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Revisions to Rainfall Intensity Algorithms in PRZM5.0 to Improve Estimates of Off-Field Runoff, Eroded Sediment and Pesticide Mass

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REVISIONS TO RAINFALL INTENSITY ALGORITHMS IN PRZM5.0 TO IMPROVE ESTIMATES OF OFF-FIELD RUNOFF, ERODED SEDIMENT AND PESTICIDE MASS

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ABSTRACT

The Environmental Protection Agency (EPA) model Pesticide Root Zone Model, version 5.0 (PRZM5.0) is used to estimate off-field loadings of pesticide concentrations in runoff and eroded sediment. Climate change has resulted in an increase in rainfall intensity patterns for much of the United States. This change impacts off-field runoff and eroded sediment as well as off-field pesticide loads from agricultural fields. Thus, the PRZM5.0 EPA "lookup" table for runoff curve numbers and the internal algorithm for eroded sediment estimation have become outdated since both temporal and geographical conditions have changed. This research presents (1) a revised method for estimating runoff curve numbers that better represent current rainfall intensity patterns as well as more geographically representative based on the Natural Resources Conservation Service (NRCS) single event method for estimating runoff curve numbers; (2) a revised PRZM5.0 version with a modified erosion algorithm that includes empirical coefficients from an 2014 NRCS updated storm intensity system and (3) examination of the effect of these PRZM5.0 revisions for six EPA standard environmental crop modelling scenarios and three example pesticides compared to the established EPA practices.

CHAPTER 1 – LITERATURE REVIEW

1.1 Off-Field Movement of Pesticides in the Environment

When pesticides are applied to an agricultural field, a complex set of interactions occur. If a crop exists in the field, foliar-applied pesticides may stick to the leaves where they may be absorbed. Rainfall may wash-off some of the pesticide residues onto to surface soil. Soil-applied pesticides directly interact with the soil surface. Once on the soil surface, pesticides interact with soil moisture and the soil particles through degradation and sorption processes, but with varying impact depending on the chemical properties of the pesticide. But pesticides do not necessarily remain within the confines of the agricultural field and can contaminate nearby surface water bodies (Whitford et al., 2001).

Pesticides don't move by themselves in the environment but rather move as a function of the natural forces, such as water and wind. This is particularly true for water which is the primary factor that affects pesticide movement in the environment. Thus, hydrology and sediment transport are major components in surface water exposure modelling of pesticides. The general rule is that pesticide residues go where the water goes (Jones et al, 1998; EPA, 2009). When pesticides are applied to agricultural fields, they can enter off-target surface water via being dissolved in agricultural field runoff water, sorbed to soil particles in eroded sediment from the field, leached below the field into groundwater with subsequent lateral movement to surface water or off-field drift from pesticide application. Rainfall is the primary driver of runoff, eroded sediment and leaching into groundwater (Jones et al, 1998). A diagram of the hydrologic cycle is display in Figure 1.1.

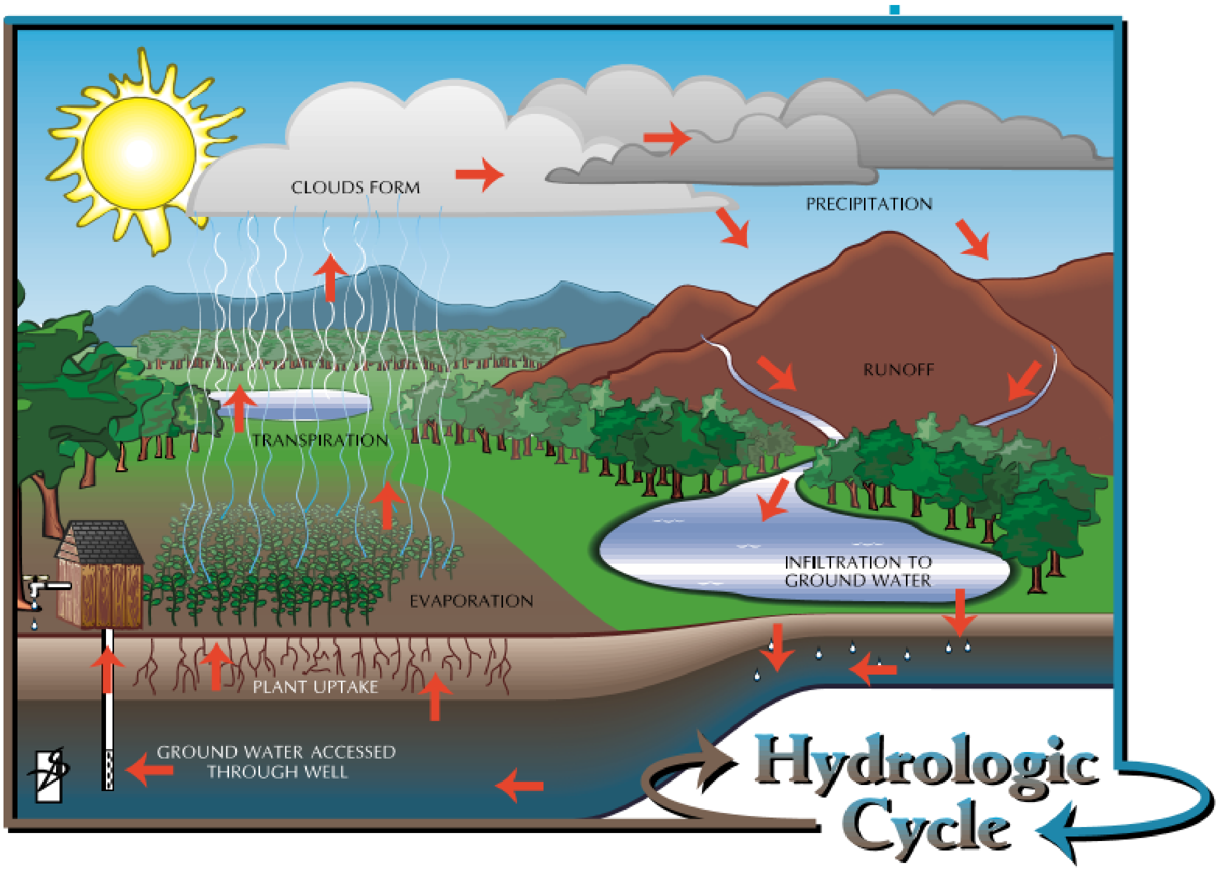

Figure 1. 1 Hydrologic Cycle Diagram (Whitford et al., 2001)

To protect off-target surface water from pesticide contamination, EPA evaluates many kinds of data including laboratory studies, field studies, monitoring studies and computer modelling to assess potential surface water contamination. Computer modelling allows for assessment of multiple geographical locations over long time periods with more diverse weather conditions than are feasible with field or monitoring studies, alone. Computer modelling also allows for simultaneous results from multiple laboratory and field studies (Whitford et al, 2001).

The established practice by EPA is to simulate an agricultural field receiving pesticide applications using the field-scale model, Pesticide Root Zone Model, version 5.0 (PRZM5.0) and then "load" PRZM5.0 predicted off-field estimates of runoff, eroded sediment and pesticide mass

into the surface water scale model, Variable Volume Water Model (VVWM) [an revised model based on the Exposure Analysis Modelling System, version 2.98] to estimate pesticide concentrations in surface water for ecological and drinking water risk assessment (Young, 2016).

1.2 PRZM5.0 Regulatory Modelling of Pesticide Off-Field Movement for Surface Water Risk Assessment

During the early 1990's, the EPA, United States Department of Agriculture, academia and industry agreed upon a standardized tiered approach to conducting surface water modelling for assessing pesticide concentrations in surface water for both U.S. regulatory ecological and drinking surface water risk assessments. This process involved running the EPA field-scale model PRZM3.12.2 to estimate off-field loads of runoff, eroded sediment, and pesticide mass which were then loaded into the EPA water model, EXAMS2.98, to estimate pesticide concentrations in surface water (FIFRA Exposure Modelling Work Group, 1995).

It was decided that EPA would develop a series of geographically-specific PRZM3.12.2 input scenarios that represent a desired crop with conservative assigned associated runoff, soil and weather conditions for that geographical area. Originally, a NOAA SAMSON weather time series from 1947-1976 was assigned to each of these original EPA PRZM3.12.2 "standard environmental crop scenarios" (FIFRA Exposure Modelling Work Group, 1995). Over time, the SAMSON weather series was updated to be the current NOAA SAMSON weather time series of 1961-1990 and the PRZM standard environmental crop scenario set grew to 133 across the U.S. In 2015, EPA updated the PRZM3.12.2 model to PRZM version 5.0 (PRZM5.0) and switched from using EXAMS2.98 to VVWM for surface water modelling (Young, 2016).

For regulatory modelling of off-field movement of eroded sediment and pesticide sorbed to the sediment, the PRZM5.0 employs the Modified Universal Soil Loss for Small Watershed

(MUSS) equation (Singh, 1995, Wischmeier and Smith, 1978) which incorporates a rainfall intensity estimate using the Natural Resources Conservation Service (NRCS) 1986 “IREG” storm intensity distributions.

The equation for MUSS is as follows:

$$X_e = 0.79\,(V_r\,q_p)^{0.65} A^{0.009} K\,LS\,C\,P$$

(eq.1.1)

where:

X_e = the event soil loss (metric tonnes day^{-1})

V_r = volume of daily runoff event (mm)

q_p = peak storm runoff rate (mm/h)

A = field size (ha)

K = soil erodibility factor (dimensionless)

LS = length-slope factor (dimensionless)

C = soil cover factor (dimensionless)

P = conservation practice factor (dimensionless)

(Suarez, 2005)

The parameters A, K, LS, C and P are all non-weather related and are fixed for each EPA PRZM5.0 standard environmental crop scenario. Only the V_r and q_p parameters are dependent on the rainfall and rainfall storm intensity in the equation. Thus, these are the only parameters that change with each daily weather increment when PRZM5.0 is run. V_r is internally calculated by

PRZM5.0 as a function of the daily input of rainfall total minus the internally tracked amount of rainfall infiltrating into the soil profile or trapped by the plants in the field. This amount is then adjusted by the peak storm runoff rate, q_p, (mm/h) which is the rainfall intensity parameter. Thus q_p is the parameter which represents rainfall intensity in the MUSS erosion algorithm in PRZM5.0.

Further, q_p is calculated using the Soil Conservation Service Graphical Peak Discharge Method from 1986 (Suarez, 2005) via the following equation:

$$q_p = a\, q_u\, A\, V_r\, F_p$$

(eq. 1.2)

where:

q_u = unit peak discharge rate

F_p = pond and swamp adjustment factor (preprogrammed to a value of 1.0 in PRZM5.0)

a = units conversion factor

The unit peak discharge rate, q_u is calculated by the empirical equation:

$$\log(q_u) = C_0 + C_1 \log(T_c) + C_2 [T_c]^2$$

(eq.1.3)

Here T_c is time of concentration (hours) and is defined as "time it takes water to flow from the furthest point in the watershed to a point of interest within the watershed, and is a function of basin shape, topography, and surface cover. T_c is calculated by summing the travel times for various designated flow segments within the watershed" (Suarez, 2005). The coefficients C_0, C_1, and C_2 are regional coefficients that are related storm intensity and

precipitation volume assigned per the 1986 “IREG” storm intensity distributions in PRZM5.0 (Suarez, 2005).

Literature review failed to locate anything about the history of these “IREG” storm intensity distributions in PRZM5.0 except that they were developed from historic storm intensity data from National Weather Service duration-frequency data prior to 1986. No literature was found discussing rainfall intensity sensitivity in the MUSS equation or how the “IREG” storm intensity coefficient empirical equation predicted peak discharge rates compare to contemporary measured values across the U.S. Also, no recent literature or studies (i.e., within the last fifteen years) were found comparing PRZM5.0 predicted off-field erosion or pesticide mass to observed data. Most published runoff field studies are over 20 years old and represent runoff conditions with storm intensity less than average conditions observed during the last decade.

NRCS is in the process of developing new storm intensity distributions based on the National Oceanic and Atmospheric Administration Atlas 14 data (“NOAA-14”) to replace the “IREG” storm intensity distributions for the entire U.S. “NOAA-14” divides the U.S. into much smaller storm intensity distribution regions, including subdividing states into multiple regions (NRCS, 2015).

For regulatory modelling of off-field movement of runoff and dissolved pesticides, PRZM5.0 employs the NRCS Curve Number (CN) method (NRCS, 2003) and a process of partitioning user input daily precipitation between soil infiltrated water and surface runoff (Suarez, 2005). It employs a user-supplied runoff curve number (CN) to represent the average antecedent condition, CNII. Then it calculates the associated low (CNI) and high (CNIII) antecedent conditions from the CN tables provided by NRCS (NRCS, 2003). PRZM5.0 then

calculates the average soil moisture in the top 10 cm of soil for each day to determine the adjusted daily predicted runoff curve (CN) value based on this soil moisture (Young and Fry, 2014).

This calculated adjusted daily predicted CN value is then used in the NRCS Curve Number (CN) method to estimate runoff from the daily precipitation using the following formula:

$$Q = \begin{Bmatrix} 0 & , P \leq 0.2S \\ \dfrac{(P - 0.2S)^2}{P + 0.8S} & , P > 0.2S \end{Bmatrix}$$

(eq. 1.4)

Where Q = runoff (cm)

P = Precipitation (cm)

S = potential maximum retention (cm), is related to soil type, crop cover, and management practices

S is calculated from user-supplied runoff curve (CN) value as follows:

$$S = \frac{2540}{CN} - 25.4$$

(eq. 1.5)

(Young and Fry, 2016)

The above Runoff Curve number method was originally developed by the Soil Conservation Service (now NRCS) in the late 1950's as an "inter-agency" tool for the estimation of runoff from rainfall events on small agricultural fields. It was never published or subjected to the peer-review process. The method has been revised over time to account for changes in land use and changes in agricultural management practices. CN values range from

0 – 100 where 0 means no runoff and 100 indicates an extreme runoff event. The CN values listed in the "look-up" tables are based on empirical evaluations of runoff depth as a function of rainfall, land use, management practice and soil hydrologic conditions (Woodward, 1991).

Review of the literature revealed there is no published research addressing whether the current table "look-up" method for identifying runoff curve numbers (CN) combined with 1961-1990 or updated weather time series are adequately representing observed runoff quantities when simulated by the PRZM5.0 EPA standard environmental crop scenarios or other exposure/hydrology models.

1.3 Objectives of this Research

In a FIFRA Scientific Advisory Panel (SAP) Meeting held in Washington, D.C. in Dec. 2010, the issue of climate change and whether the current practice of using 1961-1990 daily rainfall time series data in the PRZM5.0 field-scale model with the EPA set of standard environmental crop scenarios is adequate for forecasting future off-field pesticide mass, runoff and eroded sediment potential was discussed (FIFRA SAP, 2011). Subsequently, EPA proposed updating the daily rainfall time series to better represent current weather time series. However, this will only change how the modelling simulates rainy versus dry day patterns as well as total rainfall amounts within a day without addressing storm intensity climate change issues.

Runoff and erosion quantities are sensitive to storm intensity as well as rainfall depth. Thus, the overall objectives of this research was to (1) identify the internal algorithms in PRZM5.0 that simulate rainfall intensity; (2) evaluate whether these methods represent current methods; (3) when appropriate, develop new methods or enhance PRZM5.0 with updated methods; and (4) compare the PRZM5.0 established storm intensity method predicted off-field

runoff, eroded sediment, and pesticide mass to predicted results from new methods from this research for a select set of PRZM5.0 EPA standard environmental crop scenarios to evaluate new potential methods for use in ecological and drinking water regulatory risk assessment.

The EPA field-scale model, PRZM5.0, is used to estimate off-field loadings of runoff, eroded sediment and pesticide mass. However, PRZM5.0 runs on a daily time step basis with daily total rainfall depth as the only user-supplied input for precipitation (Suarez, 2005).

For erosion, rainfall intensity is internally estimated in PRZM5.0 using the 1986 NRCS/SCS "IREG" rainfall distribution method which divides the U.S. into four geographical regions. The user supplies the "IREG" distribution as input into PRZM5.0. Within PRZM5.0, each "IREG" distribution has a series of "IREG" empirical storm intensity coefficients assigned to it which are then used to estimate the peak storm runoff rate (mm/hr) for the Modified Universal Soil Loss for Small Watershed (MUSS) erosion algorithm (Singh, 1995) (Young and Fry, 2014).

In 2015, the NRCS-SCS issued a draft document with an alternative "IREG" storm intensity distribution system call "NOAA-14". When complete, this system will reassign empirical storm intensity coefficients to the entire U.S. at a sub-state level based on more current rainfall data. Thus, the new storm intensity distributions will not only be more temporally current but also more spatially accurate.

The objective of the erosion component of this research was to examine the effect of updating the "IREG" storm intensity distribution system in the (MUSS) erosion algorithm (Singh, 1995) in PRZM5.0 to reflect more recent storm intensity distributions through software installation of the empirical storm intensity coefficients from the new "NOAA-14" storm intensity distribution system. A series of EPA standard environmental crop scenarios were

simulated using both storm intensity distribution systems for comparisons. Additionally, since the EPA standard environmental crop scenarios are paired with 1961-1990 SAMSON station weather time series input data, it was desirable to create extended weather time series to simulate more current conditions for these same SAMSON weather stations to examine for potential any climate change effects in PRZM5.0 predictions of off-field eroded sediment and pesticide mass.

The objective of the runoff component of this research was to develop an alternative method for identifying runoff curve numbers for input into PRZM5.0. PRZM5.0 currently uses the NRCS Curve Number method to estimate runoff which requires manual user input of runoff curve numbers. For the PRZM5.0 EPA standard environmental crop scenarios, these runoff curve numbers were identified by the common EPA "table look-up" method where runoff curve numbers are identified from a "look-up" table, often the 1984 table from the GLEAMS Users' Manual (Knisel, 1984), based on hydrologic soil group number, land use, and hydrologic drainage condition. This method is neither geographically nor weather condition specific.

The objective of this research was to develop a geographically and weather specific method that statistically estimates runoff curve numbers from current time series of data (with climate change conditions). For the research, comparisons were made with PRZM5.0 predicted off-field runoff from simulations using both runoff curve number estimation methods for six EPA standard environmental crop scenarios. This task was performed to evaluate whether PRZM5.0 predicted runoff from the newly developed runoff curve number estimation method for this research demonstrates improved fit to observed runoff data versus the established EPA table "look-up" method. The new method results were also evaluated to assure that results are sufficiently conservative and do not under-estimate off-field runoff as is required to be

protective in preventing pesticide contamination of surface water for regulatory risk assessment purposes.

The objective of the final phase of this research was to compare PRZM5.0 predicted dissolved and sorbed off-field pesticide mass results from the combined "NOAA-14" revised storm intensity coefficient system used in the erosion algorithm with the revised runoff curve number (CN) method against the EPA established approach of using a table look-up method for identifying runoff curve numbers (CN) combined with "IREG" system of coefficients for the erosion algorithm. To accomplish this, three pesticides were simulated using PRZM5.0, atrazine, propiconazole, and chlorpyrifos. These three pesticides were selected to examine a range of pesticide sorption behavior in off-field runoff and eroded sediment (Estes et al., 2015). Results of this phase of the research may be used to identify which storm intensity distribution system for erosion and which runoff curve number identification method shows the best potential for future use with the PRZM5.0 model and EPA standard environmental crop scenarios for predicting off-field pesticide mass to address climate change concerns.

1.4 References

(1) EPA. (2009). Guidance for Selecting Input Parameters in Modelling the Environmental Fate and Transport of Pesticides, Version 2.1. U. S. Environmental Protection Agency, Office of Pesticide Programs, Environmental Fate and Effects Division, Washington, D.C. October 22, 2009.

(2) Estes, T.L., and P. Hendley. (2000). The Sensitivity of PRZM-EXAMS to Key Assumptions – Implications for Pesticide Aquatic Risk Assessments. Poster: 21st Annual Meeting of the Society of Environmental Toxicology and Chemistry, Nashville, Tennessee, Nov. 12-16, 2000.

(3) FIFRA Exposure Model Working Group. (1995). Primary, Secondary, and Screening Models for Pesticide Registration. Available : www.acpa.erg/public/science-reg/misc/gmp-dot.html.

(4) FIFRA SAP. (2011). Memorandum – Transmittal of Meeting Minutes of the FIFRA Scientific Advisory Panel Meeting Held December 7, 2010 on Pesticide Exposure Modeling and Climate Change. U.S. Environmental Protection Agency, Office of Chemical Safety and Pollution Prevention, Washington, D.C., Mar. 3, 2011.

(5) Jones, R. D., S Abel, W. Effland, R Matzner, and R. Parker. (1998). An Index Reservoir for Use in Assessing Drinking Water Exposure. Chapter IV in Proposed Methods for Basin-Scale Estimation of Pesticide Concentrations in Flowing Water and Reservoirs for Tolerance Reassessment., presented to the FIFRA Science Advisory Panel, July 29, 1998.

(6) Knisel, W.G., F.M. Davis, and R.A. Leonard. (1994) GLEAMS Version 2.0 –Part III: User Manual. USDA-ARS, Coastal Plain Experiment Station. Southeast Watershed Research Laboratory. Tifton, Georgia, 31793.200 pp.

(7) NRCS. (2003). National Engineering Handbook Section 4: Hydrology. Natural Resources Conservation Service, United States Department of Agriculture, Washington DC.

(8) NRCS. (2015). National Engineering Handbook. Part 630 Hydrology. Chapter 4 (DRAFT) Storm Rainfall Depth and Distribution. NRCS 210-NEH, 3/93.

(9) Singh, V.P., editor. (1995). Computer Models of Watershed Hydrology. Water Resources Publications, Highlands Ranch, Colorado, USA.

(10) Suarez, L.A. (2005). PRZM-3, A Model for Predicting Pesticide and Nitrogen Fate in the Crop Root and Unsaturated Soil Zones: User's Manual for Release 3.12.2. US EPA, Office of Research and Development, Athens Georgia.

(11) Whitford, F., J. Wolt, H. Nelson, M. Barrett, S. Brichford, and R. Turco. (2001). Pesticides and Water Quality Principles, Policies, and Programs.
A. Blessing, ed. Purdue Pesticide Programs. Purdue Pesticide Programs,
Purdue University Cooperative Extension Service, West Lafayette, IN 47907,
PPP-35.

(12) Wischmeier, W. H., and D. D. Smith. (1978). Predicting Rainfall Erosion Losses - A Guide to Conservation Planning. Agriculture Handbook 537. U.S. Department of Agriculture, Washington, DC, USA.

(13) Woodward, D.E. (1991). Progress Report ARS/SCS Runoff Curve Number Work Group. ASAE Paper 912607. Chicago IL.

(14) Young, D.F. (2016). Pesticide in Water Calculator User Manual for Versions 1.50 and 1.52. US Environmental Protection Agency, Office of Pesticide Programs, Washington, D.C. USEPA/OPP, revision date: Feb. 25, 2016.

(15) Young, D.F. and M.M. Fry. (2014). PRZM5, A Model for Predicting Pesticide in Runoff, Erosion and Leachate: User Manual. US Environmental Protection Agency, Office of Pesticide Programs, Washington, D.C. USEPA/OPP 734F14002.

CHAPTER 2 - EQUATION COEFFICIENTS IN PREDICTED OFF-FIELD ERODED SOIL MASS IN THE US EPA MODEL PRZM5.0

2.1 Introduction

The objective of this phase of the research was to examine the effect of updating the storm intensity algorithm in the Modified Universal Soil Loss for Small Watershed (MUSS) erosion algorithm (Singh, 1995) in PRZM5.0 to reflect more current storm intensity distributions. The existing algorithm in PRZM5.0 is based on 1986 "IREG" storm intensity distributions (Suarez, 2005).

