Inorganic Fertilizer Data: Insights and Best Practices

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Presented to the Chesapeake Bay Program,

Fertilizer Expert Group

Agenda

- Data Processing Procedures
- New Understanding of Data Characteristics
- Discussion/Next Steps

Background

- Chemical fertilizer* in the Chesapeake Bay Watershed is a large source of nutrients that leads to low dissolved oxygen and increased chlorophyll α.

  **Inorganic fertilizer available for application to crops*

- Modeling chemical fertilizer application rates is important for management decisions.

- Jurisdictions are concerned with the accuracy of chemical fertilizer data used in modeling efforts.

Chesapeake Bay Program

Nutrient Application and Crop Nutrients

Loads are affected by multiple factors

Typical application rate, "crop need"	Amount of manure available	Fertilizer sales data	NASS yields	Acres of cropland	BMPs

The typical application rate is the amount of nutrients a crop is estimated to require to produce a typical crop yield.

Nutrient Management Core BMP reduces the typical application rate

Application Rate Calculation

Application rate is referenced in terms of **ratio applied**, the ratio of an estimate of the *amount of nitrogen and phosphorus available to be applied* with the amount that *should be applied in typical situations*. Sometimes, ratio applied is greater than 100%, indicating that more nitrogen and phosphorus are available than is necessary to achieve a crop yield in that typical situation.

- The amount of nitrogen available is derived from animal counts (manure sources) and fertilizer sales (inorganic sources).
- Example:
  - The amount of nitrogen available is 150 lbs
  - The typical amount needed is 100 lbs
  - The ratio applied is 150/100 or 150%
- Crop yield may be measured in bushels, tons, bales, etc. depending on the crop.
- Typical rate = TN lbs / crop yield / acre
  - *Data provided by states, typically drawn from land grant university recommendations + an increase for non-nutrient management amounts*
- Actual rate = Typical rate * (NASS yield / acre)
- Actual rate = (TN lbs / crop yield / acre) * (NASS yield / acre)
- Timing and specification of organic or inorganic are also factors

Table 34. **Specified Crops Harvested - Yield per Acre Irrigated and Nonirrigated: 2017**

[Totals may not add due to rounding. For meaning of abbreviations and symbols, see introductory text.]

Crop	Entire crop irrigated			Part of crop irrigated				None of crop irrigated		
	Farms	Acres	Average yield per acre	Farms	Acres irrigated	Acres not irrigated	Average yield per acre	Farms	Acres	Average yield per acre
Barley for grain (bushels)	2,638	602,296	110.6	463	131,049	125,695	75.2	8,087	1,347,768	56.2
Corn for grain (bushels)	14,786	4,995,223	193.0	20,560	7,372,651	7,811,690	175.3	269,455	64,558,998	(X)
Corn for silage or greenchop (tons)	6,360	1,356,605	25.6	1,248	204,704	219,902	20.6	51,892	4,328,203	17.8
Cotton, all (bales)	3,442	1,932,082	2.3	4,283	2,194,642	2,687,493	1.7	8,424	4,587,748	1.7
Upland cotton (bales)	3,139	1,680,384	2.3	4,279	2,193,806	2,683,888	1.7	8,428	4,591,353	1.7
Pima cotton (bales)	453	252,534	2.7	-	-	-	-	-	-	-
Dry edible beans, excluding chickpeas and limas (cwt) (see text)	1,964	351,228	25.0	251	74,800	57,505	21.7	3,193	986,603	19.2
Oats for grain (bushels)	496	31,902	77.2	117	10,205	7,587	66.2	19,229	764,446	61.2
Peanuts for nuts (pounds)	1,287	352,543	4,147.5	1,405	320,314	303,150	4,116.2	3,687	810,760	3,806.9
Rice (cwt)	4,637	2,395,054	73.6	-	-	-	-	-	-	-
Sorghum for grain (bushels)	753	145,916	86.5	939	164,488	448,964	76.4	13,647	4,310,791	68.5
Soybeans for beans (bushels)	8,328	3,624,435	56.3	16,574	5,730,230	6,038,683	52.3	278,289	74,756,132	47.3
Sugarbeets for sugar (tons)	1,259	372,174	35.5	52	9,061	25,568	28.5	2,185	743,879	28.6
Sugarcane for sugar (tons)	197	(D)	40.7	7	(D)	(D)	(D)	423	(D)	(D)
Tobacco (pounds)	419	22,836	2,393.7	407	20,806	28,438	2,238.0	5,411	259,473	2,121.9
Wheat for grain, all (bushels)	5,218	1,335,074	88.2	4,183	1,054,111	2,414,501	52.4	95,391	34,007,934	43.8
Winter wheat for grain (bushels)	3,583	831,920	84.1	3,611	859,851	2,011,146	52.1	79,402	22,483,500	47.4
Durum wheat for grain (bushels)	509	168,066	93.3	49	14,704	25,067	49.0	2,535	1,998,332	22.8
Other spring wheat for grain (bushels)	1,735	394,255	94.2	486	120,389	195,134	52.1	17,855	9,709,255	39.9
Forage - land used for all hay and haylage, grass silage, and greenchop (tons, dry equivalent) (see text)	71,795	8,880,567	(X)	12,687	1,348,771	1,903,734	(X)	715,145	44,725,550	(X)
Alfalfa hay (tons, dry)	47,971	5,595,393	4.6	5,368	572,095	645,290	3.0	205,477	11,057,171	2.3
Other dry hay (tons, dry) (see text)	28,511	2,828,924	2.5	4,921	322,019	558,958	2.2	495,537	28,886,607	1.9
Haylage or greenchop from alfalfa or alfalfa mixtures (tons, green)	3,150	419,231	6.6	613	50,637	88,714	8.2	34,760	2,714,908	7.0
All other haylage, grass silage, and greenchop (tons, green)	6,721	631,076	9.9	936	60,254	78,846	8.2	78,607	3,472,054	4.0
Land in vegetables (see text)	28,458	2,574,006	(X)	8,139	375,959	222,185	(X)	37,679	793,471	(X)
Land in orchards (see text)	61,964	4,772,593	(X)	2,436	152,240	116,766	(X)	47,555	624,001	(X)
Land in berries (see text)	15,191	202,881	(X)	795	32,449	15,305	(X)	17,933	51,563	(X)

These data are available for each county

Application Rate Calculation (cont.)

- **Beyond 2016**

  Based on animal numbers and fertilizer sales, the *amount applied* in 2016 is used.

