricultural products, the state facilities that are most vulnerable to hailstorm threats are those that are food and agriculture-related. These agricultural critical facilities are both food producers and food manufacturers, and are located in both urban and rural areas, all of whom could be directly or indirectly impacted by a hailstorm event. Table 4.3.6-3 lists these facilities by county. Lancaster County has the most facilities with 18, followed by Dauphin County with 12 facilities.

Table 4.3.6-3 Number of agriculture State Critical Facilities per county.

COUNTY	NUMBER OF AGRICULTURE CRITICAL FACILITIES	COUNTY	NUMBER OF AGRICULTURE CRITICAL FACILITIES
Adams	5	Lancaster	18
Allegheny	4	Lebanon	3
Berks	8	Lehigh	1
Blair	2	Luzerne	1
Bradford	1	Lycoming	2
Bucks	1	Mercer	1
Cambria	1	Mifflin	1
Chester	3	Montgomery	3
Clearfield	1	Northampton	2
Columbia	2	Northumberland	5
Cumberland	4	Philadelphia	4
Dauphin	12	Schuylkill	4
Delaware	1	Snyder	2
Erie	3	Somerset	1
Fayette	1	Susquehanna	1
Franklin	1	Washington	1
Juniata	1	Westmoreland	1
Lackawanna	1	York	3

4.3.6.8. Jurisdictional Loss Estimation

Across all communities in Pennsylvania, hailstorm events between 1950 and 2013 have caused $5,575,500 in property damage and $3,487,000 in crop damage (NCDC, 2013). As reported by the NCDC, the top hailstorm occurrences involving the largest property damage and crop damage came within Erie County. In Erie County, dime size hail was reported over a large area. Around 3,000 acres of grapes on 24 farms were damaged by the hail. Approximately 25 percent of the grape crop on these 3,000 acres was destroyed. Initial estimates put the financial loss at $2,000,000. A complete list of all damages reported within Pennsylvania is listed in Table 4.3.6-4.

Table 4.3.6-4 Hailstorms per county according to the NCDC between 1950 and 2013 (NCDC, 2013)

COUNTY	HAIL EVENTS	PROP. DAMAGE	CROP DAMAGE	COUNTY	HAIL EVENTS	PROP. DAMAGE	CROP DAMAGE
Adams	42	$10,000	*	Lackawanna	48	$95,000	*
Allegheny	267	$6,000	*	Lancaster	139	$5,000	*
Armstrong	31	*	*	Lawrence	57	$5,000	*
Beaver	108	$1,000	*	Lebanon	41	$5,000	*
Bedford	30	*	*	Lehigh	38	$100,000	$50,000
Berks	68	*	*	Luzerne	63	$113,000	$1,000
Blair	15	*	*	Lycoming	96	$351,000	$500,000
Bradford	58	$79,000	*	McKean	43	$30,000	*
Bucks	67	$10,000	$400,000	Mercer	98	*	*
Butler	117	$51,000	$500,000	Mifflin	14	$30,000	*
Cambria	34	*	*	Monroe	46	*	*
Cameron	11	*	*	Montgomery	67	*	*
Carbon	33	$1,050,000	*	Montour	4	*	*
Centre	53	*	*	Northampton	37	$250,000	*
Chester	72	*	*	Northumberland	27	*	*
Clarion	37	*	*	Perry	29	$15,000	*
Clearfield	33	$2,000	*	Philadelphia	29	*	*
Clinton	28	$7,500	*	Pike	43	$3,000	$1,000
Columbia	36	*	*	Potter	30	*	*
Crawford	146	$1,723,000	$15,000	Schuylkill	37	*	*
Cumberland	40	*	*	Snyder	13	*	$5,000
Dauphin	64	*	*	Somerset	32	*	$5,000
Delaware	36	*	*	Sullivan	14	*	*
Elk	21	*	*	Susquehanna	50	$30,000	*
Erie	167	$1,446,000	$2,010,000	Tioga	50	$10,000	*
Fayette	92	*	*	Union	11	*	*