Storm intensity distributions are spatially variable across the U.S. and are temporally variable within any given storm intensity categorized region. This temporal variability has become of additional concern since climate change literature indicate that rainfall intensity has changed in the time period since 1986 (Palecki et al, 2004). In agricultural fields, off-field eroded sediment, and consequently, off-field sorbed pesticide mass movement, is directly impacted by change in rainfall intensity since this is a major driver for activating these physical processes.

EPA uses PRZM5.0 with a series of geographically specific environmental standard crop scenarios with 30 year daily rainfall time series data to evaluate the behavior of pesticides on agricultural fields. Rainfall events are simulated which may result in predicted off-field loadings of eroded sediment and sorbed pesticide mass. These off-field loadings of eroded sediment and sorbed pesticide mass are then "dumped" into other models that simulate surface water bodies to estimate pesticide concentrations in surface water (Burns, 2006). For this reason, adequate simulation of erosion physical processes by PRZM5.0 is important because it

directly impacts decisions on potential pesticide risks in surface water, especially those involving benthic sediment.

The issue of PRZM5.0 using 1986 “IREG” based storm intensity algorithm is especially of concern for geographical areas where rainfall intensity since 1986 has increased significantly. This problem will cause PRZM5.0 to underestimate off-field erosion and sorbed pesticide loads. Thus, less sorbed pesticide mass could be estimated to be “dumped” into the simulated surface water and subsequently pesticide concentrations could be under-estimated for ecological and drinking water risk assessments.

It was found that the coefficients in the empirical equations in the PRZM5.0 internally built-in 1986 “IREG” based storm intensity algorithm are outdated. In 2014, the Natural Resources Conservation Service (NRCS) and National Oceanic and Atmospheric Administration (NOAA) began development of an updated system of empirical coefficients to the 1986 based “IREG” storm intensity algorithm named “NOAA-14”. This new system includes more current weather trends and is more spatially variable than the 1986 “IREG” distribution system.

For this research, a special version of PRZM5.0 was developed which contains both the empirical coefficients from the old 1986 “IREG” and the new “NOAA-2014” erosion systems for comparisons. A series of six EPA PRZM5.0 standard environmental crop scenarios were run using both the old “IREG” and the new “NOAA-14” storm intensity coefficients. These were run using both the standard EPA 1961-1990 SAMSON weather time series and a non-standard but more recent, 1991-2015 weather time series (compiled for this research) to evaluate differences in predicted eroded sediment mass.

2.2 Background

Research by Palecki et al (2004) found that climate change in the United States not only impacts change in rainfall patterns but change in storm intensity distributions. This paper examined storm intensity, breaking down the U.S. into the same nine zones internally used in PRZM5.0 for storm intensity, based on the “IREG” storm intensity distributions from 1986 (Suarez, 2005). However, for 6 of the 9 zones, the duration of the storms from the “IREG” storm intensity distributions was approximately double that of the storm duration reported by Palecki et al (2004). Thus, storms have become shorter for the same amount of rainfall, which would result in more flash flooding. Figure 2.1 displays a map of the nine representative mean storm duration zones used in both the PRZM5.0 internal algorithms and the Palecki et al. (2004) paper:

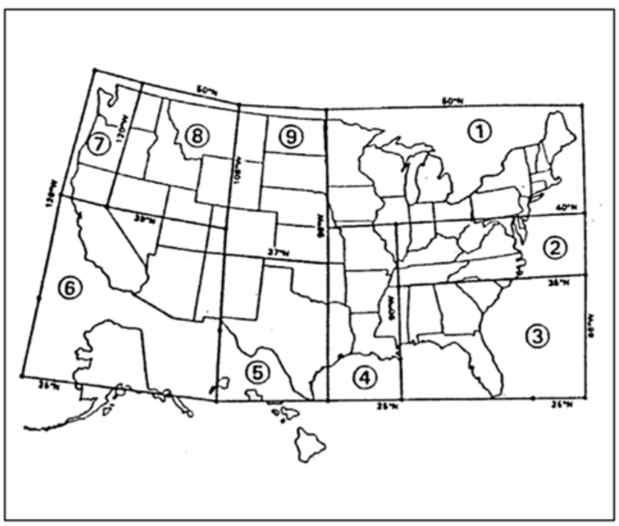

Figure 2. 1 Map of the Nine Representative Mean Storm Duration Zones Used by both Palecki et al. (2004) and in PRZM5.0 (Suarez, 2005)

Comparison of the 1986 summer mean duration (hours) table from the PRZM5.0 User’s Manual (Suarez, 2005) to the Table 2.1 from the Palecki et al. (2004) paper illustrates significant differences in summer storm duration patterns.

Table 2. 1 U.S. Mean Storm Duration in the Summer (hours) (Palecki et al., 2004)

U.S. Mean Storm Duration in the Summer (hours)									
	Zone								
	1	2	3	4	5	6	7	8	9
PRZM5.0 User's Manual (based on 1986 IREG data)	4.4	4.2	4.9	5.2	3.2	2.6	11.4	2.8	3.1
Palecki et al. (2004)	2	2.3	2.1	2.5	2.4	2.8	1.9	2.6	3.4

As seen above, for most of the U.S., storm duration has decreased significantly without simultaneously having a national drought. Thus, rainfall storm intensity has increased. For agriculture, summer storm intensity is especially important since, for much of the country (including the Midwest), summer is the time of year in which the crops are grown, thus the time in which the pesticides are generally applied.

Since the Palecki et al. research was published in 2004, it is possible that storm duration may have shortened in the subsequent decade and thus, rainfall storm intensity may have continued to increase. Or zones that previously did not experience significant shortening in storm duration may now be experiencing this same phenomena due to climate change. Updated statistical analyses of national storm data could provide updated data for these issues.

PRZM5.0 is the model that EPA uses to simulate an agricultural field receiving a pesticide application. It is a one-dimensional, dynamic, compartmental model that can be used to simulate chemical and water movement within and immediately below the plant root zone of the soil profile. It is comprised of two major components: hydrology and chemical transport (Suarez, 2005). It is also a daily time-step model which includes daily rainfall total as a user-

supplied input value (Young and Fry, 2014). In the “real-world”, rainfall intensity (inches/hr or mm/hr) takes place in a sub-daily interval and is a driving factor in the quantity of off-field eroded sediment and consequently, off-field sorbed pesticides. Thus, based on its input daily rainfall total, PRZM5.0 has no means of knowing if a storm took place during two hours or ten hours. For example, if a day has 2 inches of rain that took actually took place in two hours, there would be more off-field eroded sediment than if the same amount of rainfall took place in a six hour storm.

A review of literature has not unearthed any published literature where researchers have updated the PRZM5.0 (or previous PRZM versions) internal algorithms to reflect changes in storm intensity. Thus, this research provides a unique opportunity to improve the ability of PRZM5.0 to simulate contemporary storm intensity conditions for use in future off-field eroded sediment and sorbed pesticide predictions and thus, improve future regulatory surface water and benthic sediment risk assessments.

2.3 Materials and Methods

Instead of requiring hourly rainfall data (which could be used to directly simulate storm intensity), PRZM5.0 combines the user supplied daily rainfall total with an internal erosion algorithm which uses empirically derived storm intensity equations to estimate storm intensity for specific rainfall total ranges (Suarez, 2005).

To estimate agricultural off-field erosion for the PRZM5.0 EPA standard environmental crop scenarios, the Modified Universal Soil Loss for Small Watershed (MUSS) equation (Singh, 1995, Wischmeier and Smith, 1978) is used which incorporates a storm intensity estimate using the NCRS Soil Conservation Service (NRCS) 1986 “IREG” storm intensity distributions.

The equation for MUSS is as follows:

$$X_e = 0.79\,(V_r\, q_p)^{0.65} A^{0.009} K\, LS\, C\, P$$

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LS = length-slope factor (dimensionless)

C = soil cover factor (dimensionless)

P = conservation practice factor (dimensionless)

(Suarez, 2005)

The parameters *A, K, LS, C* and *P* are all non-weather related and are fixed for each EPA PRZM5.0 standard environmental crop scenario. Only the V_r and q_p parameters are dependent on the rainfall and storm intensity in the equation. Thus, these are the only parameters that change daily with each daily weather simulation increment when PRZM5.0 is run. V_r is internally calculated by PRZM5.0 as a function of the daily input of rainfall total minus internally tracked amount of rainfall infiltrating into the soil profile or trapped by the plants in the field. This amount is then adjusted by the peak storm runoff rate, q_p, (mm/h) which is the rainfall intensity parameter. Thus q_p is the parameter which represents storm intensity in the MUSS erosion algorithm in PRZM5.0.

Further, q_p is calculated using the Soil Conservation Service Graphical Peak Discharge Method from 1986 (Suarez, 2005) via the following equation:

$$q_p = a\, q_u\, A\, V_r\, F_p$$

(eq. 2.2)

where:

q_u = unit peak discharge rate (cfs/inch/sq mile)

F_p = pond and swamp adjustment factor (preprogrammed to a value of 1.0 in PRZM5.0)

a = units conversion factor

The unit peak discharge rate, q_u is calculated by the empirical equation:

$$\log(q_u) = C_0 + C_1 \log(T_c) + C_2 [T_c]^2$$

(eq. 2.3)

Here T_c is time of concentration (hours) and is defined as "time it takes water to flow from the furthest point in the watershed to a point of interest within the watershed, and is a function of basin shape, topography, and surface cover. T_c is calculated by summing the travel times for various designated flow segments within the watershed" (Suarez, 2005). The coefficients C_0, C_1, and C_2 are regional coefficients that are related storm intensity and precipitation volume assigned per the 1986 "IREG" storm intensity distributions in PRZM5.0 (Suarez, 2005).

These "IREG" storm intensity distributions in PRZM5.0 were developed from historic storm intensity data from National Weather Service duration-frequency data prior to 1986. NRCS is in the process of developing storm intensity distributions based on the NOAA Atlas 14 data ("NOAA-14") to replace the "IREG" storm intensity distributions for the entire U.S. "NOAA-14" divides the U.S. into much smaller rainfall distribution regions, including

subdividing states into multiple regions. NOAA has developed a software program called "EFH-2" which generates peak runoff and discharge estimates using "NOAA-14" regional specific coefficients (NRCS, 2015).

In this project, q_p values were calculated for six states (Georgia, Indiana, Louisiana, Maine, Pennsylvania, and North Carolina) using the empirical coefficients calculated for the "NOAA-14" distributions for varying daily rainfall totals. Each of these states were classified as IREG II or IREG III in the "IREG" storm intensity distributions in PRZM5.0. Figure 2.2 displays a map is of the "IREG" storm intensity distribution categorizations.

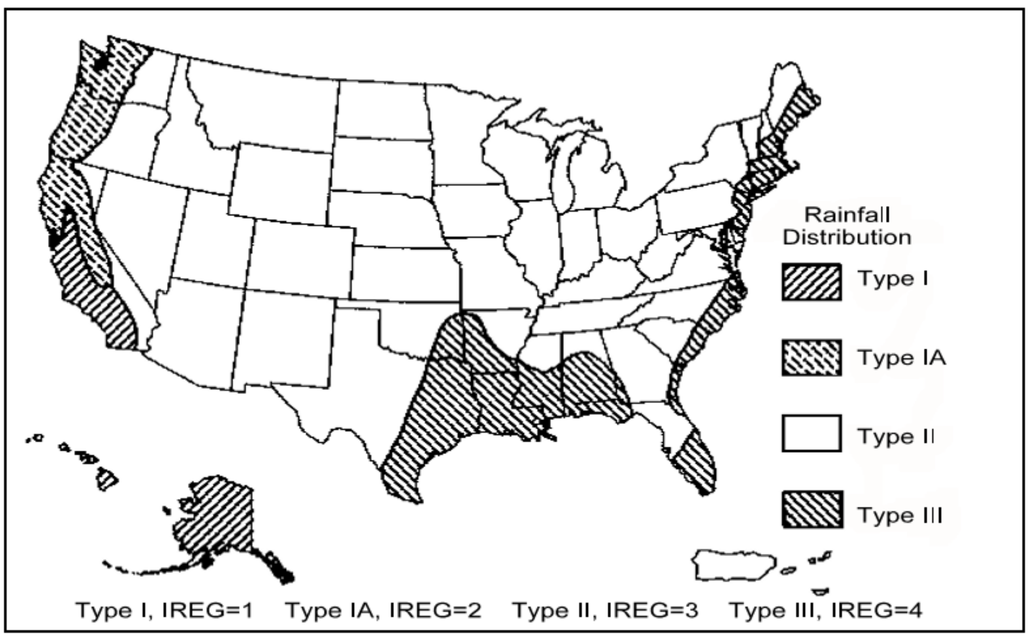

Figure 2. 2 Map of the "IREG" Storm Intensity Distribution Categorizations (Suarez, 2005)

The six states were selected based on two criteria: (1) availability of an EPA PRZM5.0 environmental standard crop scenario in the state and (2) availability of "NOAA-14" regional specific coefficients for the state. [Unfortunately, "NOAA-14" regional specific coefficients are not yet available for the entire U.S. Thus, it was not yet possible to evaluate the west coast states.]

For preliminary investigation, q_p parameter values were calculated from the IREG II and IREG III storm intensity distributions and the "NOAA-14" distributions using a series of daily rainfall totals with a time of concentration of 0.4 hours to examine for potential change in the PRZM5.0 MUSS results. [The time of concentration of 0.4 hours was identified based on typical ranges of values discovered from internal processing of PRZM5.0 calculations from several EPA environmental standard crop scenarios].

In the new "NOAA-14" categorization, Pennsylvania is divided into four sub-regions. Under the "IREG" categorization, most of the state was in the Type II storm distribution category (NRCS, 2011). The "NOAA-14" map for Pennsylvania is display in Figure 2.3.

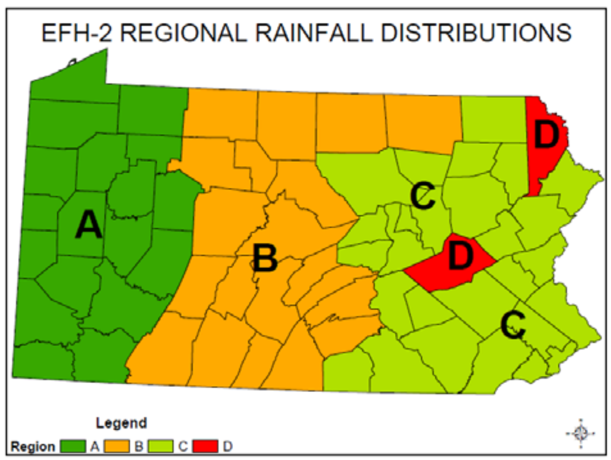

Figure 2. 3 Map of the "NOAA-14" map for Pennsylvania (NRCS, 2011)

For this research, the preliminary investigation was followed by the development of a "custom" version of the PRZM5.0 Fortran program which was modified to include additional code to run the new "NOAA-14" storm intensity C_0, C_1, and C_2 coefficients that corresponded to the location of the PRZM5.0 EPA standard environmental crop scenario for each of the six states in the internal MUSS algorithm code in addition to the standard "IREG" coefficients. A copy of the modified Fortran subroutine is included in Appendix A. For each of the six different

state PRZM5.0 EPA standard environmental crop scenarios, this special version of PRZM5.0 was run both with the scenario's appropriate "IREG" storm distribution coefficients and the new "NOAA-14" storm distribution coefficients. Both the EPA traditional 1961-1990 SAMSON weather time series and a time series using the same SAMSON weather stations but with Jan.1, 1991 – Dec. 31, 2016 weather time series (developed exclusively for this research) were simulated to examine for potential changes in patterns between the two storm intensity distribution systems due to changes in weather patterns over time. The 1991-2016 custom weather time series files were comprised of observed daily precipitation, temperature, and wind speed data from the same NOAA SAMSON stations used to generate the 1961-1990 EPA weather time series. Additionally, daily pan evaporation values were estimated using the Linacre Model (Benzaghta et al., 2012) and solar radiation values were estimated using the method described by the Food and Agriculture Organization of the United Nations - Natural Resources Management and Environment Department (FAO, 1990).

For each simulation, predicted daily off-field eroded sediment mass from PRZM5.0 was output. The predicted daily off-field eroded sediment mass between the two different storm intensity distribution systems was used as the measure of comparison between the old "IREG" storm distribution coefficients and the new "NOAA-14" storm distributions coefficients. Graphs of daily eroded sediment as well as cumulative eroded sediment over time were generated to examine for pattern differences. Finally, paired student t-tests were conducted to statistically analyze whether the "IREG" storm distributions was statistically different from the new "NOAA-14" storm distributions for each individual state EPA PRZM5.0 standard environmental crop scenario and weather time series.

2.4 Results and Discussion

"NOAA-14" storm intensity categorization coefficients were obtained for Georgia, Indiana, Louisiana, Maine, Pennsylvania, and North Carolina. Like Pennsylvania, each of the other five states were subdivided into multiple sub-regions with each sub-region having its own set of individual empirical coefficients for calculation of unit peak discharge, q_p.

For a 0.4 hour time of concentration (T_c) assumption, the "IREG" II and "IREG" III storm intensity distribution coefficients and each the "NOAA-14" storm intensity coefficients for each state's sub-region were used to calculate q_u values at non-infiltrated precipitation depths (cm) of 0.1, 0.3, 0.4, and 0.5 for each of the six states. Since q_u is the only parameter that changes q_p in the Soil Conservation Service Graphical Peak Discharge Method equation, significant change in q_u will significantly change q_p and, in turn, significantly change the predicted off-field eroded sediment by MUSS.

At each non-infiltrated precipitation depth for every sub-region and for each of the six states examined, the "NOAA-14" q_u values were different than the "IREG" II or "IREG" III q_u value. Additionally, differences in these values were bigger for smaller non-infiltrated precipitation depths than larger (i.e., bigger for 0.1 cm vs 0.5 cm). This makes sense since climate change may be decreasing the duration of smaller rainfall total events more dramatically than higher rainfall events. Tables 2.2-2.7 detail the results from these q_u calculations for an assumed time of concentration set to 0.4 hours for the appropriate "IREG" II or III and new "NOAA-14" designations for each of the six states included in this research. Examination of differences in these q_u values indicated that modifying the PRZM5.0 code to include the "NOAA-14" storm intensity coefficients would significantly change predicted off-field eroded sediment mass.

Table 2. 2 Georgia q_u Example Calculation with NOAA-14 Coefficients and Assumed Time of Concentration Set to 0.4 Hours.

Georgia *q_u (cfs/inch/sq mile)*					
Non-Infiltrated Precipitation (cm)	IREG (II)	NOAA-14 (MSE 3)	NOAA-14 (MSE 4)	NOAA-14 (MSE 5)	NOAA-14 (MSE 6)
0.1	591.61	661.58	590.48	507.28	451.70
0.3	291.96	329.00	507.88	432.82	324.59
0.4	392.09	278.87	407.79	339.65	294.21
0.5	254.78	220.80	274.99	215.66	175.98

Table 2. 3 Indiana q_u Example Calculation with NOAA-14 Coefficients and Assumed Time of Concentration Set to 0.4 Hours.

Indiana *q_u (cfs/inch/sq mile)*			
Non-Infiltrated Precipitation (cm)	IREG (II)	NOAA-14 (NOAA_A)	NOAA-14 (NOAA_B)
0.1	591.61	642.40	565.54
0.3	291.96	325.54	487.05
0.4	392.09	276.89	391.87
0.5	254.78	220.55	265.15

Table 2. 4 Louisiana q_u Example Calculation with NOAA-14 Coefficients and Assumed Time of Concentration Set to 0.4 Hours.

Louisiana *q_u (cfs/inch/sq mile)*			
Non-Infiltrated Precipitation (cm)	IREG (III)	NOAA-14 (MSE 5)	NOAA-14 (MSE 6)
0.1	449.20	507.28	451.70
0.3	379.37	432.82	382.49
0.4	298.47	339.65	294.21
0.5	203.75	215.66	175.98

Table 2. 5 Maine q_u Example Calculation with NOAA-14 Coefficients and Assumed Time of Concentration Set to 0.4 Hours.

Maine *q_u (cfs/inch/sq mile)*					
Non-Infiltrated Precipitation (cm)	IREG (II)	IREG (III)	NOAA-14 (NRCC_B)	NOAA-14 (NRCC_C)	NOAA-14 (NRCC_D)
0.1	591.61	449.20	541.79	474.29	417.63
0.3	291.96	379.37	276.06	401.75	351.05
0.4	392.09	298.47	225.94	309.47	263.11
0.5	254.78	203.75	167.84	185.42	144.61

Table 2. 6 North Carolina q_u Example Calculation with NOAA-14 Coefficients and Assumed Time of Concentration Set to 0.4 Hours.

North Carolina *q_u(cfs/inch/sq mile)*						
Non-Infiltrated Precipitation (cm)	IREG (II)	IREG (III)	NOAA-14 (NOAA A)	NOAA-14 (NOAA B)	NOAA-14 (NOAA C)	NOAA-14 (NOAA D)
0.1	591.61	449.20	642.40	565.54	505.71	452.64
0.3	291.96	379.37	325.54	487.05	431.67	324.19
0.4	392.09	298.47	276.89	391.87	339.70	295.62
0.5	254.78	203.75	220.55	265.15	216.63	177.46

Table 2. 7 Pennsylvania q_u Example Calculation with "NOAA-14" Coefficients and Assumed Time of Concentration Set to 0.4 Hours.

Pennsylvania *q_u (cfs/inch/sq mile)*					
Non-Infiltrated Precipitation (cm)	IREG (II)	NOAA-14 (NOAA A)	NOAA-14 (NOAA B)	NOAA-14 (NOAA C)	NOAA-14 (NOAA D)
0.1	591.61	642.40	565.54	505.71	452.64
0.3	291.96	325.54	487.05	431.67	324.19
0.4	392.09	276.89	391.87	339.70	295.62
0.5	254.78	220.55	265.15	216.63	177.46

The above tables showed distinct differences between the "IREG" results and the "NOAA-14" results indicating that if the "NOAA-14" coefficients are installed into the PRZM5.0 software, they would change the predicted off-field eroded sediment algorithm output. Thus, after this preliminary investigation, the decision was made to develop a special version of PRZM5.0 which provides user access to the "NOAA-14" storm intensity coefficients associated with the location for each of the six state EPA PRZM5.0 standard environmental crop scenarios.

The EPA PRZM5.0 standard environmental crop scenarios selected for this study were: Louisiana sugarcane, Indiana corn, Pennsylvania corn, Georgia peach, Maine potato, and North Carolina peanuts. These were selected because they were the only six states that currently have both available "NOAA-14" coefficients and an EPA PRZM5.0 standard environmental crop scenario. Selection of the corn scenario for Indiana, sugarcane for Louisiana and potatoes for Maine was simple since these are the only available EPA PRZM5.0 standard environmental crop scenarios for these states. For Georgia, the peach scenario was selected to include an orchard land-use scenario in the set of scenarios to be evaluated. With the exception of the orchard apple scenario and the non-agricultural turf scenario, the Pennsylvania EPA PRZM5.0 standard environmental crop scenarios are all located in the Lancaster County area and have similar crop parameterizations, so the corn scenario was selected for estimation of off-field erosion and runoff. Finally, since two corn scenarios were already selected and an orchard scenario was selected, this left only the peanut or cotton scenario as possible unique scenarios for North Carolina. Both of these represent the same geographical location with very similar crop parameterizations, so selection of either would not make difference in prediction of off-field erosion. Thus, it was decided to use the North Carolina peanut scenario for this research.

First, the custom version of PRZM5.0 was run for each the EPA PRZM5.0 standard environmental crop scenarios with the usual EPA provided 1961-1990 SAMSON weather time series. Graphical comparisons (both daily and cumulative) of the “IREG” versus “NOAA-14” PRZM5.0 predicted off-field eroded sediment over time for 1961-1990 are detailed in Figures 2.4-2.15. Next, the custom version of PRZM5.0 was run for each the EPA standard environmental crop scenarios with the 1991-2016 SAMSON weather time series generated for this research. Graphical comparisons (both daily and cumulative) of the “IREG” versus “NOAA-14” PRZM5.0 predicted off-field eroded sediment over time for 1991-2016 are detailed in Figures 2.16-2.27.