  If the amount applied in 2016 was 150% of ratio applied, then 150% will be applied in 2017 and later years.

  The same ratio is used even though the pounds vary with yields.

- **2016 and Prior**

  The ratio applied is calculated based on manure, AAPFCO fertilizer sales data, and NASS yields *for the progress scenario, for that year.*

  Yields from NASS are generally only available for 11 crop types. *CAST includes 101 crop and pasture types.*

- Timing and specification of organic or inorganic are also factors

USDA NASS Corn for Grain Yields (2010-2021)

https://quickstats.nass.usda.gov/results/22518199-8A05-3923-9006-7BC375910F78

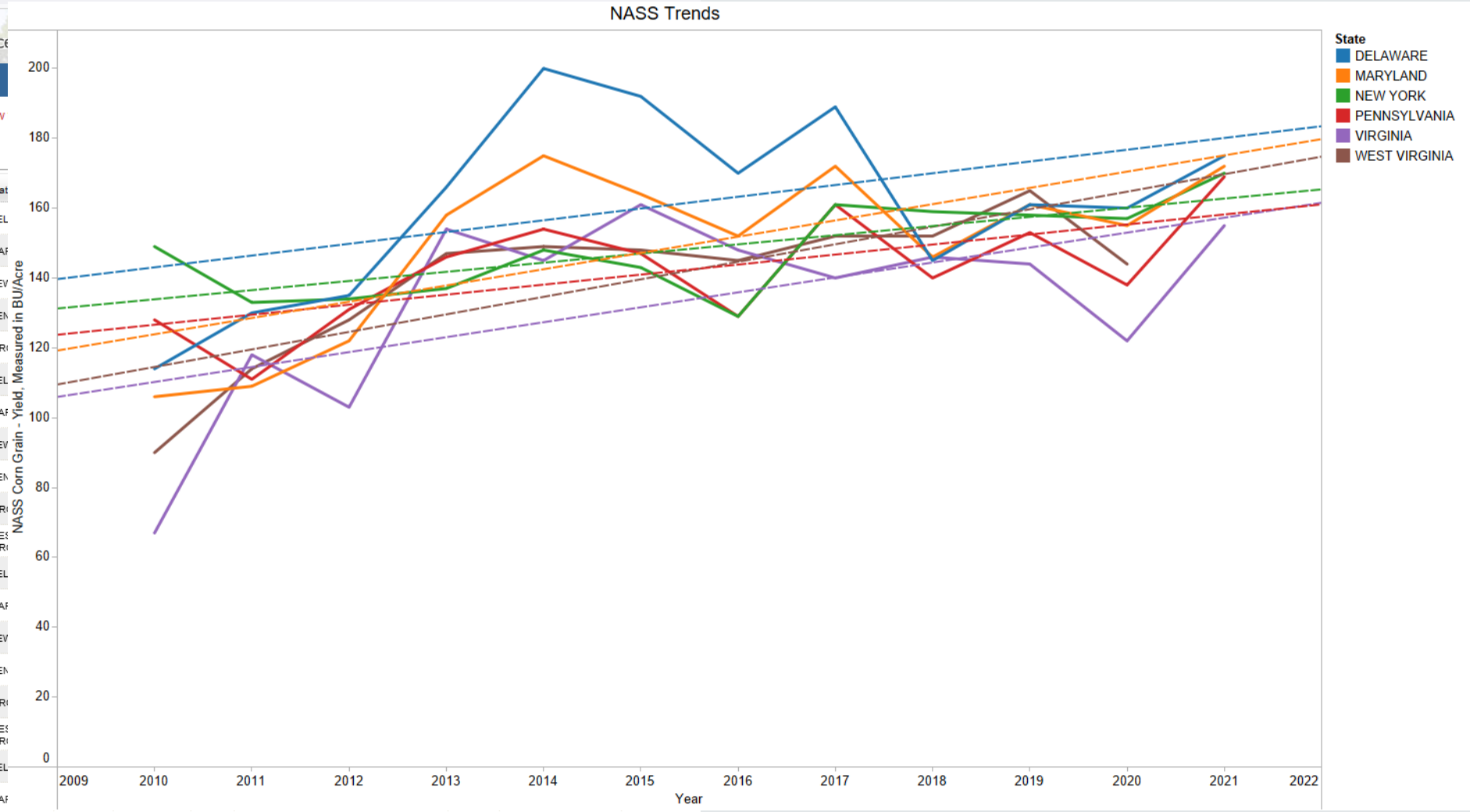
USDA United States Department of Agriculture
National Agricultural Statistics Service

Quick Stats

Double click any cell below

Navigation History: Data

Program	Year	Period	Geo Level	Stat							
SURVEY	2021	YEAR	STATE	DEL							
SURVEY	2021	YEAR	STATE	MAR							
SURVEY	2021	YEAR	STATE	NEV							
SURVEY	2021	YEAR	STATE	PEN							
SURVEY	2021	YEAR	STATE	VIR							
SURVEY	2020	YEAR	STATE	DEL							
SURVEY	2020	YEAR	STATE	MAR							
SURVEY	2020	YEAR	STATE	NEV							
SURVEY	2020	YEAR	STATE	PEN							
SURVEY	2020	YEAR	STATE	VIR							
SURVEY	2020	YEAR	STATE	WES VIR							
SURVEY	2019	YEAR	STATE	DEL							
SURVEY	2019	YEAR	STATE	MAR							
SURVEY	2019	YEAR	STATE	NEV							
SURVEY	2019	YEAR	STATE	PEN							
SURVEY	2019	YEAR	STATE	VIR							
SURVEY	2019	YEAR	STATE	WES VIR							
SURVEY	2018	YEAR	STATE	DEL							
SURVEY	2018	YEAR	STATE	MAR							
SURVEY	2018	YEAR	STATE	NEW YORK	36	00000000	CORN	CORN, GRAIN - YIELD, MEASURED IN BU / ACRE	TOTAL	NOT SPECIFIED	159
SURVEY	2018	YEAR	STATE	PENNSYLVAN	42	00000000	CORN	CORN, GRAIN - YIELD, MEASURED IN BU / ACRE	TOTAL	NOT SPECIFIED	140



Current Urban Fertilizer Data Sources

1987 – 2006 and projected to 2012

- NAWQA (AAPFCO)

2013 - Present

- AAPFCO

AAPFCO Data Characteristics

- Fertilizer Use Codes
- Percent TN or TP with “E” in the number
- Outlier and Rolling Average Method
- Negative Values = Product Returns
- Unknown counties (FIPS=999)