Table 4.3.6-4 Hailstorms per county according to the NCDC between 1950 and 2013 (NCDC, 2013)

COUNTY	HAIL EVENTS	PROP. DAMAGE	CROP DAMAGE	COUNTY	HAIL EVENTS	PROP. DAMAGE	CROP DAMAGE
Forest	11	$10,000	*	Venango	64	$12,000	*
Franklin	59	*	*	Warren	34	$20,000	*
Fulton	11	$2,000	*	Washington	93	*	*
Greene	25	*	*	Wayne	47	*	*
Huntingdon	33	*	*	Westmoreland	225	*	*
Indiana	38	$100,000	*	Wyoming	19	*	*
Jefferson	53	*	*	York	121	$4,000	*
Juniata	9	*	*	**TOTAL**	**3,704**	**$5,575,500**	**$3,487,000**

* *Damage results marked with an asterisk indicate that no reported damage values were provided by the NCDC, not necessarily that the event did not cause any damage.*

Jurisdictional loss estimation stems from lost agricultural revenues statewide. Table 4.3.6-5 enumerates each county's farmland acreage as well as the annual market value of all agricultural products sold, from 2007. As stated in Section 4.3.6.6., Lancaster, Chester, Berks, Franklin, Lebanon, Adams, York, Cumberland, Schuylkill, and Bradford counties are the counties most threatened by hailstorms; if a hailstorm were to eliminate these counties' agricultural yield, total losses could top $3.3 billion.

Table 4.3.6-5 Estimated jurisdictional losses relating to agricultural production (USDA Census of Agriculture 2007)

COUNTY	IMPACTED FARMLAND ACREAGE	MARKET VALUE OF ALL AGRICULTURAL PRODUCTS
Adams	174,595	$216,994,000
Allegheny	38,023	$9,514,000
Armstrong	122,275	$51,976,000
Beaver	67,075	$15,187,000
Bedford	210,990	$90,858,000
Berks	222,119	$367,840,000
Blair	87,434	$85,199,000
Bradford	266,635	$121,311,000
Bucks	75,883	$70,573,000
Butler	129,850	$38,664,000
Cambria	87,924	$23,168,000
Cameron	5,092	$828,000
Carbon	20,035	$8,944,000
Centre	148,464	$69,661,000
Chester	166,891	$553,290,000
Clarion	132,140	$21,958,000
Clearfield	62,721	$11,102,000
Clinton	56,626	$43,661,000
Columbia	122,621	$45,874,000
Crawford	232,093	$101,036,000
Cumberland	157,388	$132,803,000
Dauphin	89,533	$82,887,000
Delaware	4,361	$9,455,000
Elk	33,258	$3,717,000
Erie	173,125	$71,284,000
Fayette	140,688	$25,974,000
Forest	10,728	$3,106,000
Franklin	242,634	$304,450,000
Fulton	103,516	$38,038,000
Greene	150,203	$9,316,000
Huntingdon	148,289	$62,320,000
Indiana	187,711	$76,428,000