Paired t-tests were performed on the predicted off-field non-zero eroded sediment values by date for the “IREG” versus “NOAA-14” sets for each state EPA PRZM5.0 standard environmental crop scenario. For 1961-1990 time series, for the Georgia, Indiana, Louisiana, Pennsylvania, and North Carolina scenarios, the “NOAA-14” storm coefficients resulted in statistically significantly higher predicted off-field eroded sediment than predicted with the “IREG” storm coefficients. The Maine scenario resulted in the “IREG” coefficients predicting statistically significant higher off-field eroded sediment than the “NOAA-14” storm coefficients, however, the two storm intensity distributions were very close to each other. For the 1991-2016 time series, for the Georgia, Indiana, Louisiana, and North Carolina scenarios, the “NOAA-14” storm coefficients resulted in statistically significant higher predicted off-field eroded sediment than predicted with the “IREG” storm coefficients. The Maine scenario resulted in the “IREG” storm coefficients predicting statistically significant higher off-field eroded sediment than the “NOAA-14” storm coefficients, however, the two storm intensity distributions were very close to each other.

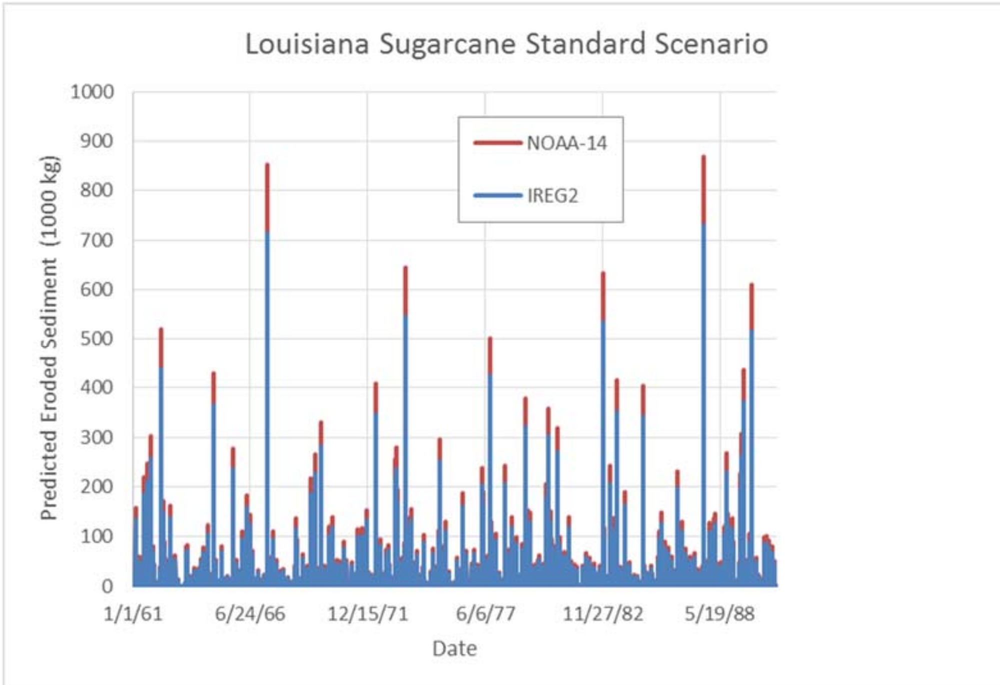

Figure 2. 4 Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1961-1990 – Louisiana Sugarcane EPA Standard Environmental Crop Scenario

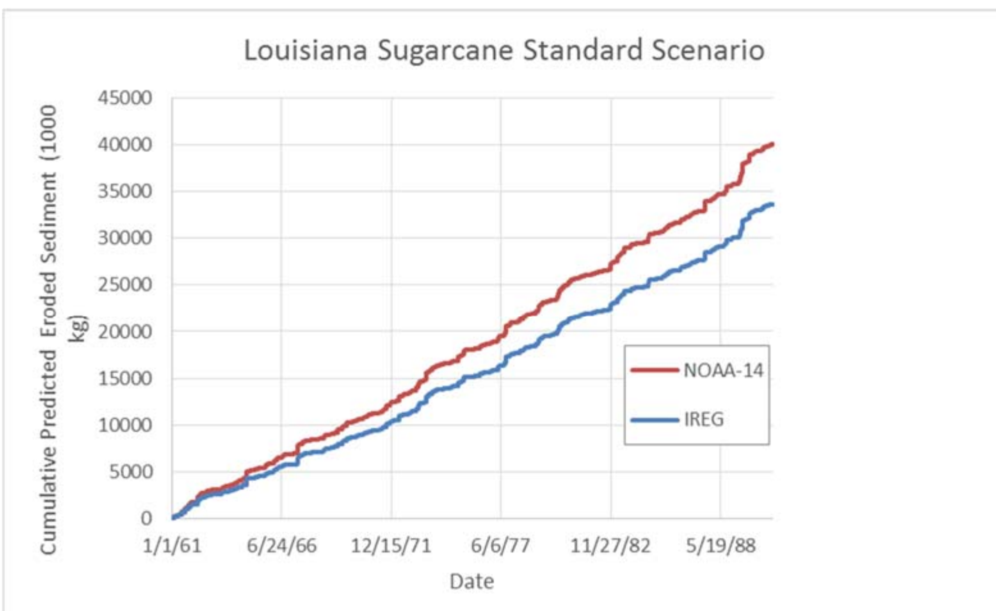

Figure 2. 5 Cumulative Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1961-1990 – Louisiana Sugarcane EPA Standard Environmental Crop Scenario

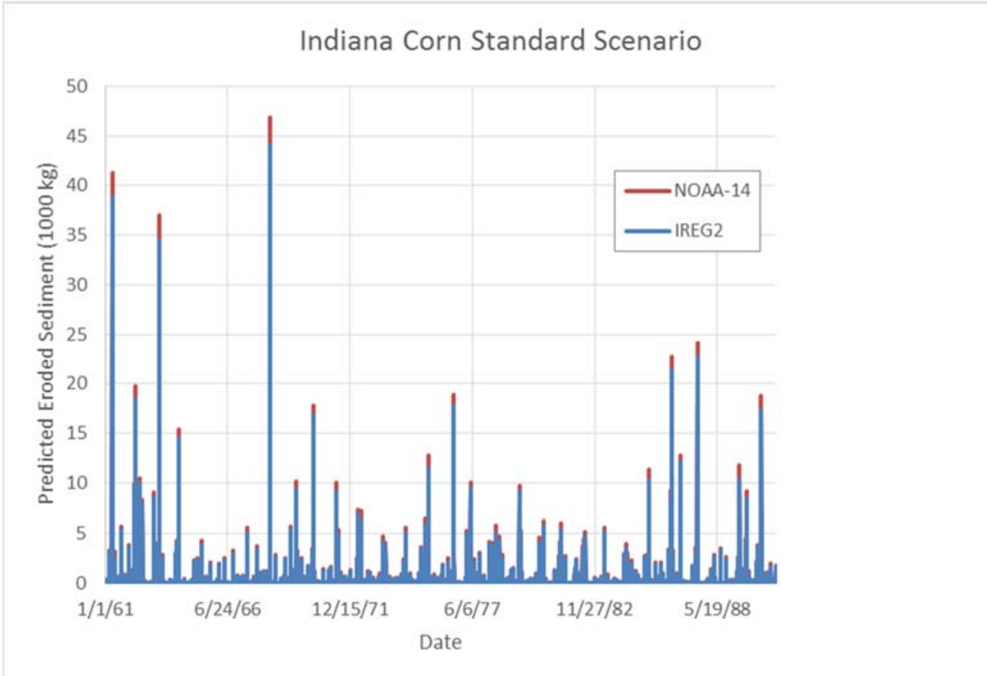

Figure 2. 6 Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1961-1990 – Indiana Corn EPA Standard Environmental Crop Scenario

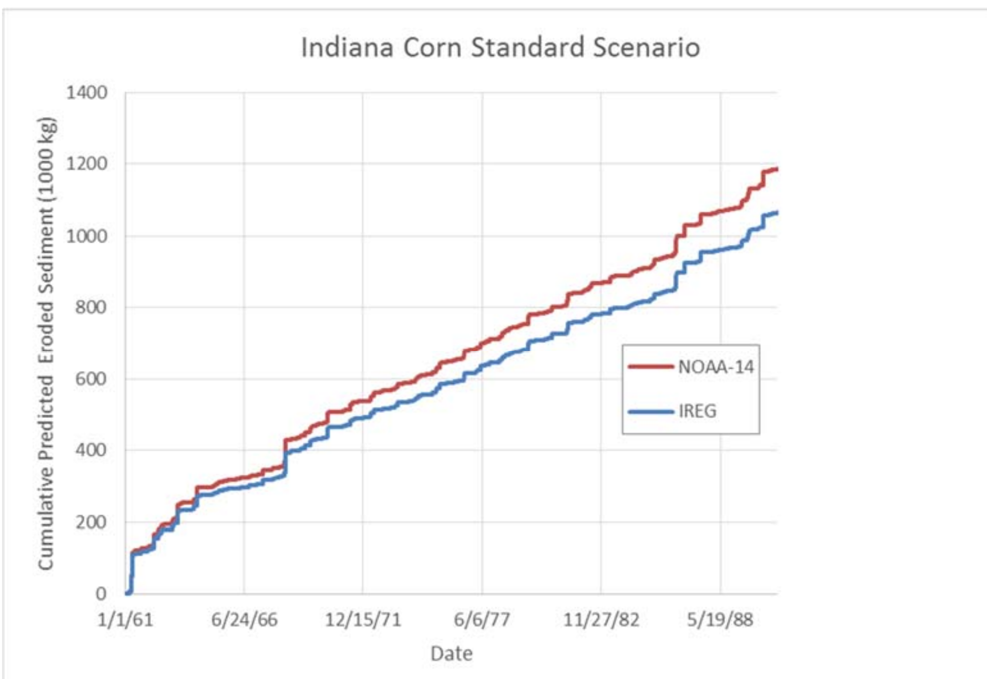

Figure 2. 7 Cumulative Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1961-1990 – Indiana Corn EPA Standard Environmental Crop Scenario

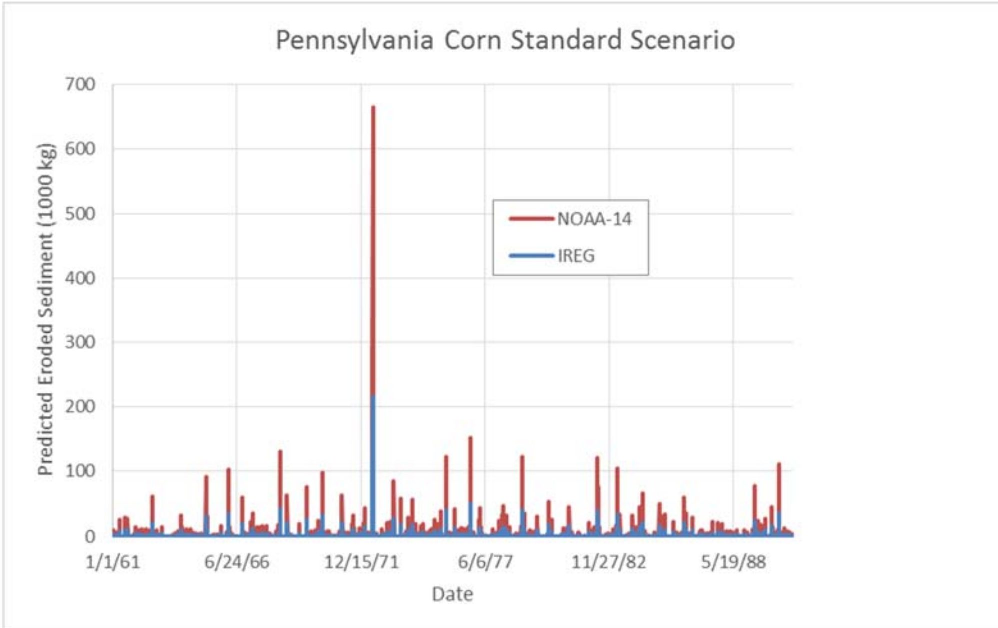

Figure 2. 8 Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1961-1990 – Pennsylvania Corn EPA Standard Environmental Crop Scenario

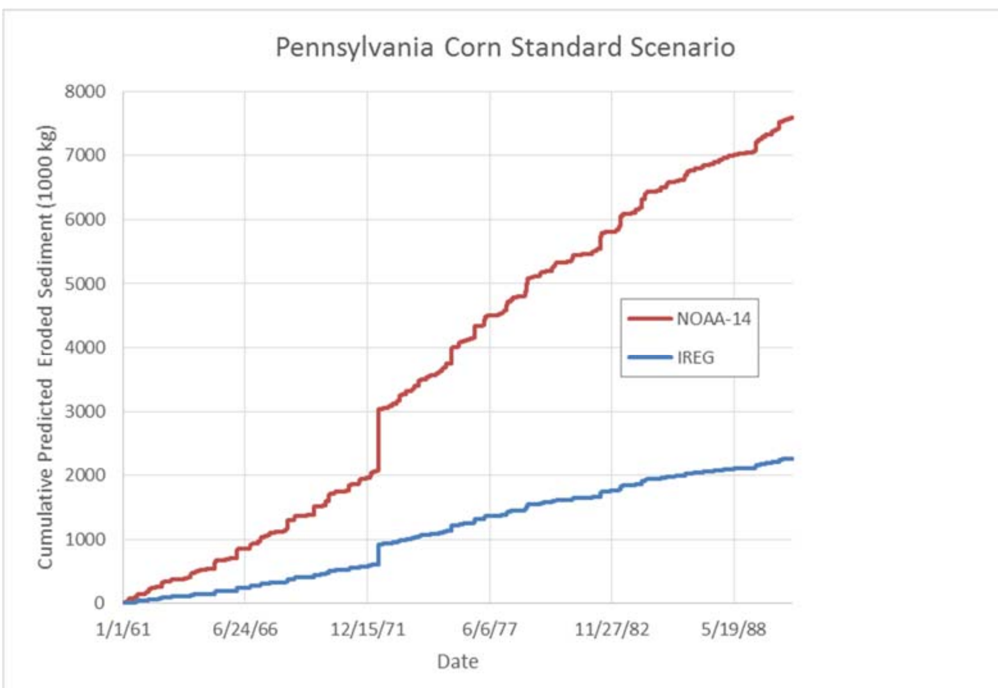

Figure 2. 9 Cumulative Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1961-1990 – Pennsylvania Corn EPA Standard Environmental Crop Scenario

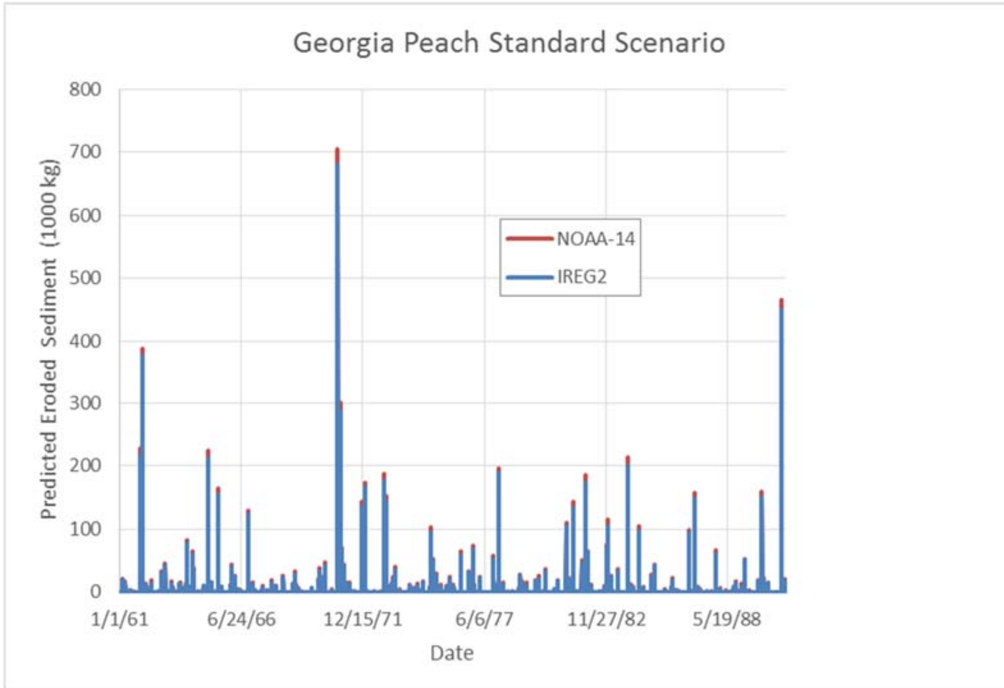

Figure 2. 10 Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1961-1990 – Georgia Peach EPA Standard Environmental Crop Scenario

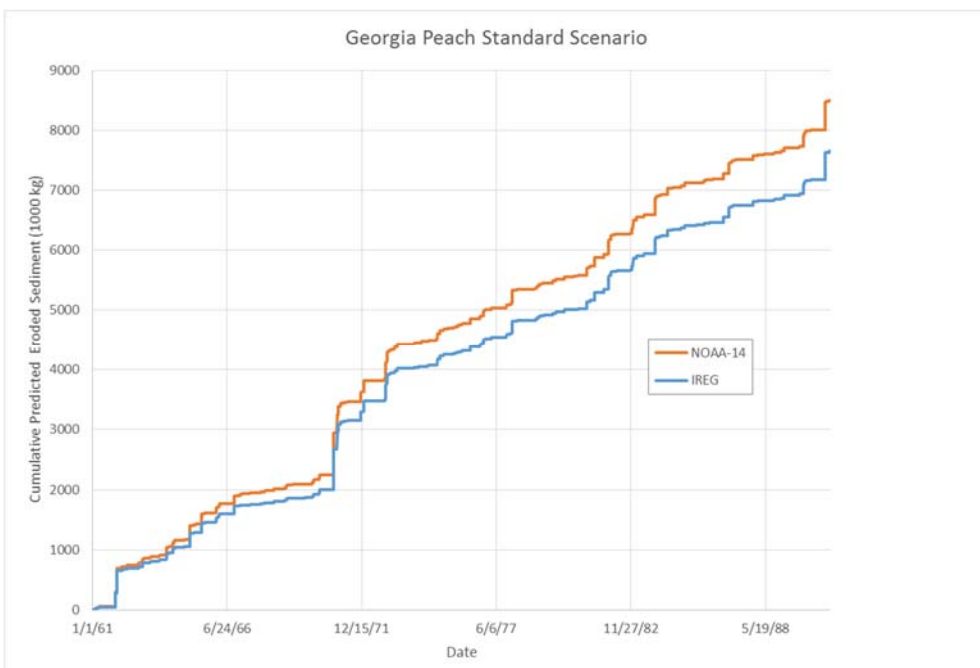

Figure 2. 11 Cumulative Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1961-1990 – Georgia Peach EPA Standard Environmental Crop Scenario

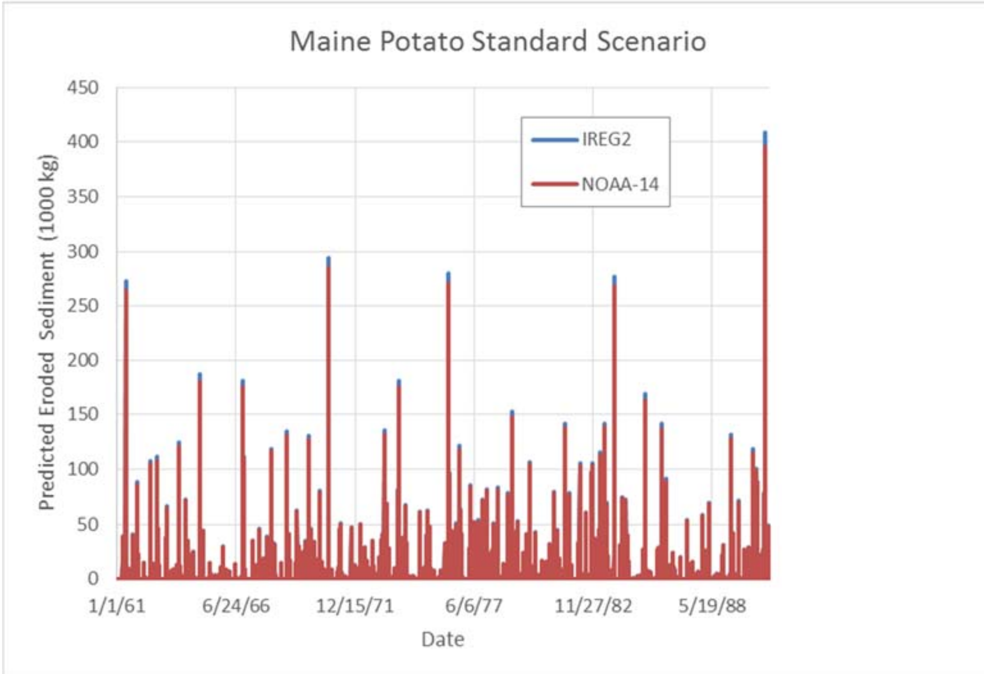

Figure 2. 12 Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1961-1990 – Maine Potato EPA Standard Environmental Crop Scenario

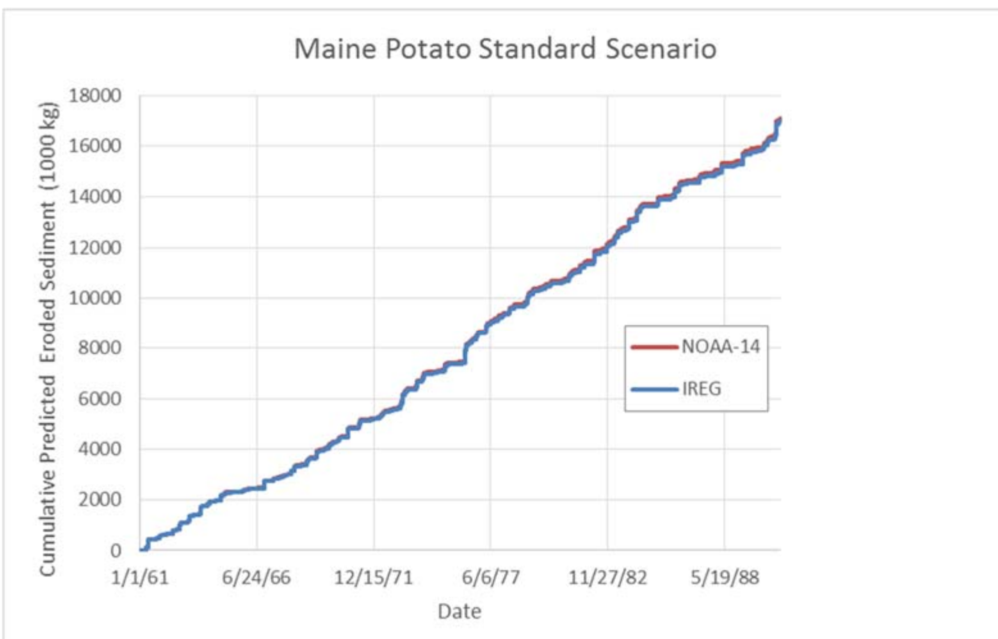

Figure 2. 13 Cumulative Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1961-1990 – Maine Potato EPA Standard Environmental Crop Scenario