Current vs. Updated Data

- **Current Data** are currently used in CAST
- **Updated Data** are newly imported from raw AAPFCO data into a relational database
- Both use the same processing procedures, but with updates based on conversations with AAPFCO and states

AAPFCO Fertilizer Use Codes

CURRENT DATA

- 1 = farm
- 2 = nonfarm
- 0,3-9,NA = unknown

  TN lbs Unknown: 1,509,902,256

  P2O5 lbs Unknown: 1,103,940,094

UPDATED DATA

- 0-1= farm
- 2-9, NA = nonfarm

AAPFCO Fertilizer Use Codes
Current Data vs. Updated Data

UNKNOWNS THAT SHOULD BE ATTRIBUTED TO **FARM** BASED ON AAPFCO'S INFORMATION

Year	TN lbs	P2O5 Lbs
1985	709,118,175	519,042,184
1986	425,875,037	304,765,500
1987	319,290,380	242,780,316
1988	21,456,613	15,737,894
1989	20,621,999	15,111,989
1990	1,108	1,108
1992	17,123	28,895
2002	2,550	2,550
2003	253,426	264

Year	TN lbs	P2O5 Lbs
2004	955,392	999
2006	180	-
2007	250	125
2010	336	-
2013	2	6
2014	5	2
2015	3,800	-
2016	101	34
Total	**1,497,596,477**	**1,097,471,866**

AAPFCO Fertilizer Use Codes
Current Data vs. Updated Data

UNKNOWNS THAT SHOULD BE ATTRIBUTED TO **NONFARM** BASED ON AAPFCO'S INFORMATION

Year	TN lbs	P2O5 Lbs
1987	3,557,239	2,634,080
1988	1,546,186	1,049,947
1992	15,233	28,190
2000	242,500	51,340
2004	1,152	2,144
2008	273	-
2014	160	880
2015	1,574,902	551,123
2016	5,368,134	2,150,524
Total	**12,305,779**	**6,468,228**

‘E’ in Percent Values

CURRENT DATA

- ‘E’ creates a stop in a string of numeric values
- Ex. If the value is 2E4, then it is 2

UPDATED DATA

- Values containing ‘E’ should be treated as 0

‘E’ in Percent Values
Current Data vs. Updated Data

String Input	Year	State	FIPS	Tons	Updated TN Conc	Current TN Conc	Additional TN lbs in Current Data
09 MD99906000000400097.25E3000000	2009	MD	24999	4	0	5	40,000
09 PA033120000001000066124E3000000	2009	PA	42033	1	0	4	8,000
09 PA133120000029000066124E3000000	2009	PA	42133	29	0	4	232,000
12 MD021120000001000000212E3040014	2012	MD	24021	1	0	2	4,000
12 WV037120000025000006312E3000000	2012	WV	54037	25	0	2	100,000
14 PA071060000001800351112E3000000	2014	PA	42071	1.8	0	2	7,200
15 PA071060000001800351112E3000000	2015	PA	42071	1.8	0	2	7,200
14 PA039060000012000002103121E3049	2014	PA	42039	12	0	1	24,000
15 PA039060000012000002103121E3049	2015	PA	42039	12	0	1	24,000
16 MD013060000001000000110452E3032	2016	MD	24013	1	0	2	4,000

Outliers

- Farm fertilizer outliers are calculated by state (whole state, not just the counties that have some portion in the watershed), year, and nutrient – with all fertilizer uses combined
- The partnership defines outliers as 2 standard deviations from the median
- For years defined as outliers, replace the value with an average of the post and prior years' values
- Current data have unknowns and updated data have no unknowns
- Ex. If 1985 is an outlier, the value for 1986 is used. If there are two years in a row where there are outliers, then the first year is the same as the prior year, and the subsequent year is computed as an average of the new prior year (really two years ago) and the subsequent year. So, if 1991 and 1992 are outliers, then 1991=1990 and 1992=avg(1991, 1993)

TN Outliers Current Data vs. Updated Data

Bolded are years where Current has no data, but there are data in the original AAPFCO files.

TN Current		Both	TN Updated	
Year	**State**		**Year**	**State**
1992	VA	✓	1992	VA
1994	NY	✓	1994	NY
1997	DE			
1997	MD			
1997	NY			
1997	PA			
1997	VA			
1997	WV			
1999	VA	✓	1999	VA
2000	MD	✓	2000	MD
2005	WV	✓	2005	WV
2006	WV	✓	2006	WV
2014	PA	✓	2014	PA
2015	DE	✓	2015	DE
2015	PA	✓	2015	PA
Total	**15**		**Total**	**9**

P2O5 Outliers Current Data vs. Updated Data

Bolded are years where Current has no data, but there are data in the original AAPFCO files.

P2O5 Current		Both	P2O5 Updated	
Year	**State**		**Year**	**State**
1985	NY	✓	1985	NY
1990	DE			
1990	MD			
1991	WV	✓	1991	WV
1992	WV	✓	1992	WV
1993	PA			
1994	NY	✓	1994	NY
1997	DE			
1997	MD			
1997	NY			
1997	PA			
1997	VA			
1997	WV			
Total	**13**		**Total**	**4**

Rolling Average

- Rolling average is calculated after outliers are removed on the percent TN or percent P2O5
- 1993 is chosen as the starting point for rolling averages. That value is used for all prior years
- Calculate the ratio of farm TN to total TN using the fraction of TN in the total tons of fertilizer. Same for P2O5.

  Formulas:

  Current: (Farm TN+Unknown TN)/(farm+nonfarm+unknownTN lbs) and
  (Farm P2O5+Unknown P2O5)/(farm+nonfarm+unknown P2O5 lbs)

  Updated: does not have any unknowns
- Calculate the rolling average on these fractions. Ex. For a 1995 ratio, average fractions from 1993, 1994, and 1995
- Then, multiply the rolled average ratio results by the TN to get a smoothed Farm TN and Farm P2O5 pounds

TN Rolling Average
Current Data vs. Updated Data

Year	Current TN Farm Fraction	Updated TN Farm Fraction	Difference
1985-1993 (all years use same values)	0.88210398	0.8715	0.0106
1994	0.892997004	0.8673	0.0257
1995	0.870539528	0.8554	0.0151
1996	0.873475272	0.8584	0.0151
1997	0.843390935	0.8467	-0.0033
1998	0.855800838	0.8550	0.0008
1999	0.87948313	0.8615	0.0180
2000	0.89892191	0.8587	0.0402
2001	0.876311503	0.8361	0.0402
2002	0.860616463	0.8297	0.0309
2003	0.812925828	0.8131	-0.0001