Table 4.3.6-5 Estimated jurisdictional losses relating to agricultural production (USDA Census of Agriculture 2007)		
COUNTY	**IMPACTED FARMLAND ACREAGE**	**MARKET VALUE OF ALL AGRICULTURAL PRODUCTS**
Jefferson	87,043	$25,317,000
Juniata	97,681	$91,658,000
Lackawanna	39,756	$16,216,000
Lancaster	425,336	$1,072,151,000
Lawrence	92,391	$35,639,000
Lebanon	113,486	$257,097,000
Lehigh	84,643	$72,059,000
Luzerne	66,577	$18,151,000
Lycoming	160,456	$53,381,000
McKean	41,466	$5,185,000
Mercer	171,860	$60,655,000
Mifflin	94,133	$86,818,000
Monroe	29,165	$7,819,000
Montgomery	41,908	$30,028,000
Montour	50,252	$36,193,000
Northampton	68,252	$31,762,000
Northumberland	147,660	$110,978,000
Perry	144,375	$105,052,000
Philadelphia	262	$487,000
Pike	27,569	$2,524,000
Potter	88,457	$31,377,000
Schuylkill	118,501	$124,752,000
Snyder	100,179	$109,041,000
Somerset	206,651	$83,152,000
Sullivan	27,821	$7,240,000
Susquehanna	158,218	$49,287,000
Tioga	184,108	$53,828,000
Union	63,795	$90,497,000
Venango	64,796	$11,796,000
Warren	99,582	$18,603,000
Washington	211,053	$28,649,000
Wayne	92,939	$29,428,000
Westmoreland	167,489	$58,437,000
Wyoming	77,957	$13,496,000
York	292,507	$212,634,000
TOTAL	***7,809,244***	***$5,808,803,000***

4.3.6.9. State Facility Loss Estimation

The vulnerable state critical facilities identified in Section 4.3.6.7 are agriculture-related facilities, all but three of which are privately held entities for which replacement values are unavailable. The three publicly held agriculture facilities are offices and laboratory space of the Department of Agriculture which are unlikely to face serious impacts from hailstorms.

4.3.7. Hurricane, Tropical Storm, Nor'easter

4.3.7.1. Location and Extent

Pennsylvania does not have any open-ocean coastline. However, the impacts of coastal storm systems such as hurricanes, tropical storms, and nor'easters can extend well inland. Tropical storm systems (i.e. hurricanes, tropical storms, tropical depressions) impacting Pennsylvania develop in tropical or sub-tropical waters of the Atlantic Ocean, Gulf of Mexico, or Caribbean Sea. Nor'easters are extra-tropical storms which typically develop from low-pressure centers off the Atlantic Coast north of North Carolina during the winter months. Extra-tropical is a term used to describe a hurricane or tropical storm that's cyclone has lost its 'tropical' characteristics. While an extra-tropical storm donates a change in weather pattern and how the storm is gathering energy, it may still have winds that are tropical storm or hurricane force.

In some cases, the center of circulation for these storm systems where wind and precipitation effects are often most intense can track inland and move directly through Pennsylvania. However, due to the size of these storms, the Commonwealth is more often affected when circulation centers pass at a distance of several hundred miles. In either case, these coastal storms are regional events that can impact very large areas hundreds to thousands of miles across over the life of the storm. In general, coastal storm systems affect communities in the eastern portion of Pennsylvania more often than western communities. However, these storms have the potential to impact all communities across Commonwealth.

4.3.7.2. Range of Magnitude

Intense precipitation and wind resulting in flood and wind damage (see Sections 4.3.5 and 4.3.14 respectively) are the most common impacts associated with coastal storm systems in Pennsylvania. Nor'easters develop as extra-tropical cyclonic weather systems over the Atlantic Ocean and are capable of producing winds equivalent to hurricane or tropical storm force; precipitation from these storms may also come in the form of heavy snow or ice (see Section 4.3.16).

Tropical cyclones with maximum sustained winds of less than 39 miles per hour (mph) are called *tropical depressions*. A *tropical storm* is a cyclone with maximum sustained winds between 39-74 mph. These storms sometimes develop into *hurricanes* with wind speeds in excess of 74 mph. The impacts associated with hurricanes and tropical storms are primarily wind damage and flooding. It is not uncommon for tornadoes to develop during these events. Historically, tropical cyclone events have brought intense rainfall to Pennsylvania, sometimes leading to damaging floods, northeast winds, which, combined with waterlogged soils, caused trees and utility poles to fall.

The impact tropical storm or hurricane events have on an area is typically measured in terms of wind speed. Expected damage from hurricane force winds is measured using the Saffir-