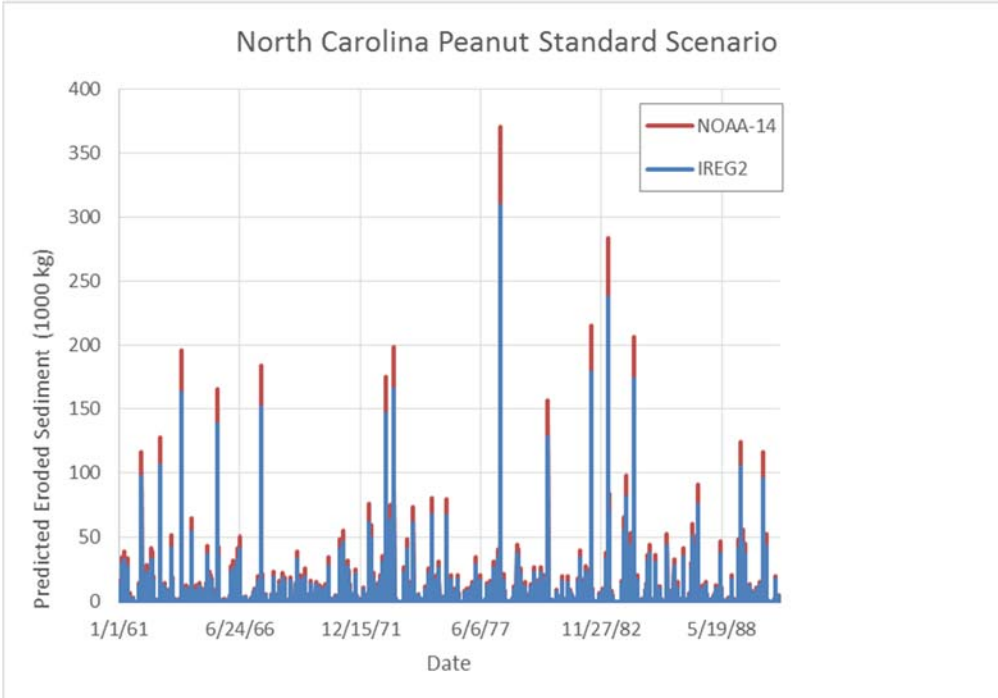

Figure 2. 14 Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1961-1990 – North Carolina Peanuts EPA Standard Environmental Crop Scenario

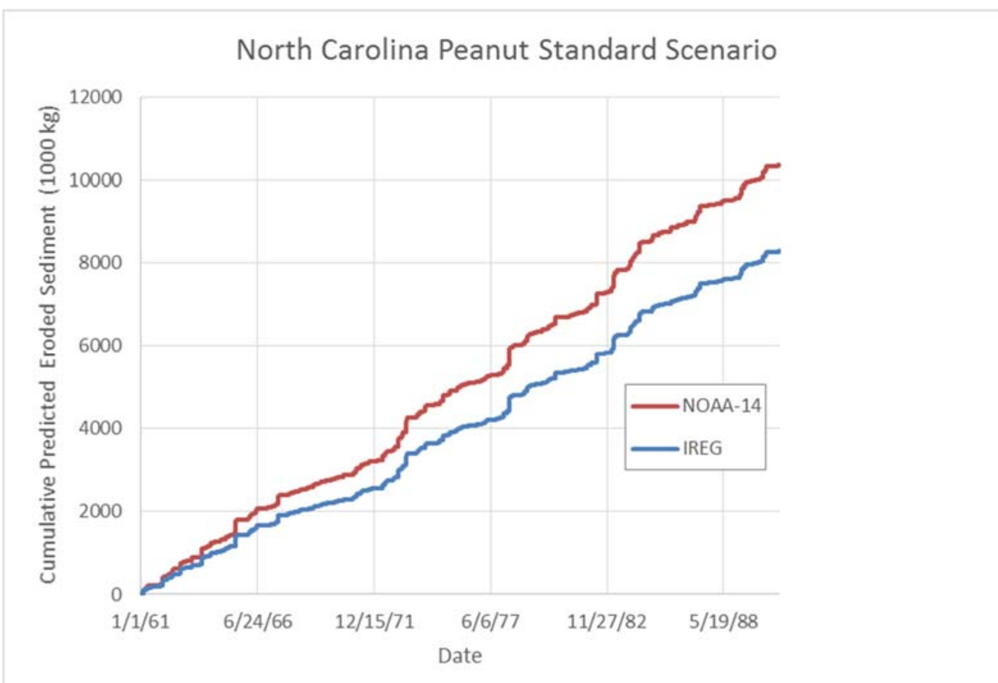

Figure 2. 15 Cumulative Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1961-1990 – North Carolina Peanuts EPA Standard Environmental Crop Scenario

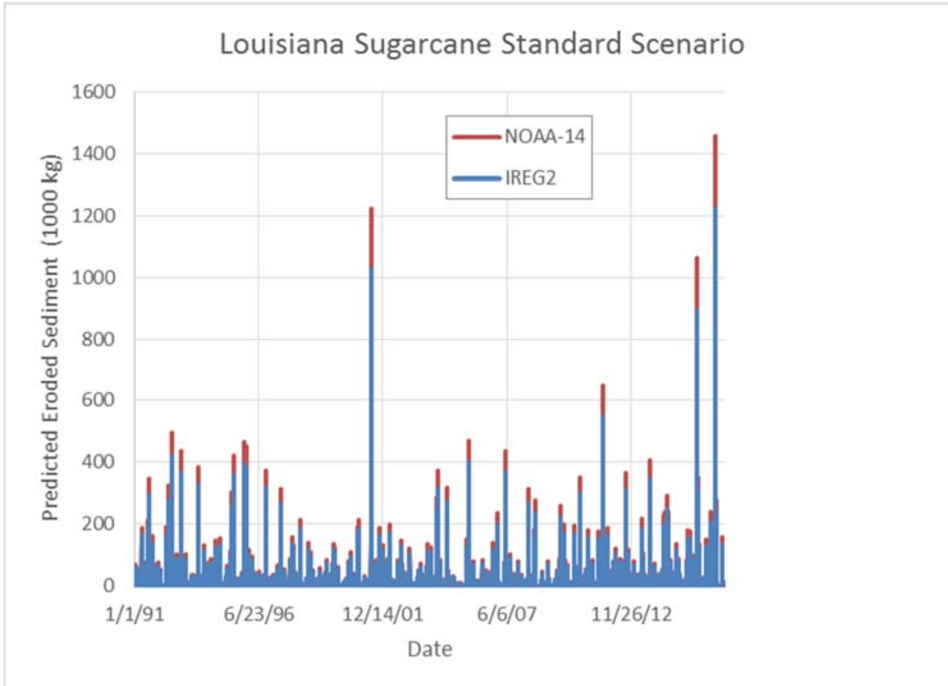

Figure 2. 16 Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1991-2016 – Louisiana Sugarcane EPA Standard Environmental Crop Scenario

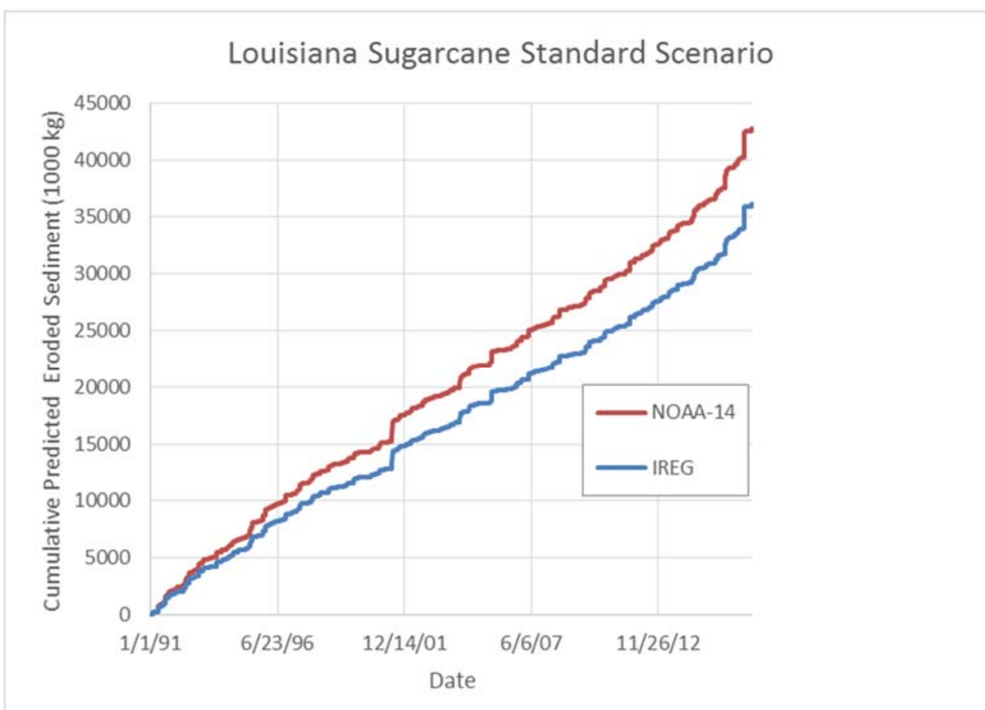

Figure 2. 17 Cumulative Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1991-2016 – Louisiana Sugarcane EPA Standard Environmental Crop Scenario

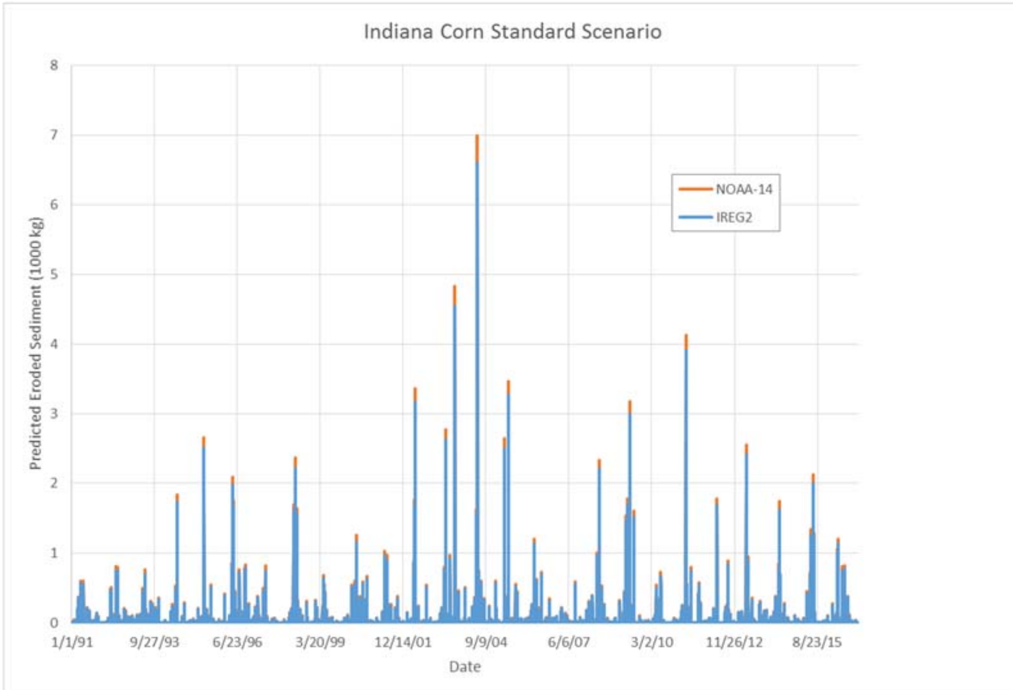

Figure 2. 18 Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1991-2016 – Indiana Corn EPA Standard Environmental Crop Scenario

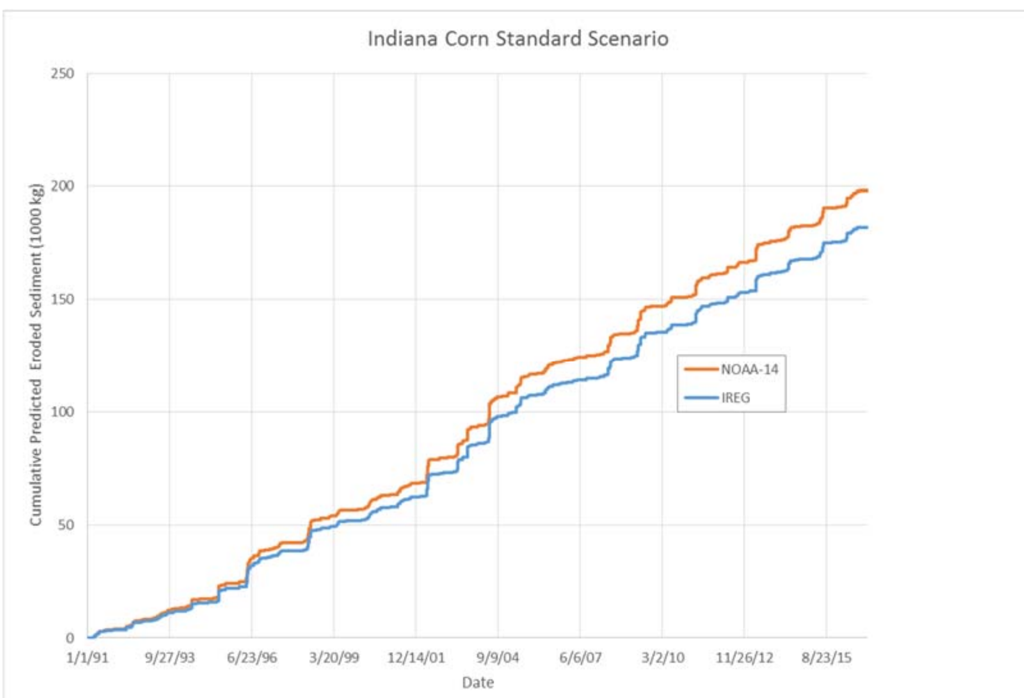

Figure 2. 19 Cumulative Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1991-2016 – Indiana Corn EPA Standard Environmental Crop Scenario

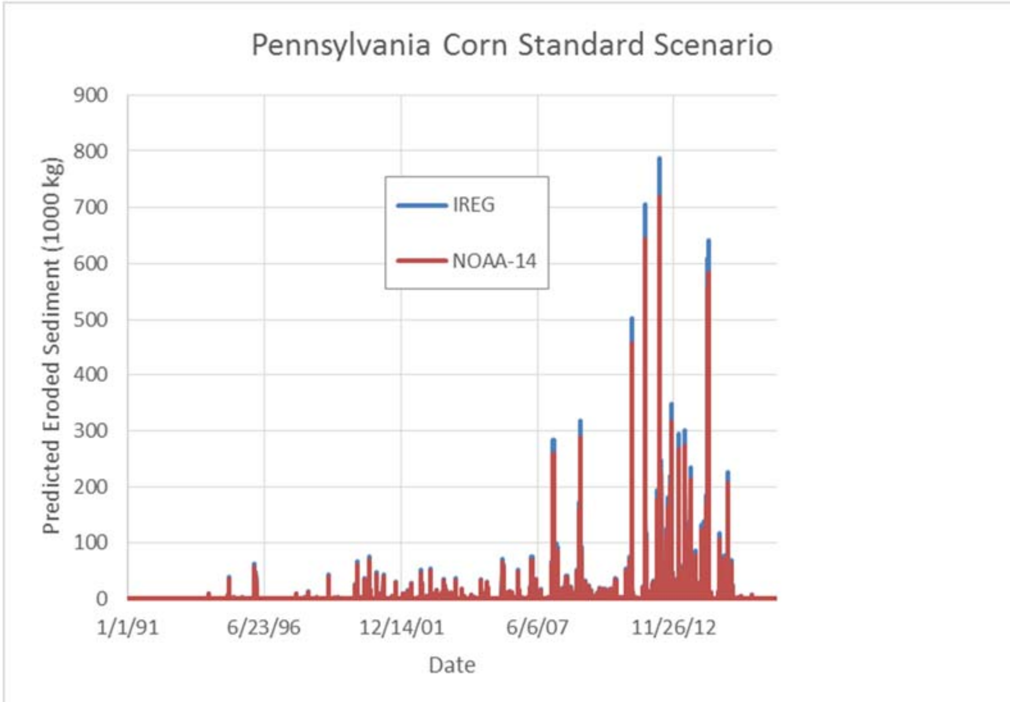

Figure 2. 20 Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1991-2016 – Pennsylvania Corn EPA Standard Environmental Crop Scenario

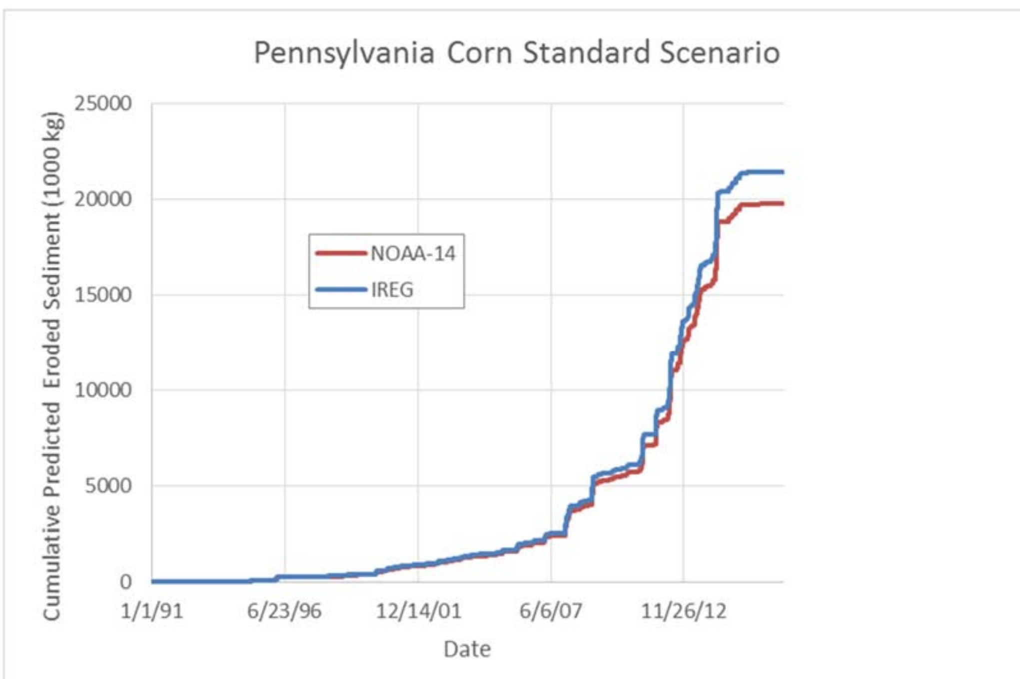

Figure 2. 21 Cumulative Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1991-2016 – Pennsylvania Corn EPA Standard Environmental Crop Scenario

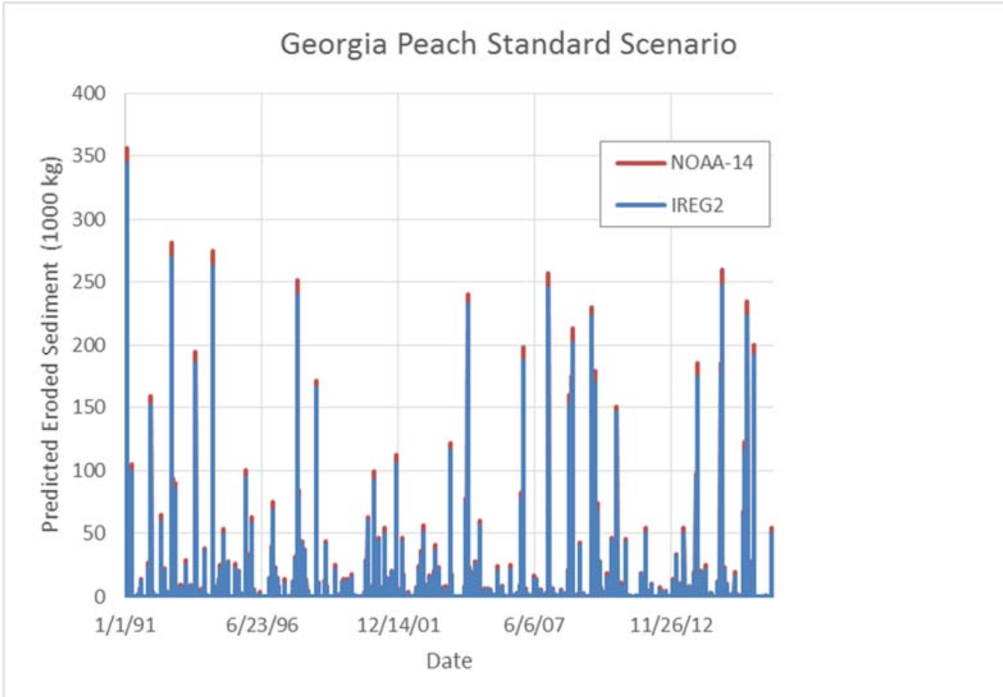

Figure 2. 22 Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1991-2016 – Georgia Peach EPA Standard Environmental Crop Scenario

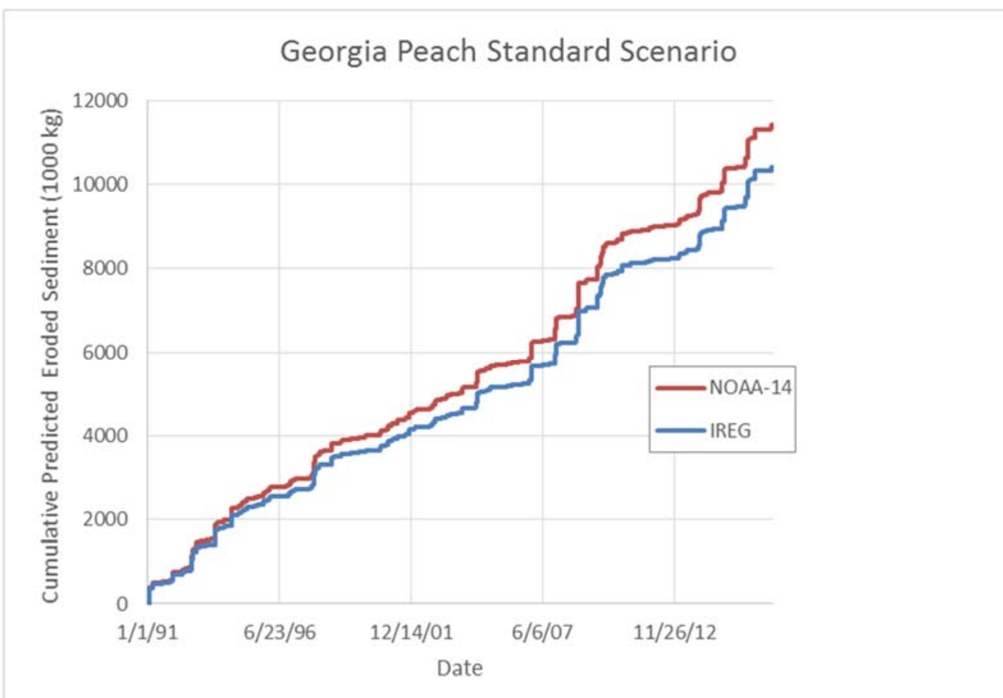

Figure 2. 23 Cumulative Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1991-2016 – Georgia Peach EPA Standard Environmental Crop Scenario