Year	Current TN Farm Fraction	Updated TN Farm Fraction	Difference
2004	0.793895503	0.7944	-0.0005
2005	0.779151751	0.7642	0.0150
2006	0.772102363	0.7534	0.0187
2007	0.749362561	0.7303	0.0191
2008	0.732210297	0.7287	0.0035
2009	0.754574778	0.7547	-0.0001
2010	0.82458612	0.8247	-0.0001
2011	0.864019052	0.8641	-0.0001
2014	0.872324729	0.8413	0.0310
2015	0.916764072	0.8464	0.0703
2016	0.919128996	0.8468	0.0723

TN Rolling Average
Current Data vs. Updated Data

Year	Current TN Farm lbs	Updated TN Farm lbs	Difference
1985	625,515,964	618,023,610	7,492,354
1986	531,707,153	525,338,430	6,368,724
1987	556,596,907	553,030,327	3,566,580
1988	544,373,903	539,201,018	5,172,885
1989	540,726,174	534,249,422	6,476,753
1990	607,094,000	471,992,535	135,101,466
1991	614,453,228	607,093,382	7,359,846
1992	678,116,570	670,007,448	8,109,122
1993	687,920,549	679,680,721	8,239,829
1994	695,467,765	675,464,369	20,003,396
1995	681,616,680	669,778,701	11,837,980
1996	648,773,209	637,543,510	11,229,700
1997	636,919,424	643,852,628	-6,933,204
1998	656,936,953	656,320,624	616,329
1999	710,770,016	696,215,012	14,555,005
2000	694,397,157	663,312,685	31,084,473
2001	633,797,553	604,693,761	29,103,792
2002	694,445,284	669,490,576	24,954,709
2003	502,196,245	502,281,371	-85,126
2004	619,383,841	619,809,812	-425,971
2005	560,682,289	549,890,067	10,792,223
2006	548,003,369	534,752,812	13,250,557
2007	564,899,780	550,518,552	14,381,228
2008	506,248,883	503,804,829	2,444,055
2009	483,678,190	483,545,443	132,747
2010	546,155,128	546,236,352	-81,223
2011	589,014,829	589,098,428	-83,599
2012	603,579,943	603,484,680	95,264
2013	643,379,035	643,373,330	5,705
2014	662,375,461	638,804,893	23,570,568
2015	673,949,609	623,807,022	50,142,587
2016	699,274,507	648,790,977	50,483,530
Total	**19,642,449,613**	**19,153,487,329**	**488,962,284**

P2O5 Rolling Average
Current Data vs. Updated Data

Year	Current P2O5 Farm Fraction	Updated P2O5 Farm Fraction	Difference
1985-1993 (all years use same values)	0.9151	0.8864	0.0287
1994	0.9307	0.8926	0.0382
1995	0.9125	0.8822	0.0303
1996	0.092	0.9037	0.0163
1997	0.8927	0.9004	-0.0077
1998	0.9096	0.9117	-0.002
1999	0.9106	0.9123	-0.0017
2015	0.8688	0.8681	0.0006
2016	0.8728	0.8698	0.003

P2O5 Rolling Average
Current Data vs. Updated Data

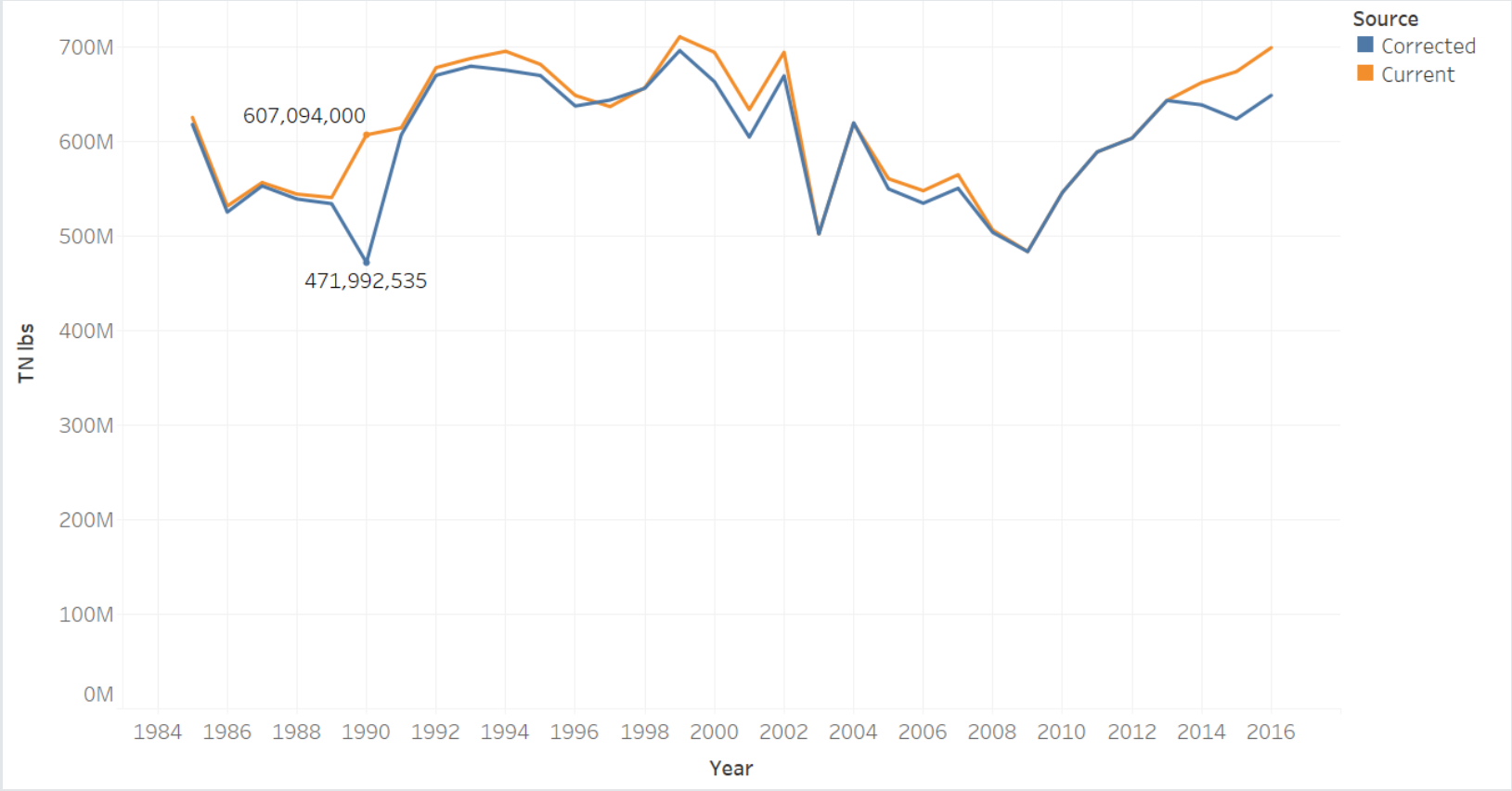
Year	Current P2O5 Farm lbs	Updated P2O5 Farm lbs	Difference
1985	452,094,657	437,900,908	14,193,749
1986	399,052,773	386,524,301	12,528,471
1987	417,148,760	406,387,008	10,761,752
1988	414,465,424	402,383,739	12,081,685
1989	388,264,697	376,074,923	12,189,774
1990	425,744,817	347,203,349	78,541,468
1991	426,017,022	412,641,994	13,375,028
1992	479,132,307	464,114,685	15,017,623
1993	449,898,973	457,427,312	-7,528,338
1994	462,661,599	443,687,704	18,973,895
1995	439,188,020	424,627,614	14,560,406
1996	391,664,228	384,711,572	6,952,656
1997	381,000,078	400,702,162	-19,702,084
1998	389,187,952	390,064,502	-876,550
1999	375,353,468	376,064,736	-711,269
2002	344,309,432	344,310,282	-850
2003	240,935,823	240,936,517	-693
2004	267,910,443	267,911,553	-1,110
2005	226,902,102	226,902,473	-371
2006	229,374,744	229,375,033	-289
2007	218,779,687	218,779,728	-42
2008	195,802,016	195,802,054	-38
2009	149,737,211	149,737,239	-28
2013	220,276,265	220,276,267	-2
2014	226,796,959	226,776,044	20,915
2015	225,328,734	225,618,962	-290,228
2016	224,702,456	225,791,210	-1,088,753
Total (all years)	**10,404,907,192**	**10,225,910,412**	**178,996,780**