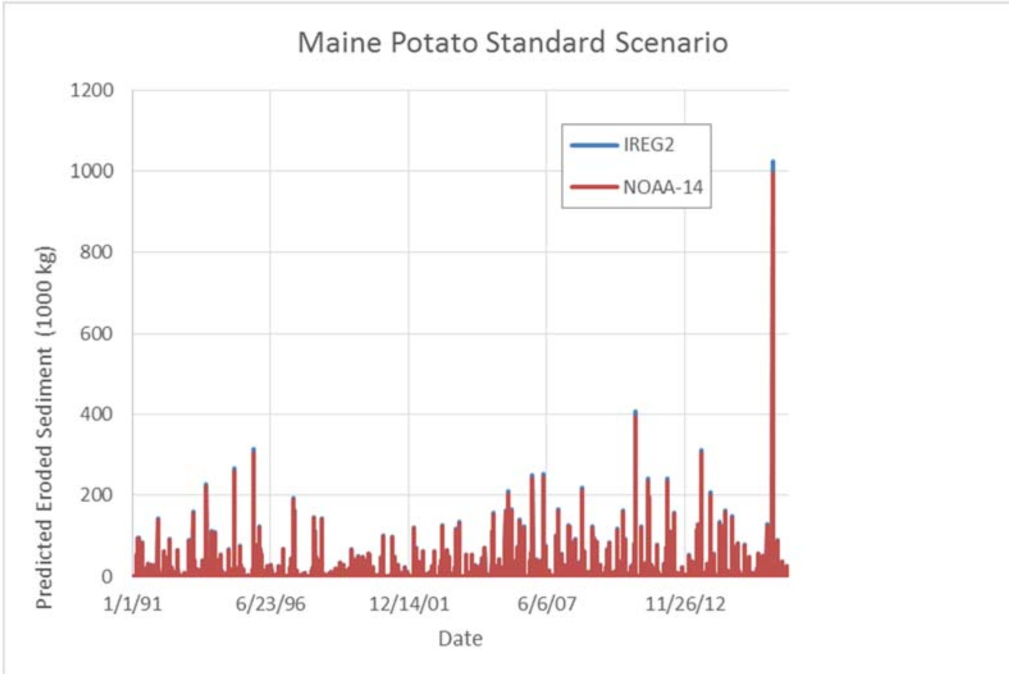

Figure 2. 24 Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1991-2016 – Maine Potato EPA Standard Environmental Crop Scenario

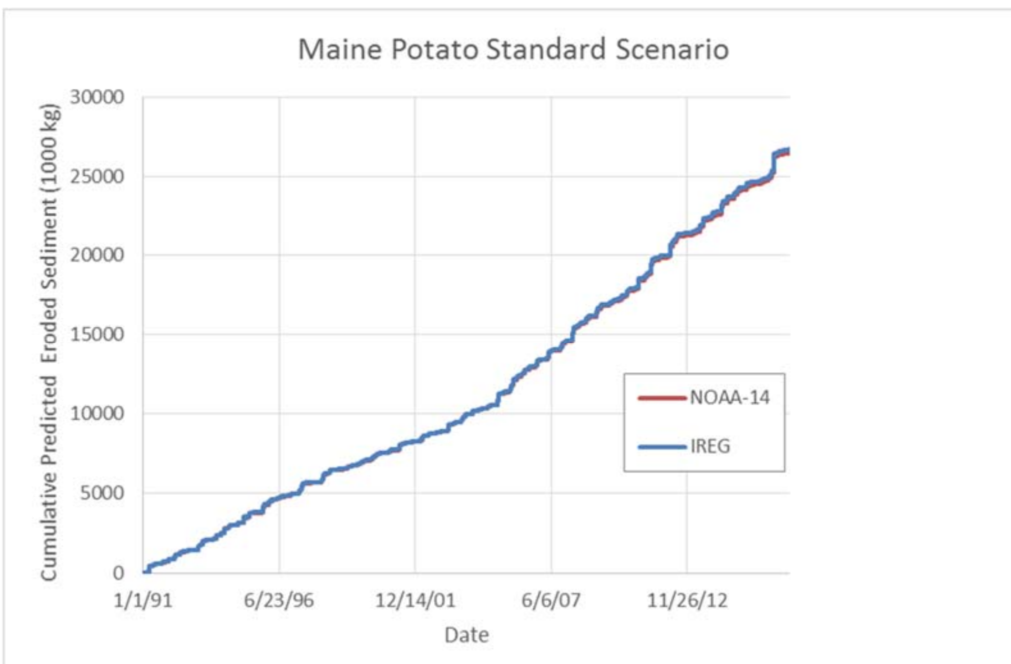

Figure 2. 25 Cumulative Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1991-2016 – Maine Potato EPA Standard Environmental Crop Scenario

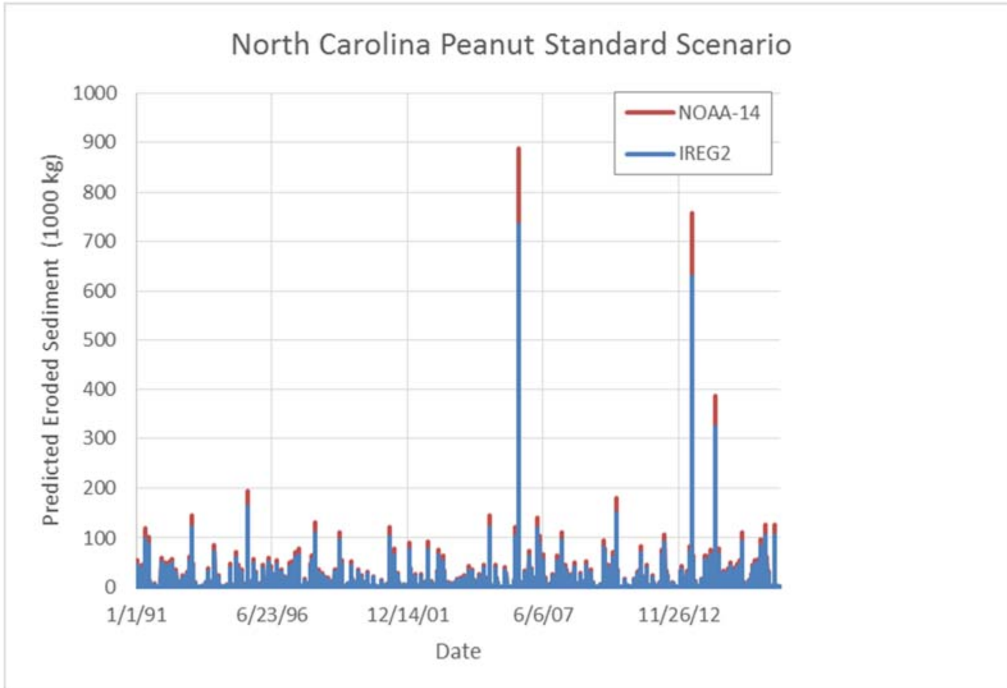

Figure 2. 26 Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1991-2016 – North Carolina Peanut EPA Standard Environmental Crop Scenario

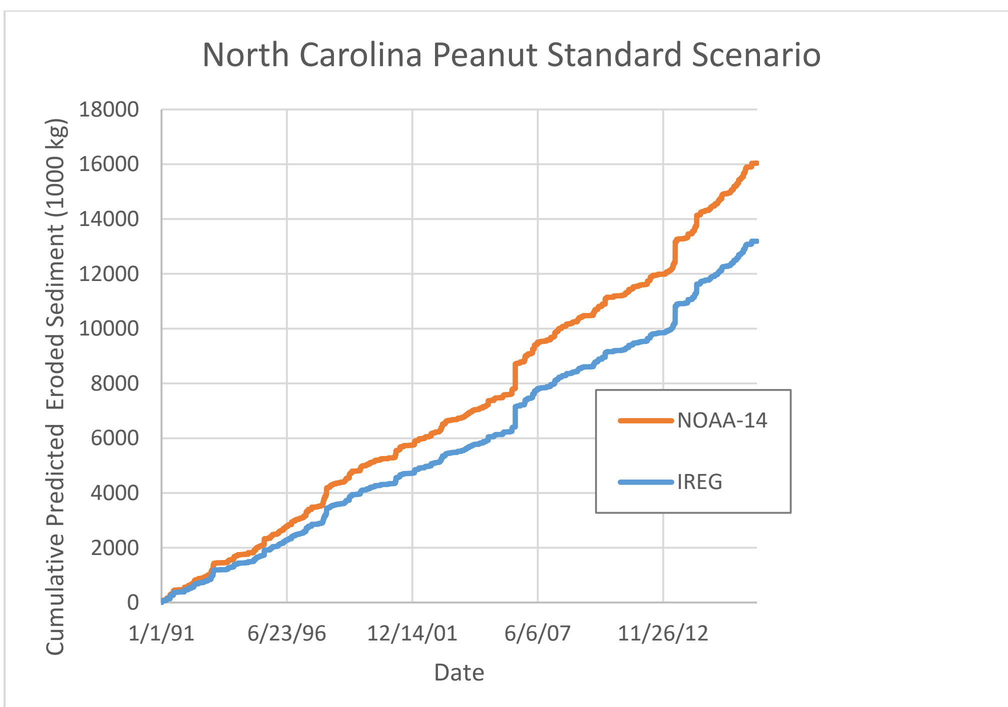

Figure 2. 27 Cumulative Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1991-2016 – North Carolina Peanut EPA Standard Environmental Crop Scenario

The Pennsylvania scenario had an interesting pattern. For Jan. 1991 to mid-1995, the "NOAA-14" predicted off-field eroded sediment was statistically higher than the predicted "IREG" predicted off-field eroded sediment. Thereafter, the pattern reversed and the "IREG" predicted off-field eroded sediment is significantly higher, statistically. This is due to changes in daily rainfall patterns with more daily events having higher rainfall totals during 1995 – 2016 compared to 1961-1994. Graphs of this temporal difference in the Pennsylvania scenario are displayed Figures 2.28 and 2.29.

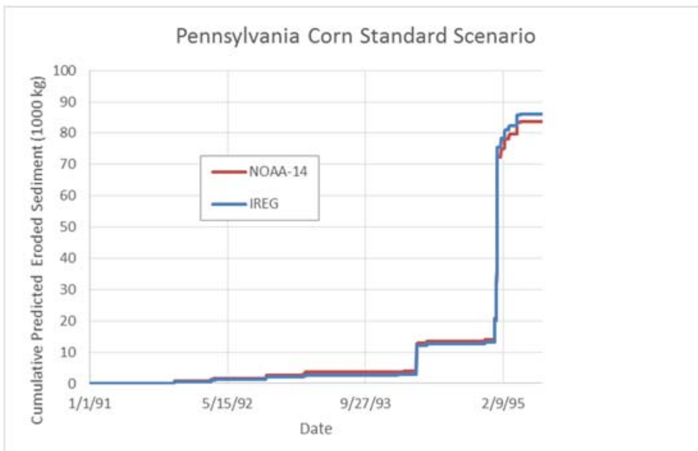

Figure 2. 28 Cumulative Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1991-mid-1995 – Pennsylvania Corn EPA Standard Environmental Crop Scenario

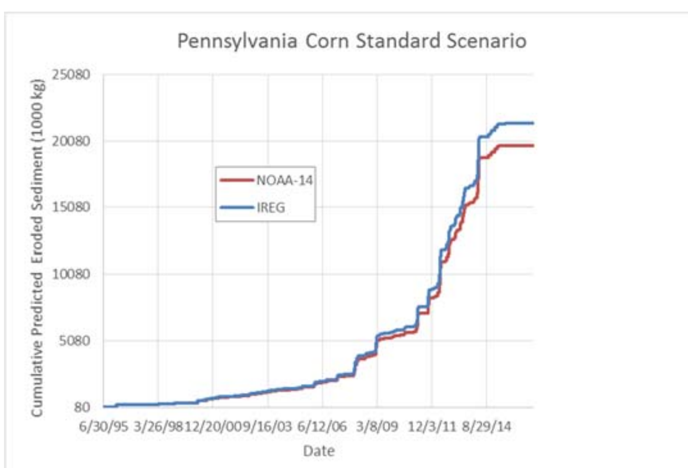

Figure 2. 29 Cumulative Daily PRZM5.0 Predicted Off-field Eroded Sediment – 1995-2016 – Pennsylvania Corn EPA Standard Environmental Crop Scenario

2.5 Conclusions

The objective of this research was to develop a method to update the EPA regulatory model PRZM5.0 to improve its internal erosion algorithm to better simulate storm intensity conditions which have changed over time due to climate change in the U.S. This research found that PRZM5.0 simulates storm intensity with the 1986 NRCS internal empirical algorithm, “IREG” storm intensity distribution system. NRCS is in the process of creating a new replacement system, “NOAA-14”, which is more temporally current and spatially representative of the varying geographical conditions in the U.S.

For this research, a custom version of PRZM5.0 was developed which, in addition to the usual “IREG storm intensity distribution system”, allows the user to simulate the “NOAA-14” storm intensity distribution systems for six EPA PRZM5.0 standard environmental crop scenarios from six different states and five different crops. Then this custom PRZM5.0 version was tested to evaluate the effect of the “NOAA-14” coefficients compared to the “IREG” coefficients on predicted off-field eroded sediment loads using the six selected EPA PRZM5.0 standard environmental crop scenarios and two weather time series, 1961-1990 and 1991-2016.

Results from this research found that for the majority of the PRZM5.0 simulations, the “NOAA-14” storm intensity distribution system predicted statistically higher off-field loadings of eroded sediment than the “IREG” storm intensity distribution system, with increase in off-field eroded sediment loadings increasing by 0.3% to as high as 69%. [The exception was the Maine potato scenario which has slightly higher predictions from the “IREG” storm intensity distribution system, but the predicted loadings are very close between the two systems. A possible explanation for this behavior may be attributable to the cold climate in Maine].

These findings indicate that if the internal erosion algorithms in PRZM5.0 are not updated to use the new spatially variable and temporally current "NOAA-14" storm intensity coefficients, it may be under-estimating off-field loadings of eroded sediment and, consequently, sorbed pesticide residues for loading into surface water models for risk assessment.

2.6 Future Work

This research provides a potential improvement PRZM5.0 to better represent current storm intensity conditions in the U.S. by modifying the Fortran code to include the "NOAA-14" storm intensity coefficients in lieu of the old 1986 "IREG' storm intensity distribution coefficients. Currently, the "NOAA-14" system is not complete for much of the U.S. Suggested future work may include:

(1) Developing a new version of PRZM5.0 with the complete set of "NOAA-14" storm intensity distribution coefficients (when the set is complete).

(2) Comparison modelling of PRZM5.0 predicted eroded sediment using "NOAA-14" storm intensity coefficients with measured off-field eroded sediment from field studies. A limitation is that available field studies in the literature are from the 1990's and are based on storm intensity conditions during that timeframe. Since storm intensity is now higher, additional field studies with higher storm intensity may be needed to truly evaluate model performance.

(3) Comprehensive patterns of "IREG" versus "NOAA-14" behavior in PRZM 5.0 across the entire US, either spatially or temporally, cannot be made since only a limited set of "NOAA-14" storm intensity coefficients were available for this work.

This is especially true given that there is not yet any available coefficients for California, Oregon, Washington, Florida, or much of the Midwest. As additional "NOAA-14" storm intensity coefficients become available, patterns of lower or greater prediction of off-field eroded sediment by 'NOAA-14" versus "IREG will allow for quantitative comparisons to be made between the two systems.

(4) Update all of the EPA standard environmental crop scenarios to their appropriate "NOAA-14" coefficient assignment after PRZM5.0 software has been updated to include the complete"'NOAA-14" storm intensity distribution coefficient system.

(5) Some high sorption pesticides may need re-evaluation of their surface water modelling with the new "NOAA-14" coefficients to guarantee that off-field loadings of the pesticide are not under-estimated.

2.7 References

(1) Benzaghta, M.A., T.A. Mohammed and A.I. Ekhmaj (2012). Prediction of Evaporation from Algardabiya Reservoir. Libyan Agriculture research Center Journal International 3 (3): 120-128, 2012.

(2) Burns, L.A. (2006). User Manual for EXPRESS, the EXAMS-PRZM Exposure Simulation Shell -Version 1.03.02, July 20, 2007. U. S. Environmental Protection Agency, Office of Research and Development, Washington D.C. 20460. EPA/600/R-06/095 September 2006.

(3) EPA. 2009. Guidance for Selecting Input Parameters in Modelling the Environmental Fate and Transport of Pesticides, Version 2.1. U. S. Environmental Protection Agency, Office of Pesticide Programs, Environmental Fate and Effects Division. October 22, 2009.

(4) FAO (1990). Crop Evapotranspiration – Guidelines for Computing crop water requirements – Chapter 3 – Meteorological Data. The Food and Agriculture Organization of the United Nations - Natural Resources Management and Environment Department. http://www.fao.org/docrep/x0490e/x0490e07.htm.

(5) Jones, R. D., S Abel, W. Effland, R Matzner, and R. Parker (1998). An Index Reservoir for Use in Assessing Drinking Water Exposure. Chapter IV in Proposed Methods for Basin-Scale Estimation of Pesticide Concentrations in Flowing Water and Reservoirs for Tolerance Reassessment., presented to the FIFRA Science Advisory Panel, July 29, 1998.

(6) NRCS (2011). Engineering Field Handbook Chapter 2: Estimating Runoff and Peak Discharges. Pennsylvania Notice 34 Supplement. NRCS. 210-VI-NEH-650-2, Notice PA-34 Supplement – November 2011.

(7) NRCS (2015). National Engineering Handbook. Part 630 Hydrology. Chapter 4 (DRAFT) Storm Rainfall Depth and Distribution. NRCS 210-NEH, 3/93.

(8) Palecki, M.A., J.R. Angel, and S.E. Hollinger (2005). Storm Precipitation in the United States. Part I: Meteorological Characteristics. Journal of Applied Meteorological Society. Vol 44, pp. 933-946. DOI: http://dx.doi.org/10.1175/JAM2243.1. Published online 2010.

(9) Singh, V.P., editor (1995). Computer Models of Watershed Hydrology. Water Resources Publications, Highlands Ranch, Colorado, USA.

(10) Suarez, L.A. (2005). PRZM-3, A Model for Predicting Pesticide and Nitrogen Fate in the Crop Root and Unsaturated Soil Zones: User's Manual for Release 3.12.2. US EPA. Office of Research and Development. Athens Georgia.

(11) Wischmeier, W. H., and D. D. Smith (1978). Predicting Rainfall Erosion Losses - A Guide to Conservation Planning. Agriculture Handbook 537, U.S. Department of Agriculture, Washington, DC, USA.

(12) Young, D.F. and M.M. Fry (2014). PRZM5, A Model for Predicting Pesticide in Runoff, Erosion and Leachate: User Manual. USEPA: Office of Pesticide Programs, Washington, D.C. USEPA/OPP 734F14002.

CHAPTER 3 - COMPARISON OF TWO METHODS FOR ESTIMATING RUNOFF CURVE NUMBERS FOR PREDICTION OF OFF-FIELD RUNOFF BY THE US EPA MODEL PRZM5.0 TO ADDRESS INCREASE IN RUNOFF QUANTITY DUE TO CLIMATE CHANGE

3.1 Introduction

EPA uses PRZM5.0 with a series of geographically specific environmental standard crop scenarios with 30 year daily rainfall time series data to evaluate the behavior of pesticides on agricultural fields. Rainfall events are simulated which may result in predicted off-field runoff and consequently, dissolved pesticide mass (Burns, 2006). Recent climate change concern has raised the question has to whether the current PRZM5.0 EPA standard environmental crop scenarios are adequately simulating established runoff quantities across the U.S. based on the current runoff estimation method.

The objective of this phase of the research was to develop an alternative method for identifying runoff curve numbers for input into PRZM5.0 which represent revised weather conditions due to climate change and are geographically representative. To estimate off-field loading of runoff, PRZM5.0 uses the NRCS Curve Number (CN) method (NRCS 2003) which requires user input of the hydrologic soil-cover complexes (CNs). For the majority of the EPA PRZM5.0 standard environmental crop scenarios, these CNs were identified by the common "table look-up" method which involves having the user identify the CN numbers using a lookup table like the table from the GLEAMS User's Manual displayed in Figure 3.1 (Knisel et al., 1994).

The "lookup" table method is based solely on general land-use, soil hydrologic group, hydrologic condition, and crop management practice. It is neither weather condition specific nor geographically location specific. This research developed a revised runoff curve number

	Cover		Hydraulic Soil Group			
Land Use	**Treatment or Practice**	**Hydrologic Condition**	**A**	**B**	**C**	**D**
Fallow Row crops	Straight Row	—	77	86	91	94
	Straight Row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured and terraced	Poor	66	74	80	82
	Contoured and terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	83	87
	Contoured	Good	61	73	81	84
	Contoured and terraced	Poor	61	72	79	82
	Contoured and terraced	Good	59	70	78	81
Close-seeded legumes[b] or rotation meadow	Straight row	Poor	66	77	85	89
	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured and terraced	Poor	63	73	80	83
	Contoured and terraced	Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow		Good	30	58	71	78
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		—	59	74	82	86
Roads (dirt)[c]		—	72	82	87	89
(hard surface)[c]		—	74	84	90	92

Figure 3. 1 Runoff Curve Number Table From PRZM3.12.2 User Manual (Knisel et al., 1994)

calculation method based on the NRCS single event manual location-specific approach which uses observed streamflow data which is detailed in the 2015 USDA National Engineering Handbook (Part 630 – Hydrology Chapter 5 Streamflow Data) (NRCS, 2015).

This revised method expanded the NRCS single event approach for use with long-term weather time series (for this research, 56 years of daily weather data) to statistically estimate annual runoff curve numbers for multiple locations within a geographical location. Then the average runoff curve numbers of the multiple locations are determined as the recommended runoff curve number for the geographical location and land-use of interest. This revised method is sensitive to changes in weather conditions, runoff patterns, geographical specific conditions, land-use and soil conditions. It is also sensitive to changes in weather and land-use conditions over time.

A series of six PRZM5.0 EPA standard environmental crop scenarios were run using both the EPA identified runoff curve numbers from the table "look-up" method and the revised method runoff curve numbers from this research and compared using both the standard EPA 1961-1990 SAMSON weather time series and a non-standard but more recent, 1991-2016 weather time series (compiled specifically for this research) to evaluate differences in predicted off-field runoff. For all six EPA PRZM5.0 standard environmental crop scenarios, the table "look-up" method runoff curve numbers resulted in predictions that are sufficient for the observed 1961-1991 weather data but underestimated observed runoff for 2007-2016 time series. PRZM5.0 simulations using the runoff curves numbers estimated from 2007-2016 weather data and the revised runoff curve number method resulted in predicted runoff that sufficiently matched observed values.

3.2 Background

In agriculture, increase in rainfall intensity will result in more off-field runoff, and thus, potential for more pesticides to move out of agricultural fields and contaminate nearby surface water bodies (Jones et al., 1998, EPA. 2009). When pesticides are applied to agricultural fields, they can enter off-target surface water via being dissolved in agricultural field runoff. Rainfall is the primary driver of runoff. Thus, proper representation of “real-world” rainfall behavior in pesticide environmental modelling is essential (Jones et al, 1998). PRZM5.0 is the model that EPA uses to simulate an agricultural field receiving a pesticide application. It is one-dimensional, dynamic, compartmental model that can be used to simulate chemical and water movement within and immediately below the plant root zone of the soil profile. It is comprised of two major components: hydrology and chemical transport (Suarez, 2005).

In the hydrology component , PRZM5.0 simulates runoff using the NRCS Curve Number (CN) method (NRCS, 2003) and a process of partitioning user input daily precipitation between soil infiltrated water and surface runoff (Suarez, 2005). It uses the user input CN value to represent the average antecedent condition, CNII. Then it calculates the associated low (CNI) and high (CNIII) antecedent conditions from the CN tables provided by NRCS (NRCS, 2003). PRZM5.0 then calculates the average soil moisture in the top 10 cm of soil for each day to determine the adjusted daily predicted CN value based on this soil moisture (Young and Fry, 2014).

Then using this calculated adjusted daily predicted CN value, the NRCS Curve Number (CN) method is used to estimate runoff from the daily precipitation using the following formula:

$$Q = \begin{cases} 0 & , P \leq 0.2S \\ \dfrac{(P - 0.2S)^2}{P + 0.8S} & , P > 0.2S \end{cases}$$

(eq. 3.1)

Where Q = runoff (cm)

P = Precipitation (cm)

S = potential maximum retention (cm), is related to soil type, crop cover, and management practices

S is calculated from user input CN as follows:

$$S = \frac{2540}{CN} - 25.4$$

(eq. 3.2)

(Young and Fry, 2016)

The above Runoff Curve number method was originally developed by the Soil Conservation Service (now NRCS) in the early 1950's as an "inter-agency" tool for the estimation of runoff from rainfall events on small agricultural fields. It was never published or subjected to the peer-review process. The method has been revised over time to account for changes in land-use and changes in agricultural management practices. CN values range from 0 – 100 where 0 means no runoff and 100 indicates extreme runoff event. The CN values listed in the "look-up" tables are based on empirical evaluations of runoff depth as a function of rainfall, land-use, management practice and soil hydrologic conditions (Woodward, 1991).

Review of literature revealed there is no published research addressing whether the current table "look-up" method runoff curve number (CN) combined with 1961-1990 or updated weather time series are adequately representing observed runoff quantities for the simulated EPA PRZM5.0 standard environmental crop scenarios. Thus, the purpose of this

research was to generate a method to improve the ability of PRZM5.0 to simulate current storm runoff conditions for use in future off-field runoff and dissolved pesticide predictions using this revised runoff curve number method and thus, improve future regulatory surface water risk assessments. Additionally, it provides a method for making runoff curve numbers more geographically and land-use specific.

3.3 Materials and Methods

To estimate agricultural off-field runoff, PRZM5.0 uses the NRCS Runoff Curve Number (CN) method (NRCS, 2003) which incorporates a user-supplied CN value. The CN number is one of the most sensitive parameters in PRZM5.0 which affects not only the estimation of off-field runoff, but also the estimation of off-field pesticide mass (Estes and Hendley, 2000). For the majority of the PRZM5.0 EPA standard environmental crop scenarios, these CN values are identified using the table "look-up" method which simply involves using a NRCS runoff curve number table like the one listed in the GLEAMS User's Manual, displayed in Figure 1, to identify an appropriate curve number for each crop growth stage (e.g., fallow versus cropping), for the appropriate soil hydrologic group, and crop management practice (EPA, 2006, Knisel,1994). This table is very general, non-geographically specific, and non-weather condition specific.

For this research, the same six states and the same six EPA PRZM5.0 standard environmental crop scenarios which were selected for the eroded sediment modelling research in Chapter 2 were used for consistency. For each of the six EPA PRZM5.0 standard environmental crop scenarios, the CN values were identified by EPA using the GLEAMS User's Manual for both cropping and fallow conditions (EPA, 2006). Since these CN values

were generated over 20 years ago, it was hypothesized that using them in PRZM5.0 may result in under-estimation of off-field runoff for observed runoff for the 2007-2016 rainfall conditions due to climate change.

For this research, a revised method for estimating CN values was developed based on the method to manually calculate a CN value for a single runoff event as detailed in Chapter 5 – Streamflow Data of the USDA Part 630 Hydrology National Engineering Handbook (USDA, 2015). But in this research, this method was applied to continual time series from Jan.1, 1961 – Dec. 31, 2016 of streamflow data (ft^3/s). It then generates statistical annual average estimates of annual average runoff curve numbers for single streamflow locations and then average overall annual average estimates of runoff curve number for multiple streamflow locations to arrive at a robust runoff curve number over the time series of interest and the general geographical location of interest.

The detailed procedure performed for each of the six EPA PRZM5.0 standard environmental crop scenarios was as follows:

(1) Identify latitude and longitude boundaries that encapsulate the description of the cropping area described for the EPA PRZM5.0 standard environmental crop scenario (EPA, 2006).

(2) Download streamflow data for the locations with 1961-2016 data from the website http://waterdata.usgs.gov/nwis/sw using the latitude and longitude boundaries from step (1) and “Historical Observations”. Streamflow data was limited to “Lake”, “Stream”, “Spring”, “Wetland”, “Land”, and “Aggregate surface-water use”.

(3) Evaluate downloaded data was evaluated to eliminate data that was incomplete or contained missing data. Remaining data was separated into individual datasets for each location.

(4) Link daily precipitation data 1961-1990 and 1991-2016 obtained for the erosion study component of this research was with the daily streamflow data for each location. The assumption was that daily rainfall was the same for all the locations. Both the EPA provided 1961-1990 SAMSON weather time series and the time series using the same SAMSON weather stations but with Jan.1, 1991 – Dec. 31, 2016 weather time series (developed exclusively for Chapter 2 eroded sediment modelling research) were simulated to examine for potential changes in patterns between the two storm distribution systems due to changes in weather patterns over time. The 1991-2016 custom weather time series files were comprised of observed daily precipitation, temperature, and wind speed data from the same NOAA SAMSON stations as used to generate the 1961-1990 EPA weather time series. Additionally, daily pan evaporation values were estimated using the Linacre Model (Benzaghta et al., 2012) and solar radiation was estimated using the method described by the Food and Agriculture Organization of the United Nations - Natural Resources Management and Environment Department (FAO, 1990).

(5) Run Fortran program, "Runoff.f90" for each streamflow location dataset to calculate revised method annual runoff curve numbers (CN) for each streamflow location. This Fortran program was developed for this research to compute the storm runoff volumes for each runoff event. It was designed to identity the rise

and flood receding pattern of flow in order to identify the base flow values as well as the values between. It calculates the total runoff (both in ft^3/s and inches) and then the direct runoff (ft^3/s and inches) for each runoff event. It then computes the average annual runoff curve (CN) values for the streamflow location. A copy of the source code for the program, "Runoff.f90" is included in Appendix B.

(6) For each location, the overall average CN of the 1961-2016, 1961-1990, and 2007-2016 time series was calculated. Then the average CN of the combined locations was calculated for the 1961-2016, 1961-1990, and 2007-2016 time series. A recommended CN for the EPA standard environmental crop scenario was identified based on the results of these analyses.

(7) Each EPA PRZM5.0 standard environmental crop scenario was run by PRZM5.0 using both the EPA CN value and the CN value identified in step (6). These combinations were run for both the 1961-1990 SAMSON weather time series and the 1991-2016 SAMSON weather time series.

(8) Predicted annual average off-field runoff from PRZM5.0 was output for every simulation and compared to the observed annual average runoff from the multiple locations to evaluate behavior of the two different methods for estimating runoff curve number (CN) values.

The six EPA PRZM5.0 standard environmental crop scenarios evaluated for this study are detailed in Table 3.1.

Table 3. 1 PRZM5.0 EPA Standard Environmental Crop Scenarios Included in Runoff Study

State	Crop	PRZM5.0 EPA Standard Environmental Crop Scenario CN Values	Number of Locations in CN Revised Method Calculations
Georgia	Peach	67, 78	4
Indiana	Corn	84, 91	39
Louisiana	Sugar Cane	87	9
Maine	Potatoes	86, 89	8
North Carolina	Peanuts	84, 89	6
Pennsylvania	Corn	83, 89	6

3.4 Results and Discussion

The observed runoff and precipitation statistical results as well as calculated runoff curve number (CN) for each state from the revised runoff curve number method from this research are detailed below. For each state, a CN number was recommended based on the results of the CN analyses. These values were as follow: Georgia: 91 (Average of 2007 – 2016 CN values); Indiana: 88 (Same value for all averaging approaches); Louisiana: 87 (Average of 2007 – 2016 CN values); Maine: 91 (Same value for all averaging approaches); North Carolina: 89 (Average of 2007 – 2016 CN values); and Pennsylvania: 93 (Average of 1961 - 1990 CN values). PRZM5.0 EPA standard environmental crop scenarios were run with these CN values to evaluate how their predicted runoff results compared to the predicted runoff results from the EPA table “look-up method against observed runoff quantities. The results of these comparisons are detailed in Tables 3.2 – 3.7

Table 3. 2 Georgia Precipitation, Runoff, CN, and PRZM5.0 Standard EPA Environmental Crop Scenario Analysis Results

Georgia Observed Precipitation (in)			
Annual Overall Average 1961- 2016	45.44	standard deviation	8.10
1961-1990 Annual Average	44.91	standard deviation	6.50
2007-2016 Annual Average	46.39	standard deviation	13.01

Georgia Revised Method Calculated CN Values and Observed Runoff					
	1961-2016 Overall CN	CN 1961-1990	CN 2007-2016	Annual Runoff (in) 1961-1990	Annual Runoff (in) 2007 - 2016
Average	89	90	91	8.75	11.91
Standard Deviation	1	2	4	6.32	6.19

EPA "Look-Up" Method CN Value Georgia PRZM5 Predicted Annual Runoff Averages (in)			
Overall Annual Average 1961-2016	4.46	Standard Deviation	2.27
Annual Average 1961 – 1990	3.48	Standard Deviation	1.66
Annual Average 2007 – 2016	5.73	Standard Deviation	2.67

Revised Method CN Georgia PRZM5 Predicted Annual Runoff Averages (in)			
Overall Annual Average 1961-2016	17.07	Standard Deviation	5.23
Annual Average 1961 – 1990	15.08	Standard Deviation	3.87
Annual Average 2007 – 2016	19.79	Standard Deviation	7.66

For Georgia, statistical analysis of the precipitation data indicates that average annual rainfall increased by 1.48 inches for the time period 2007 – 2016 compared to 1961-1990 with greater variability since the standard deviation increased by 6.51 inches.

Statistical evaluation of the observed runoff data between the 4 streamflow data locations indicates an annual average increase of 3.16 inches between of 1961-1990 and 2007-2016. The range of estimated revised method CN values from the revised method for the 4 locations was fairly tight indicating that that variation was sensitive to temporal changes due to rainfall but insensitive to location of the data source streamflow data. Even then, the overall range of annual estimated revised method CN values was tight, ranging from 89-91 with a standard deviation range of 2-4.

When the PRZM5.0 EPA standard Georgia Peach environmental crop scenario simulation was run with the EPA table "look-up" method CN values of 67 for cropping and 78 for fallow conditions, all observed runoff depths were under-estimated. For this scenario, this was attributed to the selection of the "meadow" category in the table look-up for curve number selection which is probably a poor representation of peach orchard land-use conditions. For the 1961-1990 weather time series, average annual observed runoff was under-estimated by over 5 inches and for the 2007-2016 weather time series, average annual observed runoff was under-estimated by over 7 inches.

When the PRZM5.0 EPA standard Georgia Peach environmental crop scenario simulation was run with the recommended CN values from the revised method, PRZM5.0 predicted off-field runoff over-predicted average annual observed runoff for the 4 streamflow locations and covered up to two standard deviations. This indicates that the recommended CN value is not excessively over-predicting off-field runoff for use with PRZM5.0 for regulatory purposes for simulating current weather conditions for the Georgia peach scenario as EPA standard environmental crop scenarios are designed to be conservative.

Table 3. 3 Indiana Precipitation, Runoff, CN, and PRZM5.0 Standard EPA Environmental Crop Scenario Analysis Results

Indiana Observed Precipitation (in)			
Annual Overall Average 1961-2016	41.50	standard deviation	6.36
1961-1990 Annual Average	39.91	standard deviation	5.39
2007-2016 Annual Average	43.74	standard deviation	5.78

Indiana Revised Method Calculated CN Values and Observed Runoff					
	1961-2016 Overall CN	CN 2007-2016	CN 1961-1990	Annual Runoff (in) 1961-1990	Annual Runoff (in) 2007 - 2016
Average	88	88	88	11.90	13.46
Standard Deviation	3	3	3	3.88	5.27

EPA Table "Look-Up" Method CN Indiana PRZM5 Predicted Annual Runoff Averages (in)			
Overall Annual Average 1961-2016	11.53	Standard Deviation	4.34
Annual Average 1961 – 1990	9.01	Standard Deviation	2.46
Annual Average 2007 – 2016	14.98	Standard Deviation	3.74

Revised Method CN Indiana PRZM5 Predicted Annual Runoff Averages (in)			
Overall Annual Average 1961-2016	10.98	Standard Deviation	4.30
Annual Average 1961 - 1990	8.50	Standard Deviation	2.45
Annual Average 2007 - 2016	14.15	Standard Deviation	3.61

For Indiana, statistical analysis of the precipitation data indicates that average annual rainfall increased by 3.83 inches for the time period 2007 – 2016 compared to 1961-1990 though the standard deviation only increased by 0.39 inches indicating not much change in variability. Statistical evaluation of the observed runoff data between the 39 streamflow locations indicate an annual average increase of 1.56 inches between of 1961-1990 and 2007-2016 with a standard deviation increase of 1.39 inches.

The range of estimated revised method runoff curve number (CN) values for the 39 streamflow locations was extremely tight indicating that that variation was sensitive only to temporal changes due to rainfall and insensitive to data source streamflow location. Even then, the annual average estimated revised method CN value was consistently estimated to be 88, independent of timeframe, with a standard deviation of 3.

When the PRZM5.0 EPA standard Indiana corn environmental crop scenario simulation was run with the EPA table "look-up" CN values of 84 for cropping and 91 for fallow conditions, overall 1961-2016, and 1961-1990 observed runoff depths were under-estimated. The 2007-2016 annual average runoff depth was slightly over-estimated but was then under-estimated at one standard deviation.

When the PRZM5.0 EPA standard Indiana corn environmental crop scenario simulation was run with the recommended CN value of 88 from the revised method from this research, PRZM5.0 showed the same behavior as with the EPA CN "look-up" table method values of 84 for cropping and 91 for fallow. This makes sense since 88 is the average of 84 and 91 and would basically act accordingly in the model per runoff behavior over the year. Thus, the recommended CN value from the revised method from this research did not improve runoff prediction performance for the Indiana Corn EPA standard environmental crop scenario and weather series.

Table 3. 4 Louisiana Precipitation, Runoff, CN, and PRZM5.0 Standard EPA Environmental Crop Scenario Analysis Results

Louisiana Observed Precipitation (in)			
Annual Overall Average 1961-2016	61.07	standard deviation	11.74
1961-1990 Annual Average	61.45	standard deviation	12.05
2007-2016 Annual Average	64.23	standard deviation	12.34

Louisiana Revised Method CN Values and Observed Runoff					
	1961 – 2016 Overall CN	CN 1961-1990	CN 2007-2016	Annual Runoff (in) 1961-1990	Annual Runoff (in) 2007 - 2016
Average	86	86	87	21.72	22.00
Standard Deviation	3	3	3	6.50	7.41

EPA Table "Look-Up" Method CN Value Louisiana PRZM5 Predicted Annual Runoff Averages (in)			
Overall Annual Average 1961-2016	23.62	Standard Deviation	7.24
Annual Average 1961 - 1990	22.27	Standard Deviation	7.16
Annual Average 2007 - 2016	27.33	Standard Deviation	7.91

Revised Method CN Louisiana PRZM5 Predicted Annual Runoff Averages (in)			
Overall Annual Average 1961-2016	23.62	Standard Deviation	7.24
Annual Average 1961 - 1990	22.27	Standard Deviation	7.16
Annual Average 2007 - 2016	27.33	Standard Deviation	7.91

For Louisiana, statistical analysis of the precipitation data indicates that average annual rainfall increased by 2.78 inches for the time period 2007 – 2016 compared to 1961-1990 with a standard deviation increase of only 0.29 inches. Statistical evaluation of the observed runoff data between the 9 streamflow locations indicates an annual average increase of only 0.28 inches with a standard deviation increase of only 0.91 inches between of 1961-1990 and 2007-2016, indicating not much change.

The range of estimated revised method runoff curve number (CN) values for the 9 streamflow locations was extremely tight indicating that that variation was sensitive only to temporal changes due to rainfall and insensitive to data source streamflow location. Even then, the overall range of annual estimated revised method CN values ranged only from 86-87 with a standard deviation of 3.

The EPA table "look-up" CN value for the Louisiana sugarcane standard environmental crop scenario is 87 for both cropping and fallow conditions. The recommended revised method CN calculated for this research is also 87. Thus, the PRZM5.0 simulations for the EPA CN table "look-up" method versus the recommended revised method CN for this research are identical and yield identical results. The predicted runoff from PRZM5.0 for the Louisiana sugarcane EPA standard environmental crop scenario with CN set to 87 average annual predicted runoff over-predicted the observed for the 1961-1990 by 0.55 inches, and 2007-2016 weather series by 5.33 inches. In both cases, the standard deviation of the PRZM5.0 predicted runoff was larger than the observed standard deviation, thus, this CN value should be protective for regulatory purposes and surface water modelling with PRZM5.0.

Table 3. 5 Maine Precipitation, Runoff, CN, and PRZM5.0 Standard EPA Environmental Crop Scenario Analysis Results

Maine Observed Precipitation (in)			
Annual Overall Average 1961-2016	38.51	standard deviation	6.48
1961-1990 Annual Average	36.60	standard deviation	5.88
2007-2016 Annual Average	44.63	standard deviation	6.36

Maine Revised Method CN Values and Observed Runoff					
	1961 – 2016 Overall CN	CN 2007-2016	CN 1961-1990	Annual Runoff (in) 1961-1990	Annual Runoff (in) 2007 - 2016
Average	91	91	91	7.15	9.54
Standard Deviation	2	2	2	3.35	4.82

EPA Table "Look-Up" Method CN Maine PRZM5 Predicted Annual Runoff Averages (in)			
Overall Annual Average 1961-2016	8.19	Standard Deviation	3.32
Annual Average 1961 – 1990	6.52	Standard Deviation	2.55
Annual Average 2007 - 2016	12.33	Standard Deviation	2.81

Revised Method CN Maine PRZM5 Predicted Annual Runoff Averages (in)			
Overall Annual Average 1961-2016	11.29	Standard Deviation	4.20
Annual Average 1961 - 1990	9.10	Standard Deviation	3.18
Annual Average 2007 - 2016	16.53	Standard Deviation	3.67

For Maine, statistical analysis of the precipitation data indicate that average annual rainfall increased by 8.03 inches for the time period 2007 – 2016 compared to 1961-1990 with an increase in standard deviation of only 0.48 inches. Statistical evaluation of the observed runoff data between the 8 streamflow locations indicates an annual average increase of 2.39 inches between of 1961-1990 and 2007-2016 with an increase in standard deviation of 1.47 inches.

The range of estimated revised method CN values for the 8 streamflow locations was extremely tight indicating that variation was sensitive only to temporal changes due to rainfall and insensitive to data source streamflow location. The annual estimated revised method CN value was 91 for all timeframes with a standard deviation of 2.

When the PRZM5.0 EPA standard Maine Potato environmental crop scenario simulation was run with the EPA table "look-up" method CN values of 86 for cropping and 89 for fallow conditions, overall 1961-2016 and 1961-1990 observed runoff depths were under-estimated. The 2007-2016 annual average runoff depth was slightly over-estimated but was then under-estimated at two standard deviations.

When the PRZM5.0 EPA standard environmental Maine Potato crop scenario simulation was run with the revised method recommended CN values of 91, PRZM5.0 predicted off-field runoff over-predicted average annual observed runoff for the 8 streamflow locations and covered up to two standard deviations. This indicates that the revised method CN value is not excessively over-predicting off-field runoff when used with PRZM5.0 for regulatory purposes for simulating current weather conditions for the Maine potato EPA standard environmental crop scenario.

Table 3. 6 North Carolina Precipitation, Runoff, CN, and PRZM5.0 Standard EPA Environmental Crop Scenario Analysis Results

North Carolina Observed Precipitation (in)			
Annual Overall Average 1961-2016	43.23	standard deviation	6.61
1961-1990 Annual Average	41.26	standard deviation	5.33
2007-2016 Annual Average	46.24	standard deviation	7.65

North Carolina Revised Method CN Values and Observed Runoff					
	1961 – 2016 Overall CN	CN 2007-2016	CN 1961-1990	Annual Runoff (in) 1961-1990	Annual Runoff (in) 2007 - 2016
Average	88	87	89	10.66	11.84
Standard Deviation	4	3	4	4.39	4.27

EPA Table "Look-Up" Method CN North Carolina PRZM5 Predicted Annual Runoff Averages (in)			
Overall Annual Average 1961-2016	10.17	Standard Deviation	4.30
Annual Average 1961 – 1990	7.36	Standard Deviation	1.90
Annual Average 2007 - 2016	13.95	Standard Deviation	3.51

Revised Method CN North Carolina PRZM5 Predicted Annual Runoff Averages (in)			
Overall Annual Average 1961-2016	12.27	Standard Deviation	4.93
Annual Average 1961 – 1990	9.06	Standard Deviation	2.14
Annual Average 2007 – 2016	16.63	Standard Deviation	4.18

For North Carolina, statistical analysis of the precipitation data indicates that average annual rainfall increased by 4.98 inches for the time period 2007 – 2016 compared to 1961-1990 with a standard deviation increase of 2.32 inches. Statistical evaluation of the observed runoff data between the 6 streamflow locations indicates an annual average increase of 1.18 inches with a standard deviation decrease of 0.12 inches between of 1961-1990 and 2007-2016.

The range of estimated revised method CN values for the 6 streamflow locations was extremely tight indicating that that variation was sensitive only to temporal changes due to rainfall and insensitive to data source streamflow location. Even then, the overall range of annual estimated revised method CN values ranged only from 87-89 with a standard deviation range of 3-4.

The EPA table "look-up" method CN value for the North Carolina Peanut EPA PRZM5.0 standard environmental crop scenario is 84 for cropping and 89 for fallow conditions. The recommended revised method CN for this research is also 89. Thus, the PRZM5.0 simulations for the EPA table "look-up" method CN versus the revised method CN for this research are identical during fallow conditions and will yield identical results for runoff events during those time periods. Differences will only occur during simulated cropping periods.

Both the EPA table "look-up" method CN value combination of 84 and 89 North Carolina Peanut PRZM5.0 environmental standard crop scenario and the revised method CN value of 89 North Carolina Peanut PRZM5.0 environmental standard crop scenario simulations had predicted results which under-estimated annual average runoff for the 1961-1990 weather time series (though the revised method results were closer to the observed) and predicted results which over-estimated annual average runoff results for the 2007-2016 weather time series, with the EPA table "look-up" method results being closer to the observed.

Table 3. 7 Pennsylvania Precipitation, Runoff, CN, and PRZM5.0 Standard EPA Environmental Crop Scenario Analysis Results

Pennsylvania Observed Precipitation (in)			
Annual Overall Average 1961-2016	47.69	standard deviation	33.80
1961-1990 Annual Average	39.46	standard deviation	9.09
2007-2016 Annual Average	95.13	standard deviation	55.99

Pennsylvania Revised Method CN Values and Observed Runoff					
	1961-2016 Overall CN	CN 1961-1990	CN 2007-2016	Annual Runoff (in) 1961-1990	Annual Runoff (in) 2007 - 2016
Average	88	93	76	11.69	23.00
Standard Deviation	3	3	6	7.49	6.85

EPA Table "Look-Up" Method CN Value Pennsylvania PRZM5 Predicted Annual Runoff Averages (in)			
Overall Annual Average 1961-2016	12.11	Standard Deviation	18.20
Annual Average 1961 - 1990	7.10	Standard Deviation	3.20
Annual Average 2007 - 2016	38.88	Standard Deviation	31.36

Revised Method CN Pennsylvania PRZM5 Predicted Annual Runoff Averages (in)			
Overall Annual Average 1961-2016	19.88	Standard Deviation	24.76
Annual Average 1961 - 1990	13.32	Standard Deviation	4.74
Annual Average 2007 - 2016	56.15	Standard Deviation	42.13

For Pennsylvania, statistical analysis of the precipitation data indicates that average annual rainfall increased tremendously by 55.67 inches for the time period 2007 – 2016 compared to 1961-1990 with a standard deviation increase of 46.90 inches. Investigation into the observed rainfall data confirmed these statistics with the years 2011-2014 having extreme escalation in rainfall totals compared to previous rainfall history. Statistical evaluation of the observed runoff data between the 6 streamflow locations indicates an annual average increase of 11.31 inches with a standard deviation decrease of only 0.64 inches between of 1961-1990 and 2007-2016.

The range of estimated revised method CN values for the 6 streamflow locations was relatively tight indicating that that variation was sensitive only to temporal changes due to rainfall and insensitive to data source streamflow location. The overall range of annual estimated average revised method CN values ranged from 76 - 88 with a standard deviation range of 3-6.

The EPA table "look-up" method CN values for the Pennsylvania Corn EPA PRZM5.0 standard environmental crop scenario are 83 for cropping and 89 for fallow conditions. The PRZM5.0 simulations for this standard scenario resulted in under-prediction for the 1961- 1990 weather time series and severe over-prediction (by over x1.5) for the 2007-2016 weather time series.