Rolling Average Take-Away:

There is not a large difference between the current and updated data

Total Nitrogen Compared: *Current* Processed AAPFCO and *Updated* Processed AAPFCO Fertilizer Data

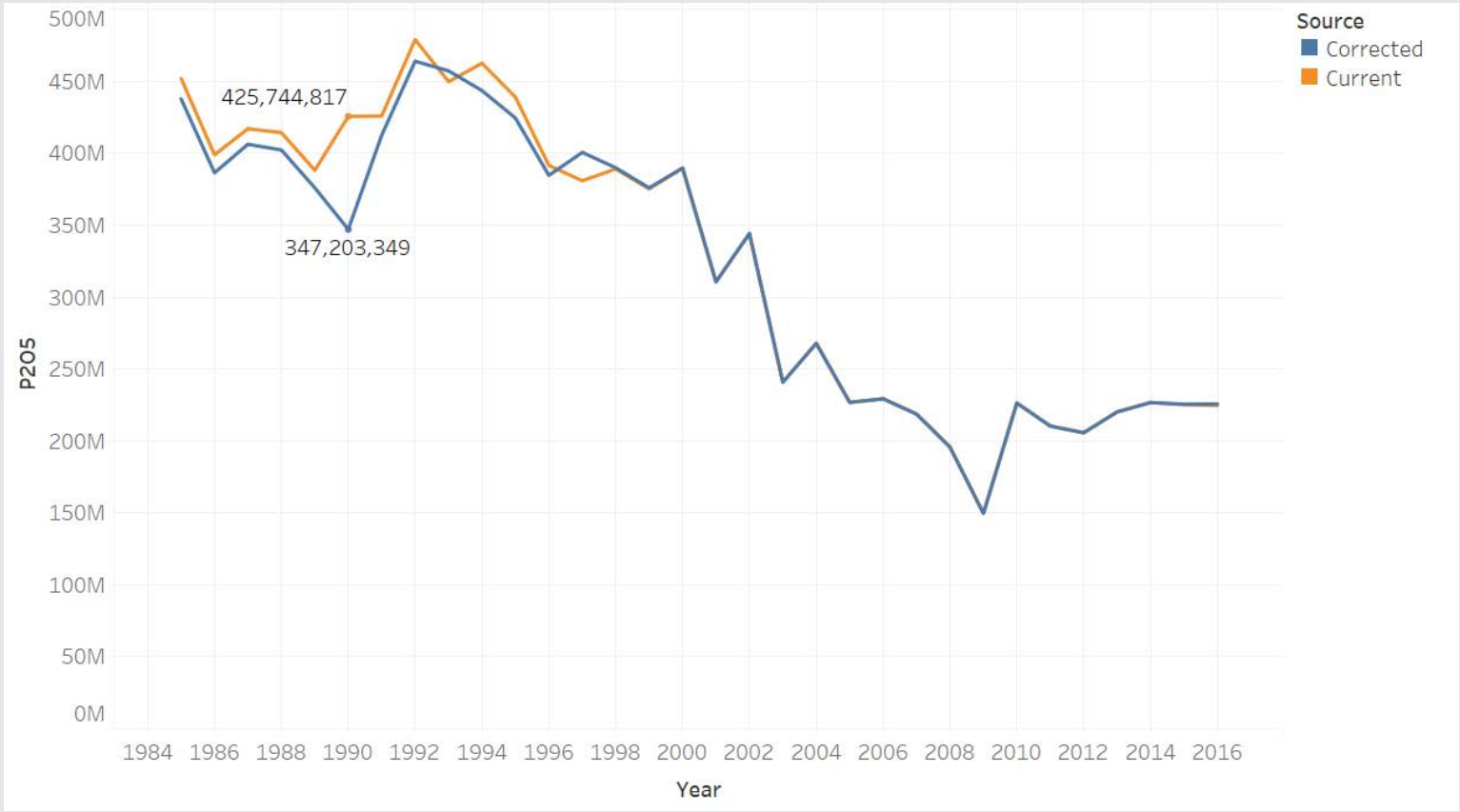
- Entire state area
- Agriculture only
- Outliers removed and rolling average applied
- Prior to using NASS fertilizer expenditure to apportion to CBWS