The recommended revised method CN value for the Pennsylvania Corn EPA PRZM5.0 standard environmental crop scenario is 93 for both cropping and fallow conditions. The PRZM5.0 simulations for this standard scenario resulted in slight over-prediction for the 1961-1990 weather time series (until under-prediction for second standard deviation) and severe over-prediction (by over 2x) for the 2007-2016 weather time series.

3.5 Conclusions

The first objective of this research was to evaluate the current NCRS runoff curve (CN) table "look-up" method runoff predictions as used in PRZM5.0 to predict off-field runoff for EPA sPRZM5.0 standard environmental crop scenarios using the standard 1961-1990 weather time series and a custom 1991-2016 weather time series (developed for this research). The CN values used in these EPA PRZM5.0 standard environmental crop scenarios were all identified using a table look-up method based on a table from the GLEAMS User's Manual (Knisel, 1994).

The second objective of this research was to develop a revised method for calculating runoff curve (CN) numbers for use in PRZM5.0 surface water risk assessment modelling with the EPA PRZM5.0 standard environmental crop scenarios. A revised method based on the calculation of a runoff curve number (CN) for single event streamflow data by NRCS was developed (NRCS, 2003). Custom software was developed that takes the single streamflow event method and extends it over long-term daily events and then calculates annual average runoff curve numbers based on the average curve numbers from the runoff events throughout the year. The software generates a series of annual runoff curve numbers from streamflow data. For this research, streamflow time series for each location had daily data from 1961-2016 and the software generates annual average runoff curve numbers for each streamflow location for each of the 56 years. From the 56 years of annual average calculated runoff curve numbers, an overall runoff curve number was calculated. Finally, the overall average runoff curve number for all streamflow locations was calculated for 1961-2016 as well as 1961-1990 and 2007-2016 to examine whether the runoff curve numbers were temporally sensitive.

The runoff curve (CN) values estimated from this revised method for each of the six state/geographical locations associated with the EPA PRZM5.0 standard environmental crop scenarios were simulated and then predicted off-field runoff results were compared to those generated with results from PRZM5.0 simulations with the EPA table "look-up" method runoff curve (CN) values for the same standard scenarios.

The major findings from this work were:

(1) Annual precipitation increased at all six weather station sites between the weather time series 1961-1990 and 2007-2016. Increases ranged from 1.48 inches to 55.56 inches. The consistent increase across the six states indicates change in climate.

(2) Annual average runoff increased at all six streamflow locations associated with the six EPA PRZM5.0 standard environmental crop scenarios. Increases ranged from 0.28 inches to 11.31 inches. Again, the consistency indicates changes in climate and is an indicator in change in storm intensity across the U.S.

(3) The revised method runoff curve number (CN) did not vary greatly between nearby streamflow locations. Variability appeared to be temporal rather than spatial.

(4) Five of the six EPA PRZM5.0 standard environmental crop scenarios simulated with the EPA table "look-up" method CN values resulted in under-estimation of observed off-field runoff for either the 1961-1990 or 2007-2016 weather time series. The consequence of this under-estimation for pesticide risk assessment would be potential under-estimation of off-field pesticide mass, especially for dissolved pesticide mass. This would affect highly water soluble pesticides the most.

(5) The only EPA PRZM5.0 standard environmental crop scenarios that the revised runoff curve number (CN) method under-estimated off-field runoff compared to

observed runoff were the Indiana corn scenario (1961-1990, and 1991-2016 after one standard deviation) and 1961-1990 weather time series for North Carolina peanut scenario.

Given the results of this research, the revised method of calculating runoff curve numbers (CN) based on time series of streamflow data developed for this research showed potential improvement in predicting off-field runoff for use with EPA PRZM5.0 standard environmental crop scenarios, especially with updated weather time series.

3.6 Future Work

Potential Future Work may include the following:

(1) Revise the runoff curve numbers, CN, for the remaining EPA PRZM5.0 standard environmental crop scenarios using the method developed for this research

(2) Improve the NRCS Runoff Curve (CN) method to better fit contemporary observed runoff data.

(3) Conduct agricultural field runoff studies with runoff quantities that better match contemporary runoff quantities.

(4) Many other models use the NRCS Runoff Curve (CN) method and the table "look-up" method for identifying runoff curve numbers for model parameterization. Results of this research indicate that this method may result in model under-estimation of off-field runoff. Future work may include extending this work to evaluating how runoff curve numbers estimated using this revised method perform in other models that currently use the NRCS Runoff Curve (CN) method to estimate off-field runoff.

3.7 References

(1) Benzaghta, M.A., T.A. Mohammed and A.I. Ekhmaj (2012). Prediction of Evaporation from Algardabiya Reservoir. Libyan Agriculture research Center Journal International 3 (3): 120-128, 2012.

(2) Estes, T.L., and P. Hendley (2000). The Sensitivity of PRZM-EXAMS to Key Assumptions – Implications for Pesticide Aquatic Risk Assessments. Poster: 21st Annual Meeting of the Society of Environmental Toxicology and Chemistry, Nashville, Tennessee.

(3) FAO (1990). Crop Evapotranspiration – Guidelines for Computing crop water requirements – Chapter 3 – Meteorological Data. The Food and Agriculture Organization of the United Nations - Natural Resources Management and Environment Department, http://www.fao.org/docrep/x0490e/x0490e07.htm.

(4) Jones, R. D., S Abel, W. Effland, R Matzner, and R. Parker (1998). An Index Reservoir for Use in Assessing Drinking Water Exposure. Chapter IV in Proposed Methods for Basin-Scale Estimation of Pesticide Concentrations in Flowing Water and Reservoirs for Tolerance Reassessment., presented to the FIFRA Science Advisory Panel, July 29, 1998.

(5) Knisel, W.G., ,F.M. Davis, and R.A. Leonard (1994) GLEAMS Version 2.0 –Part III: User Manual. USDA-ARS, Coastal Plain Experiment Station. Southeast Watershed Research Laboratory. Tifton, Georgia, 31793.200 pp.

(6) NRCS (2003). National Engineering Handbook Section 4: Hydrology. Natural Resources Conservation Service, United States Department of Agriculture, Washington DC.

(7) NRCS (2015). National Engineering Handbook. Part 630 Hydrology. Chapter 5 Streamflow Data. NRCS 210-VI-NEH, Amend. 76, November 2015.

(8) Suarez, L.A. (2005). PRZM-3, A Model for Predicting Pesticide and Nitrogen Fate in the Crop Root and Unsaturated Soil Zones: User’s Manual for Release 3.12.2. US EPA. Office of Research and Development. Athens Georgia.

(9)Woodward, D.E. (1991). Progress Report ARS/SCS Runoff Curve Number Work Group. ASAE Paper 912607. Chicago IL.

(10) Young, D.F. and M.M. Fry (2014). PRZM5, A Model for Predicting Pesticide in Runoff, Erosion and Leachate: User Manual. USEPA: Office of Pesticide Programs, Washington, D.C. USEPA/OPP 734F14002.

CHAPTER 4 COMPARISON OF TWO METHODS FOR ESTIMATING RUNOFF CURVE NUMBERS AND TWO SYSTEMS OF MUSS EROSION STORM INTENSITY COEFFICIENTS FOR PREDICTION OF OFF-FIELD PESTICIDE MASS BY THE US EPA MODEL PRZM5.0

4.1 Introduction

A key factor in the risk assessment process for the registration of pesticides by the U.S. Environmental Protection Agency (EPA) is an estimate of pesticide concentrations in surface water. Currently, EPA uses the agricultural field-scale model Pesticide Root Zone Model, version 5.0 (PRZM5.0) with a series of standard geographically-based environmental crop scenarios to estimate off-field loadings of pesticide mass which are then "loaded" into water models to estimate pesticide concentrations in surface water bodies (Young and Fry, 2014).

EPA uses PRZM5.0 with a series of geographically specific environmental standard crop scenarios with 30 year daily rainfall time series data to evaluate the behavior of pesticides on agricultural fields. Daily rainfall events are simulated which may result in predicted off-field dissolved and sorbed pesticide mass. These off-field loadings of dissolved and sorbed pesticide mass are then "dumped" into other models that simulate surface water bodies to estimate pesticide concentrations in surface water (Burns, 2006). For this reason, adequate simulation of off-field movement processes of pesticide mass by PRZM5.0 is important because it directly impacts decisions on potential pesticide risks in surface water.

Recent climate change concerns have raised the question has to whether the established EPA standard environmental crop scenarios are adequately simulating current off-field pesticide mass (both dissolved and sorbed) across the U.S. based on the current runoff and erosion estimation methods since these methods represent the 'carriers" of the off-field pesticide mass.

The previous two research components of this thesis research involved:

(1) Development of a revised method for estimating runoff curve numbers (CN) based on long-term time series of observed streamflow data from the specific geographic area to be simulated compared to the established table "look-up" method which was used to identify the runoff curve numbers (CN) used in the EPA PRZM5.0 standard environmental crop scenarios.

(2) Identification of the "NOAA-14" system of empirically derived revised peak discharge equation coefficients as a potential update to the internal "IREG" system empirically derived revised peak discharge equation coefficients built into PRZM5.0. This would update the MUSS erosion algorithm built into PRZM5.0.

The objective of this phase of the research is to evaluate how the revised runoff curve number (CN) method and NOAA-14 system coefficient system changes impact PRZM5.0 estimates of off-field pesticide mass, both dissolved and sorbed compared to the EPA established approach of using the table look-up method for identifying runoff curve numbers (CN) with IREG system of coefficients for the peak discharge equation for the MUSS erosion algorithm.

To accomplish this, three pesticides were simulated using PRZM5.0, atrazine, propiconazole, and chlorpyrifos. These three pesticides were selected to evaluate a range of sorption behavior in off-field runoff and eroded sediment. Atrazine has low sorption potential with a recommended modelling K_{OC} of 100 kg/L. Propiconazole has moderate sorption potential with a recommended modelling K_{OC} of 648. Finally, chlorpyrifos has high sorption potential with a recommended modelling K_{OC} of 6040 (Estes et al., 2015). [The three pesticides were also selected due to their sufficiently long aerobic soil metabolism half-lives: 146 days for atrazine,

109 days for chlorpyrifos and 69 days for propiconazole. Thus, the pesticides would be available for runoff versus degrading after application before runoff events occur].

The same six EPA PRZM5.0 standard environmental crop scenarios used both in Chapter 2 and Chapter 3 were run for this phase of the research for consistency. Each PRZM5.0 standard environmental crop scenario was run using both the standard EPA 1961-1990 SAMSON weather time series and a non-standard but more recent, 1991-2016 weather time series (compiled for this research) to generate 56 continuous years of predicted off-field dissolved pesticide in runoff and sorbed pesticide in eroded sediment. Each scenario was run for each of the three pesticides as well as each of the following four combinations of parameters:

(1) EPA "look-up" table method runoff curve number (CN) method with the "IREG" storm intensity coefficients method
(2) EPA "look-up" table runoff curve number (CN) method with "NOAA-14" storm intensity coefficients method
(3) Revised runoff curve number method (CN) developed for this research with "IREG" storm intensity coefficients method
(4) Revised runoff curve number method (CN) developed for this research with "NOAA-14" storm intensity coefficients method

For all of the EPA PRZM5.0 standard environmental crop scenarios and all three pesticides, the revised runoff curve number (CN) method resulted in higher off-fields estimates of dissolved pesticide mass compared to the established EPA table "look-up" method currently used for the EPA PRZM5.0 standard environmental crop scenarios (EPA, 2004). The "NOAA-14" storm intensity coefficients method resulted in slight increases in off-field sorbed mass in eroded sediment of propiconazole and chlorpyrifos. Results of this research indicate that

PRZM5.0 is highly sensitive to changes in runoff curve numbers (CN) for predictions of off-field mass of pesticides, both dissolved and sorbed.

4.2 Background

Chapter 2 discussed the identification of the NRCS "NOAA-14" storm intensity coefficient method as a potential update to the NRCS "IREG" storm intensity coefficient method which is the storm intensity algorithm currently built into PRZM5.0. In addition to being a system based on empirical analysis of more recent storm intensity data, the "NOAA-14" system is more geographically diverse than the "IREG" system. Thus, the "NOAA-14" system is more temporally current and spatially robust than the "IREG" system.

Chapter 3 discussed the development of a revised method for estimating runoff curve numbers (CN) as a potential update to the table look-up method which has been used to identify the input runoff curve numbers (CN) for the EPA PRZM5.0 standard environmental crop scenarios.

It was desired to evaluate the effect of these potential revised input parameters on PRZM5.0 estimates of off-field predictions of pesticide dissolved and sorbed mass. Three pesticides with respectively, a low, medium and high sorption coefficient (K_{OC}), were selected from a list of 66 pesticides which was compiled by EPA and industry (Estes et. al., 2015). This list includes regulatory values for application rate, sorption coefficient (K_{OC}), and soil metabolism half-life (days). Atrazine with a K_{OC} value of 100 L/kg and a soil metabolism half-life of 146 days was selected to represent a low sorption pesticide. Propiconazole with a K_{OC} value of 648 L/kg and a soil metabolism half-life of 69 days was selected to represent a medium

sorption pesticide. Finally, chlorpyrifos with a K_{OC} value of 6040 L/kg and a soil metabolism half-life of 109 days was selected to represent a high sorption pesticide (Estes et al, 2015).

4.3 Materials and Methods

For this research, the same six states and EPA PRZM5.0 standard environmental crop scenarios selected for Chapters 2 and 3 were used in this research for consistency. These EPA PRZM5.0 standard environmental crop scenarios were as follow:

1. Georgia - Peach
2. Indiana - Corn
3. Louisiana - Sugarcane
4. Maine - Potatoes
5. North Carolina - Peanuts
6. Pennsylvania – Corn

The custom version of PRZM5.0 which was developed to include the “NOAA-14” storm intensity coefficients was used to run a series of simulations for each of the above EPA PRZM5.0 standard environmental crop scenarios for atrazine, propiconazole, and chlorpyrifos for both the 1961-1990 weather time series (from EPA) and the 1991-2016 weather time series (developed for this research). A single annual application of each pesticide was simulated during the cropping period of each EPA PRZM5.0 standard environmental crop scenario. PRZM5.0 input information about the three modelled pesticides is detailed in Table 4.1.

Table 4. 1 PRZM5.0 Pesticide Input

Pesticide	Application Rate (lb ai/A)	K_{OC} (L/kg)	Aerobic Soil Metabolism Half-life (days)
Atrazine	1.0	100	146
Chlorpyrifos	4.0	6040	109
Propiconazole	0.2	648	69

In PRZM5.0, the sorption coefficient, K_d (L/kg), is the pesticide input parameter used to partition pesticide mass between soil and water phases, rather than K_{OC}. K_d is calculated for each soil horizon in a PRZM5.0 input file using the formula:

$$K_d = \% \text{ Organic Carbon x } (K_{OC} /100)$$

(eq. 4.1)

(Suarez, 2005)

For all six EPA PRZM5.0 standard environmental crop scenarios and all three pesticides and both weather time series, the custom version of PRZM5.0 was run for each of the following parameter combinations:

(1) EPA "look-up" table runoff curve number (CN) method with "IREG" storm intensity coefficients method

(2) EPA "look-up" table runoff curve number (CN) method with "NOAA-14" storm intensity coefficients method

(3) Revised runoff curve number (CN) method for this research with "IREG" storm intensity coefficients method

(4) Revised runoff curve number (CN) method for this research with "NOAA-14" storm intensity coefficients method

Daily time series of dissolved and sorbed pesticide fluxes output values (g/cm^2) were generated for every PRZM5.0 simulation. The 1961-1990 and 1991-2016 daily time series were combined and the daily time series were post-processed to calculate annual total dissolved and sorbed off-field pesticide mass in terms of % of applied. Graphs of these post-processed results were generated as well as annual averages and standard deviations were calculated for every simulation set.

4.4 Results and Discussion

4.4.1 Atrazine Results

The annual average atrazine PRZM5.0 predicted off-field mass (% of applied) for 1961-2016 for the four parameter combinations are detailed in Tables 4.2 and 4.3 below.

Table 4. 2 Atrazine Average Annual PRZM5.0 Predicted Dissolved Off-Field Mass (% Applied)

EPA Standard Environmental Crop Scenario	EPA Table "Look-Up" Method CN Values IREG storm intensity Coefficients	EPA Table "Look-Up" Method CN Values NOAA-14 storm intensity Coefficients	Revised Runoff Curve Number Method CN Values IREG storm intensity Coefficients	Revised Runoff Curve Number Method CN Values NOAA-14 storm intensity Coefficients
	Average Annual % of Applied (Standard Deviation)	Average Annual % of Applied (Standard Deviation)	Average Annual % of Applied (Standard Deviation)	Average Annual % of Applied (Standard Deviation)
GA Peach	0.287 (0.158)	0.287 (0.158)	4.142 (0.778)	4.142 (0.778)
IN Corn	1.507 (1.215)	1.507 (1.215)	2.472 (1.630)	2.472 (1.630)
LA Sugarcane	3.593 (2.390)	3.589 (2.390)	N/A	N/A
ME Potatoes	1.005 (0.825)	1.005 (0.825)	2.145 (1.340)	2.145 (1.341)
NC Peanuts	0.846 (0.814)	0.846 (0.814)	1.746 (1.311)	1.745 (1.310)
PA Corn	0.932 (1.290)	0.932 (1.290)	3.922 (3.317)	3.923 (3.320)

Table 4. 3 Atrazine Average Annual PRZM5.0 Predicted Sorbed Off-Field Mass (% Applied)

	EPA Table "Look-Up" Method CN Value IREG storm intensity Coefficients	EPA Table "Look-Up" Method CN Value NOAA-14 storm intensity Coefficients	Revised Runoff Curve Number Method CN Values IREG storm intensity Coefficients	Revised Runoff Curve Number Method CN Values NOAA-14 storm intensity Coefficients
EPA Standard Environmental Crop Scenario	Average Annual % of Applied (Standard Deviation)	Average Annual % of Applied (Standard Deviation)	Average Annual % of Applied (Standard Deviation)	Average Annual % of Applied (Standard Deviation)
GA Peach	0.002 (0.00144)	0.002 (0.00151)	0.020 (0.00946)	0.021 (0.00971)
IN Corn	0.100 (0.0835)	0.116 (0.0944)	0.179 (0.143)	0.201 (0.158)
LA Sugarcane	0.141 (0.1375)	0.162 (0.152)	N/A	N/A
ME Potatoes	0.111 (0.195)	0.117 (0.191)	0.253 (0.307)	0.258 (0.300)
NC Peanuts	0.012 (0.0178)	0.016 (0.0213)	0.029 (0.0336)	0.036 (0.0388)
PA Corn	0.018 (0.0368)	0.019 (0.0355)	0.101 (0.131)	0.099 (0.123)

Graphs displaying the comparison of PRZM5.0 predicted annual dissolved off-field atrazine mass (% of applied) for the current EPA environmental standard crop scenario method of identifying runoff curve numbers (CN) which involves using table "look-up" versus the revised method of manually calculating runoff curve numbers from observed streamflow data as described in Chapter 3 are displayed in Figures 4.1-4.5.

Note: There is not a graph for the Louisiana Sugarcane EPA standard environmental crop scenario because the revised method resulted in the same CN value identified using the table "look-up" method, thus, no change in predicted runoff.

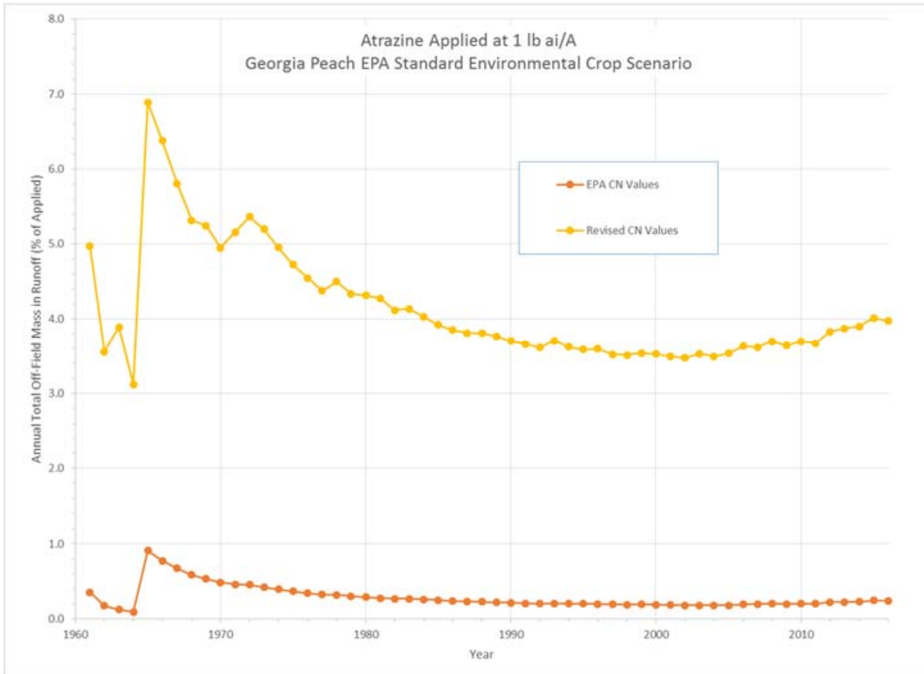

Figure 4. 1 PRZM5.0 Atrazine – Georgia Peach EPA Standard Environmental Crop Scenario – Predicted Annual Dissolved Off-field Mass (% of Applied)

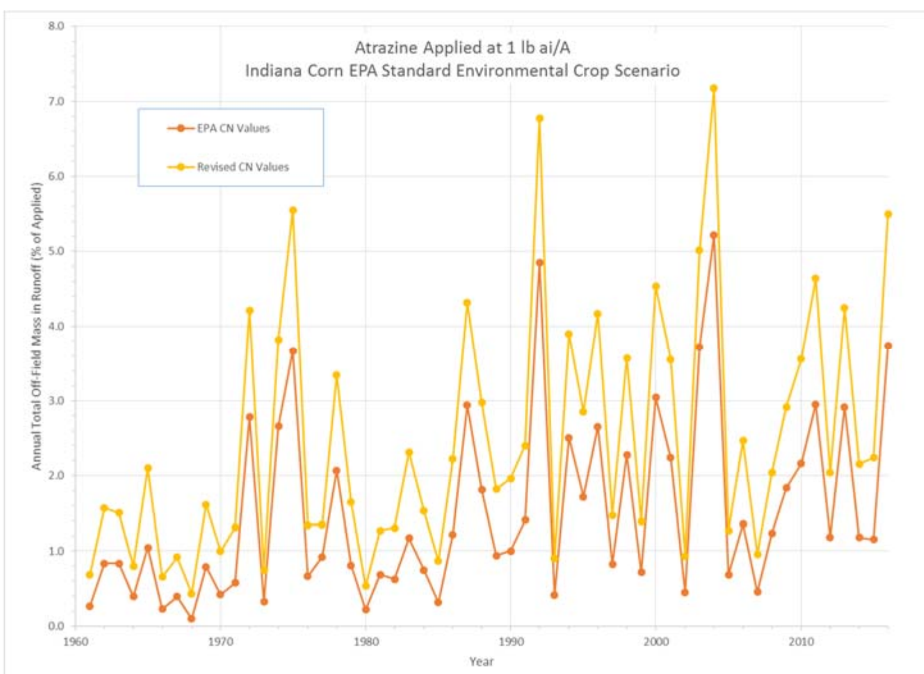

Figure 4. 2 PRZM5.0 Atrazine – Indiana Corn EPA Standard Environmental Crop Scenario – Predicted Annual Dissolved Off-field Mass (% of Applied)