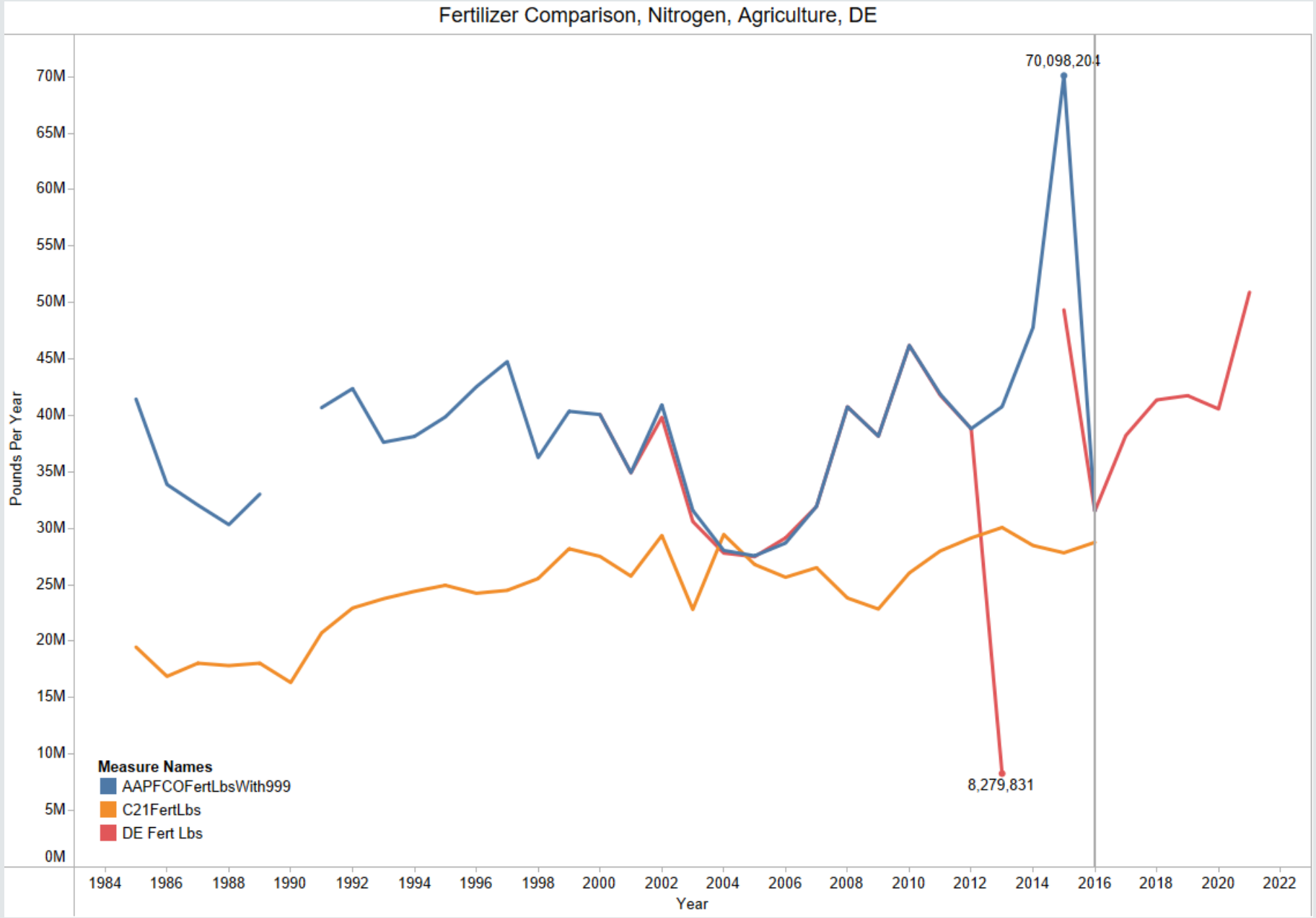


P2O5 Compared: Current Processed AAPFCO and Updated Processed AAPFCO Fertilizer Data

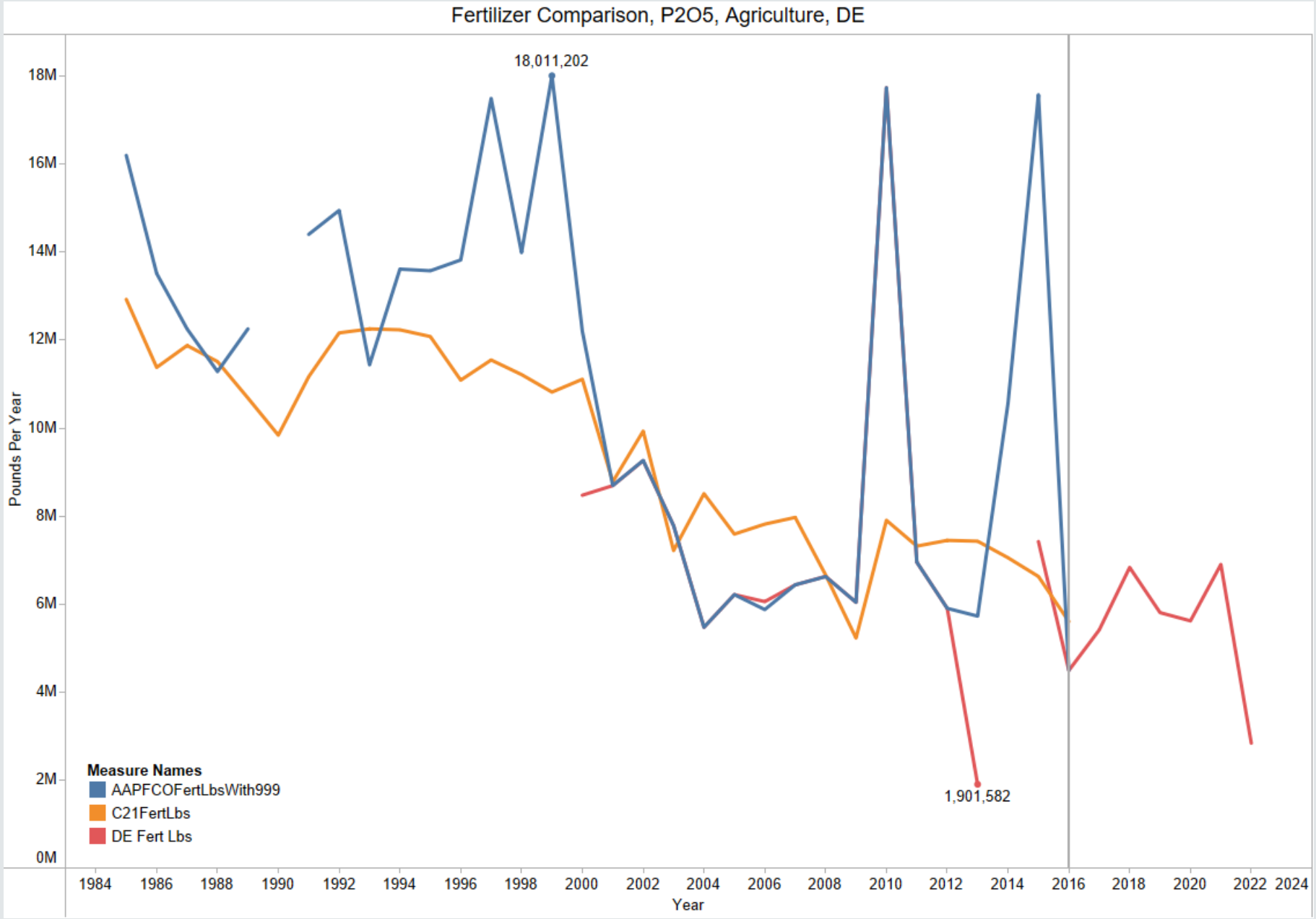
- Entire state area
- Agriculture only
- Outliers removed and rolling average applied
- Prior to using NASS fertilizer expenditure to apportion to CBWS

Both versions are very closely aligned after 1998, and the lines overlap on this graph





- DE data are missing half of 2013 and all of 2014
- It appears some TN reported for 2015 should have been 2016
- CAST data are for the CAST-2021 version with updated fertilizer data and the BMP history from 2021 and prior
- Only includes counties intersecting the CBWS, which is not how the AAPFCO data are used. Instead, data are used watershed-wide



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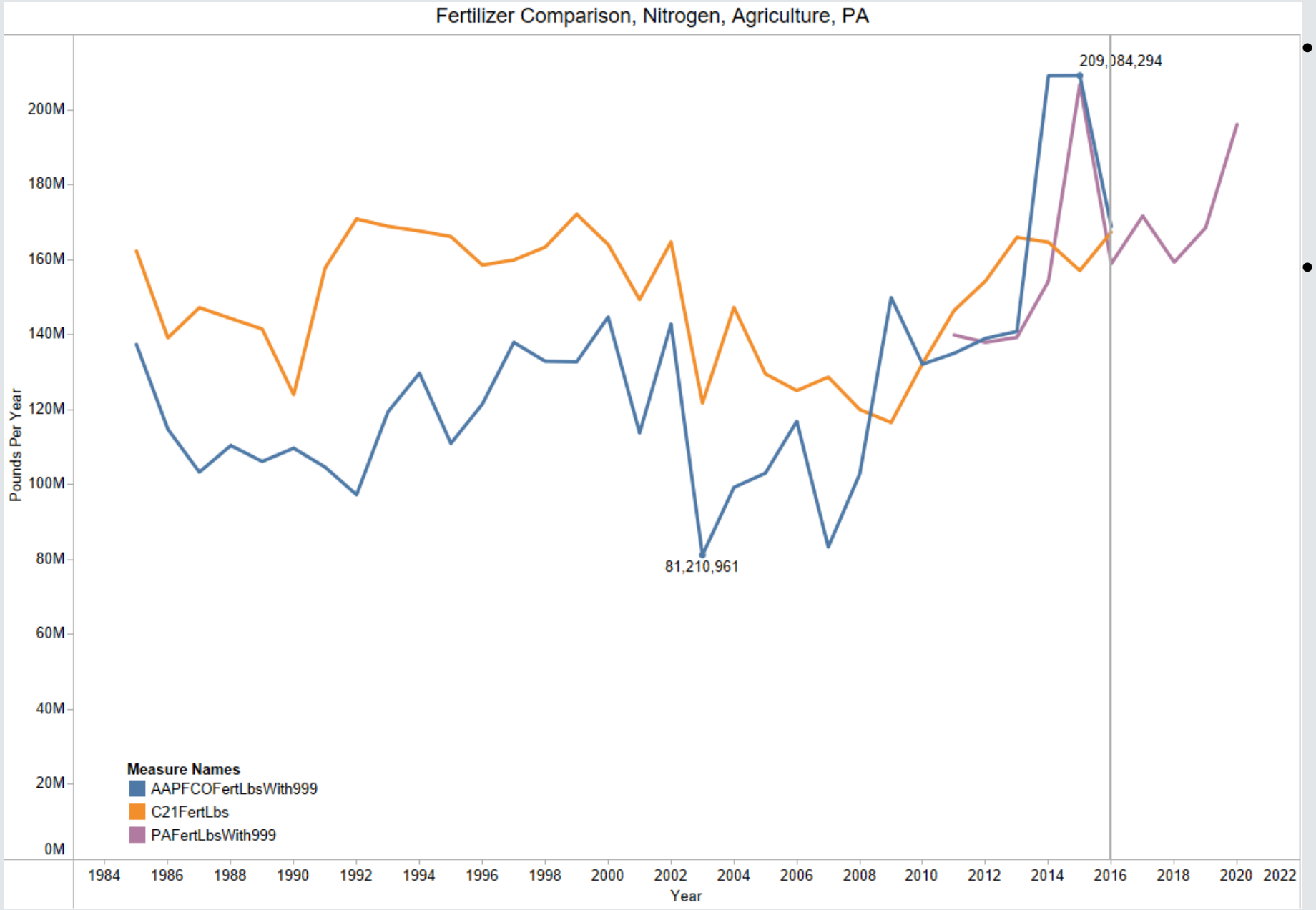

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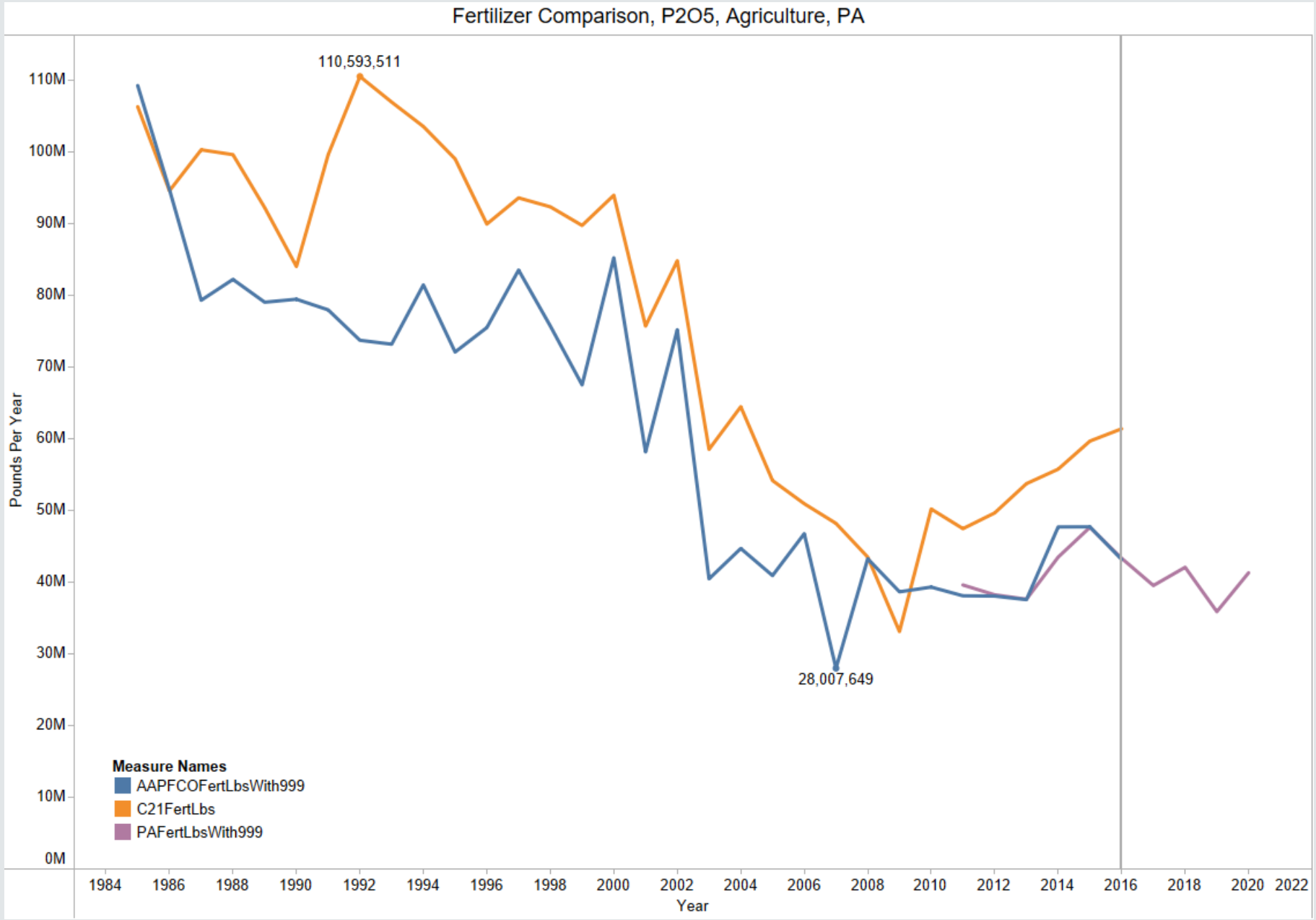

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PA Fertilizer vs. AAPFCO

- Percent difference is showing the percent change between data PA reported to AAPFCO and AAPFCO data
- Mr. David Dressler (PA Dept. of Ag) provided PA's reported data
- Mr. Joe Slater of AAPFCO learned in our recent meeting that AAPFCO aggregates the data from what the states provide. He was not aware of some of the processing steps that happen in his shop
- Mr. Joe Slater is working from spreadsheets and importing/exporting data from SAS for various processing steps. This can introduce data conversion errors
- Data comparisons were similar for most years
- There is no bias, meaning some years AAPFCO showed more TN or P2O5, other years there was less

Year	N Diff	P2O5 Diff	N Pct Diff	P2O5 Pct Diff
2011	-10,965,131	-3,401,132	-6%	-6%
2012	1,055,584	-305,937	1%	-1%
2013	3,477,762	-300,228	2%	0%
2014	58,687,481	5,979,378	20%	8%
2015	11,151,180	967,295	4%	1%
2016	12,899,123	-947,847	5%	-1%

2014 PA Fertilizer vs. AAPFCO

- 2014 TN stood out as substantially different
- Two counties accounted for most of the difference between PA and AAPFCO data
- Lebanon County (in the CBWS) is lower in the PA data
- Bucks County (not in CBWS) is higher in the PA data

Year=2014	PA	AAPFCO	Diff	Pct Diff
Tons	742,792	816,424	73,631	9%
State TN lbs	11,799,471	14,733,591	2,934,120	20%
Lebanon County TN lbs	156,812	1,292,100	1,135,288	88%
Bucks County TN lbs	775,421	292,623	-482,797	-165%

Summary

- **Unknown Uses**: There are no unknown uses

  Years after 1990 have fewer records of TN and P2O5 farm fertilizer marked as unknown in the current data

- **Letter E**: Fertilizer records (tons) that include the letter "E" are zero. Impact on TN and P2O5 is not substantial
- **Outliers**: 1997 was imported in a way that made the entire year's dataset unusable. Correctly importing removes this year as outliers. Other outliers are reduced because of updated processing.
- **Rolling Average**: The methodology assumes that there are unknown uses. Continuing with that methodology, between 0.01 to 4% of fertilizer should be attributed to farms, in most years
- **Comparison of Current vs. Updated**: Difference exist but are not substantial except in 2016 for TN
- **Comparison of State Data to AAPFCO**:

  State data are more current

  Differences are not biased as more or less in one source compared to the other

  PA data appear more accurate

  DE data are incomplete and the dates are not consistent with AAPFCO's data

- **Bottom Line**: The current method overestimated TN and P2O5 due to data processing errors, which were a result of "black box" nature of the AAPFCO data. State data are more reliable and more up to date

Addressing Outliers

- What concerns are there about the data? Why do we think there are outliers?
- Possible concerns:

  Fertilizer may not be used in the same year as it is purchased.

  Fertilizer may be moved around geographically. For example, fertilizer may be less expensive in DE because there is no sales tax. However, the distance moved is not likely to be NY to VA, something more constrained.
- For those concerns, smoothing across years and by a distance feature is suggested, not outlier removal.

For Consideration

- Phase 6 Model

  Use state fertilizer sales data

- Phase 7 Model

  Remove timing since annual average load model and TMDL

  Reevaluate outlier removal and smoothing objectives and method

  Reevaluate lumping to Chesapeake Bay watershed or other scale

More to come

- Urban fertilizer data can be presented at a future meeting