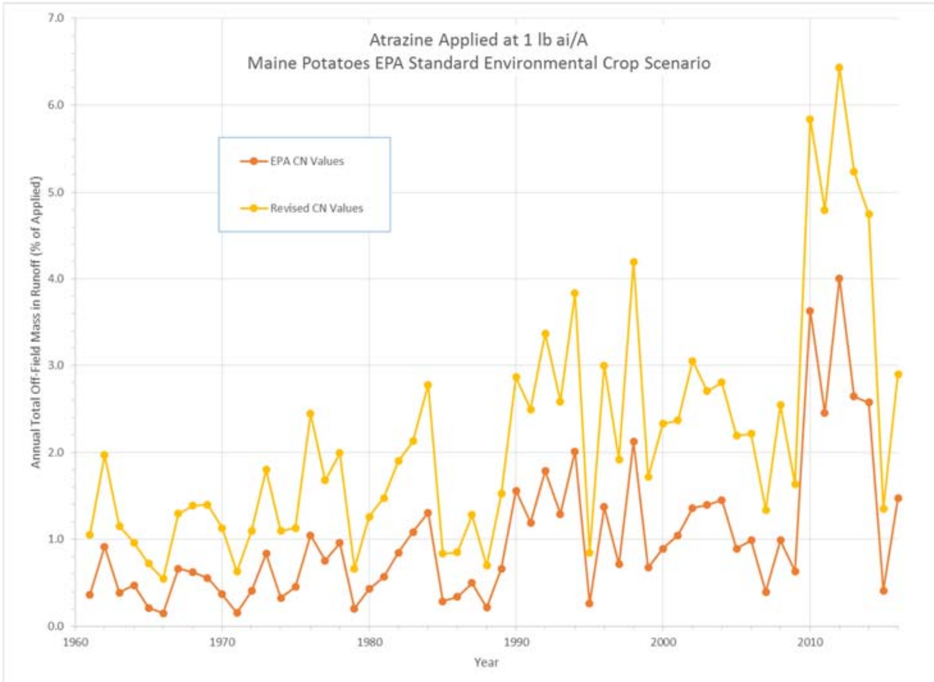

Figure 4. 3 PRZM5.0 Atrazine – Maine Potatoes EPA Standard Environmental Crop Scenario – Predicted Annual Dissolved Off-field Mass (% of Applied)

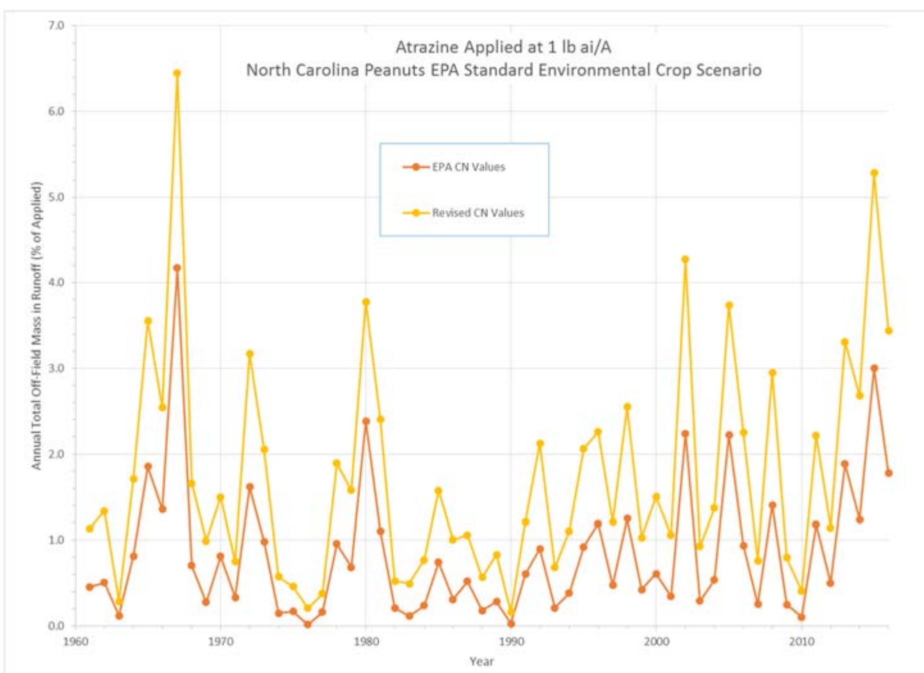

Figure 4. 4 PRZM5.0 Atrazine – North Carolina Peanuts EPA Standard Environmental Crop Scenario – Predicted Annual Dissolved Off-field Mass (% of Applied)

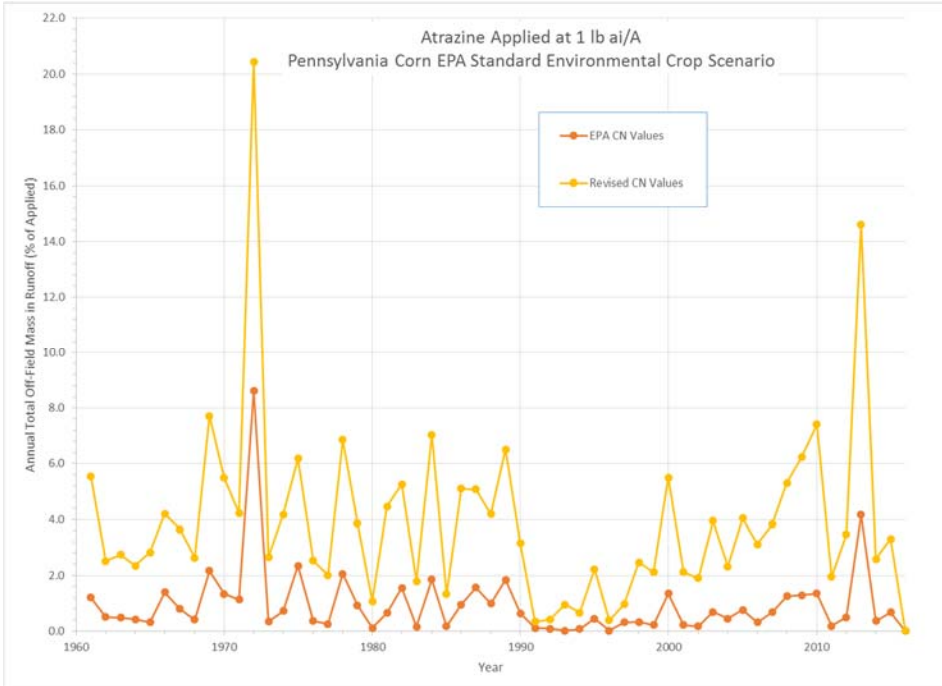

Figure 4. 5 PRZM5.0 Atrazine – Pennsylvania Corn EPA Standard Environmental Crop Scenario – Predicted Annual Dissolved Off-field Mass (% of Applied)

Graphs displaying the comparison of PRZM5.0 predicted annual sorbed off-field atrazine mass (% of applied) for the four parameter combinations (EPA "look-up" table runoff curve number (CN) method with "IREG" storm intensity coefficients method; EPA "look-up" table runoff curve number (CN) method with "NOAA-14" storm intensity coefficients method; Revised runoff curve number (CN) method (CN) developed for this research with "IREG" storm intensity coefficients method; and Revised runoff curve number (CN) method (CN) developed for this research with "NOAA-14" storm intensity coefficients method) are displayed in Figures 4.6-4.11.

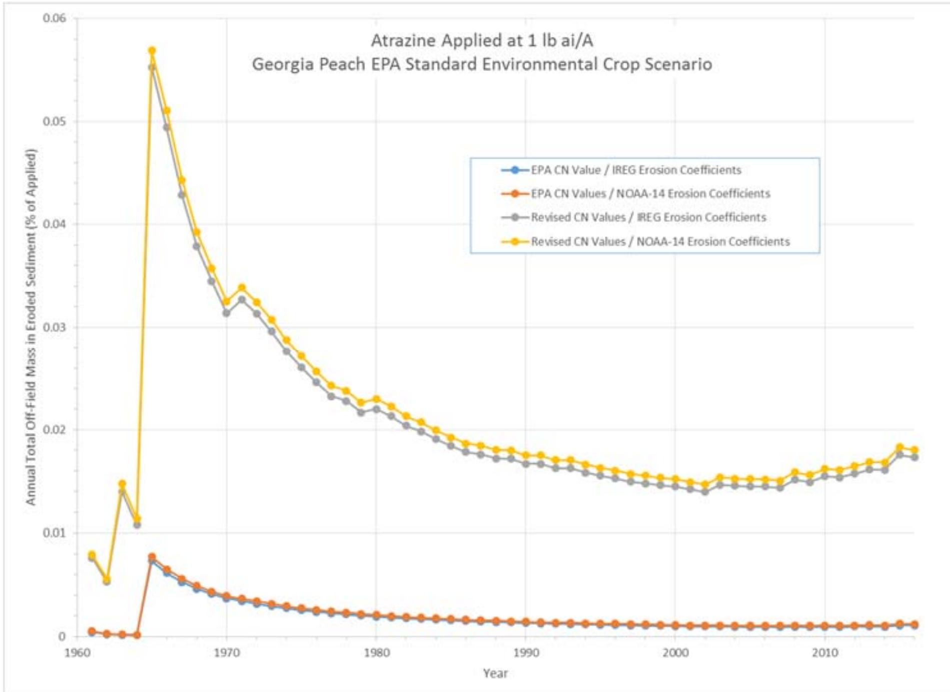

Figure 4. 6 PRZM5.0 Atrazine – Georgia Peach EPA Standard Environmental Crop Scenario – Predicted Annual Sorbed Off-field Mass (% of Applied)

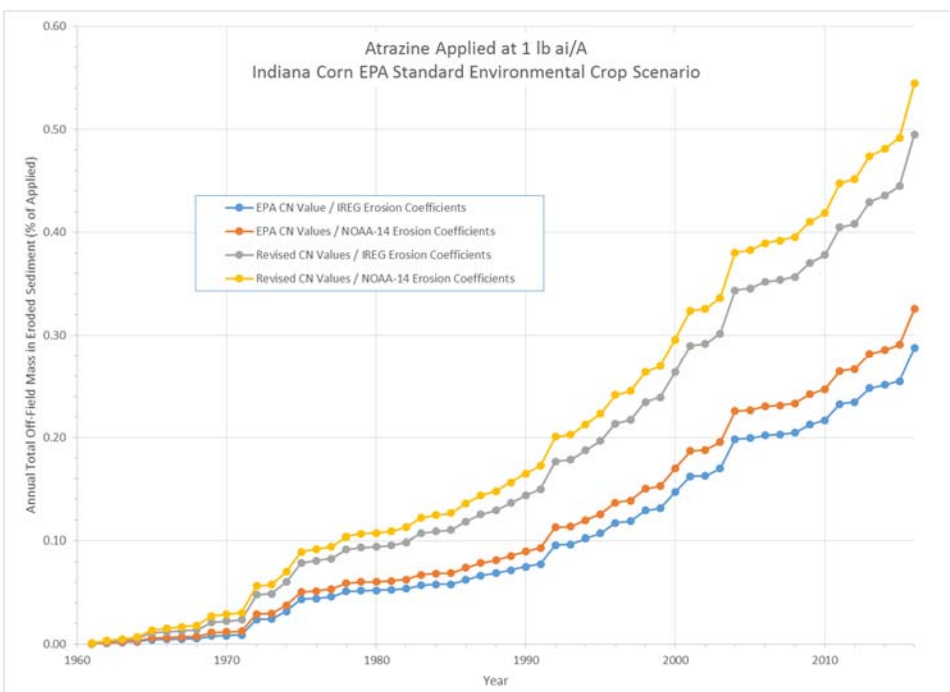

Figure 4. 7 PRZM5.0 Atrazine – Indiana Corn EPA Standard Environmental Crop Scenario – Predicted Annual Sorbed Off-field Mass (% of Applied)

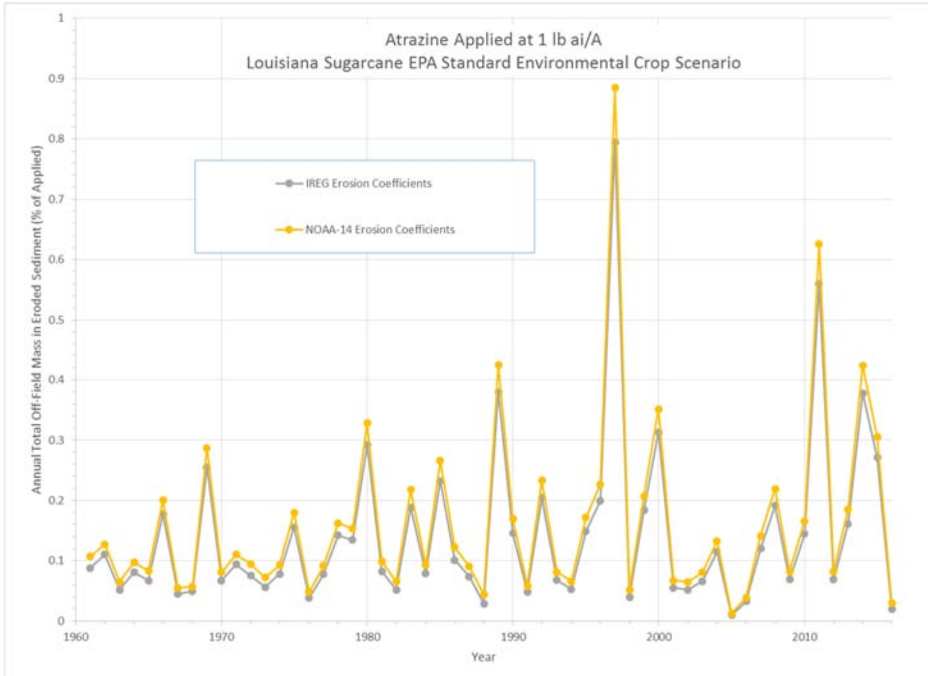

Figure 4. 8 PRZM5.0 Atrazine – Louisiana Sugarcane EPA Standard Environmental Crop Scenario – Predicted Annual Sorbed Off-field Mass (% of Applied)

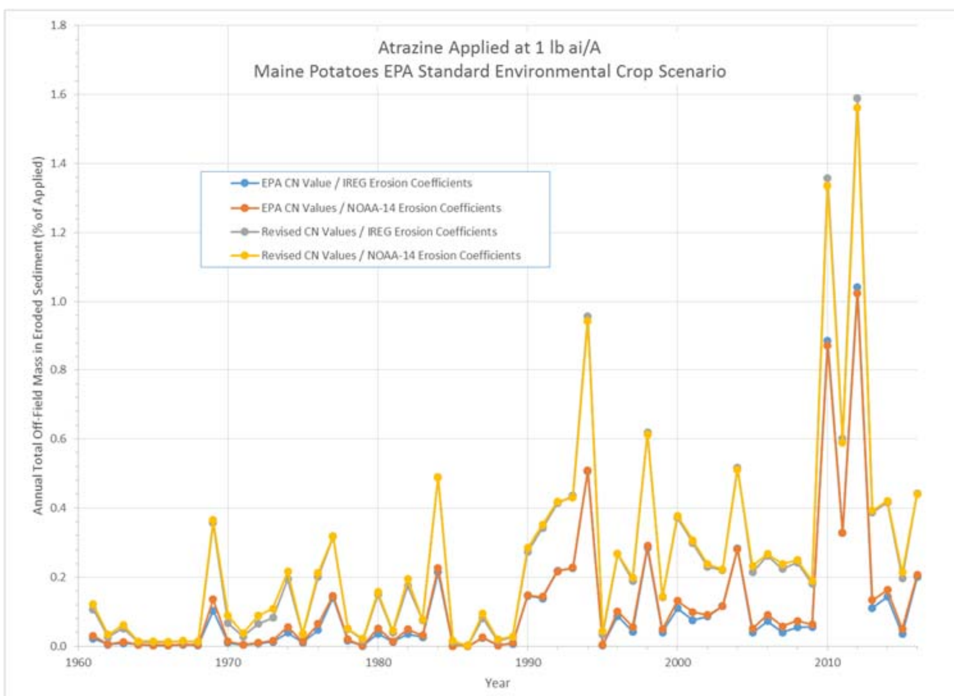

Figure 4. 9 PRZM5.0 Atrazine – Maine Potatoes EPA Standard Environmental Crop Scenario – Predicted Annual Sorbed Off-field Mass (% of Applied)

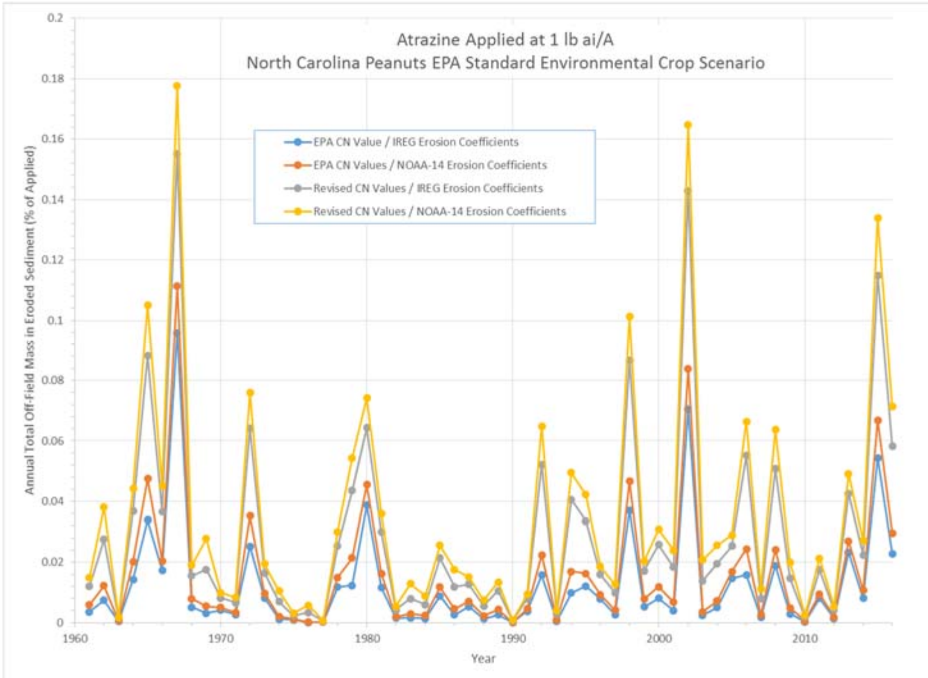

Figure 4. 10 PRZM5.0 Atrazine – North Carolina Peanuts EPA Standard Environmental Crop Scenario – Predicted Annual Sorbed Off-field Mass (% of Applied)

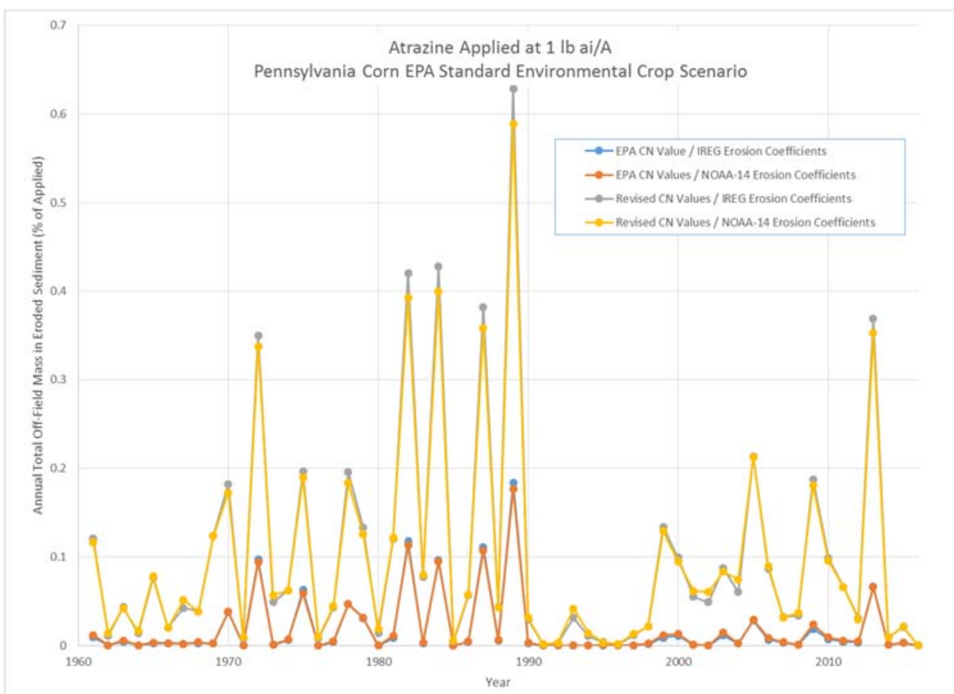

Figure 4. 11 PRZM5.0 Atrazine – Pennsylvania Corn EPA Standard Environmental Crop Scenario – Predicted Annual Sorbed Off-field Mass (% of Applied)

4.4.2 Propiconazole Results

The annual average propiconazole PRZM5.0 predicted off-field mass (% of applied) for 1961-2016 for the four parameter combinations are detailed in Tables 4.4 and 4.5 below.

Table 4. 4 Propiconazole Average Annual PRZM5.0 Predicted Dissolved Off-Field Mass (% Applied)

	EPA Table "Look-Up" Method CN Value IREG storm intensity Coefficients	EPA Table "Look-Up" Method CN Value NOAA-14 storm intensity Coefficients	Revised Runoff Curve Number Method CN Values IREG storm intensity Coefficients	Revised Runoff Curve Number Method CN Values NOAA-14 storm intensity Coefficients
EPA Standard Environmental Crop Scenario	Average Annual % of Applied (Standard Deviation)	Average Annual % of Applied (Standard Deviation)	Average Annual % of Applied (Standard Deviation)	Average Annual % of Applied (Standard Deviation)
GA Peach	0.258 (0.528)	0.258 (0.528)	3.880 (2.547)	3.879 (2.547)
IN Corn	1.588 (0.920)	1.587 (0.919)	2.212 (1.292)	2.400 (1.191)
LA Sugarcane	2.805 (0.998)	2.796 (0.993)	N/A	N/A
ME Potatoes	0.742 (0.390)	0.741 (0.390)	1.278 (0.572)	1.277 (0.572)
NC Peanuts	1.174 (0.785)	1.172 (0.784)	2.102 (1.164)	2.098 (1.161)
PA Corn	0.873 (1.074)	0.873 (1.076)	2.305 (2.231)	2.307 (2.236)

Table 4. 5 Propiconazole Average Annual PRZM5.0 Predicted Sorbed Off-Field Mass (% Applied)

	EPA Table "Look-Up" Method CN Value IREG storm intensity Coefficients	EPA Table "Look-Up" Method CN Value NOAA-14 storm intensity Coefficients	Revised Runoff Curve Number Method CN Values IREG storm intensity Coefficients	Revised Runoff Curve Number Method CN Values NOAA-14 storm intensity Coefficients
EPA Standard Environmental Crop Scenario	Average Annual % of Applied (Standard Deviation)	Average Annual % of Applied (Standard Deviation)	Average Annual % of Applied (Standard Deviation)	Average Annual % of Applied (Standard Deviation)
GA Peach	0.007 (0.02984)	0.008 (0.0315)	0.103 (0.171)	0.107 (0.174)
IN Corn	0.033 (0.0360)	0.038 (0.0381)	0.052 (0.0531)	0.061 (0.0535)
LA Sugarcane	0.715 (0.448)	0.806 (0.472)	N/A	N/A
ME Potatoes	0.632 (0.583)	0.663 (0.574)	1.164 (0.741)	1.185 (0.724)
NC Peanuts	0.115 (0.138)	0.144 (0.157)	0.239 (0.214)	0.282 (0.238
PA Corn	0.165 (0.252)	0.166 (0.243)	0.583 (0.514)	0.570 (0.493)

Graphs displaying the comparison of PRZM5.0 predicted annual dissolved off-field propiconazole mass (% of applied) for the current EPA environmental standard crop scenario method of identifying runoff curve numbers (CN) which involves using table "look-up" versus the revised method of runoff curve numbers from this research are displayed in Figures 4.12-4.16.

Note: There is not a graph for the Louisiana Sugarcane EPA standard environmental crop scenario because the revised method resulted in the same CN value identified using the table "look-up" method, thus, no change in predicted runoff.

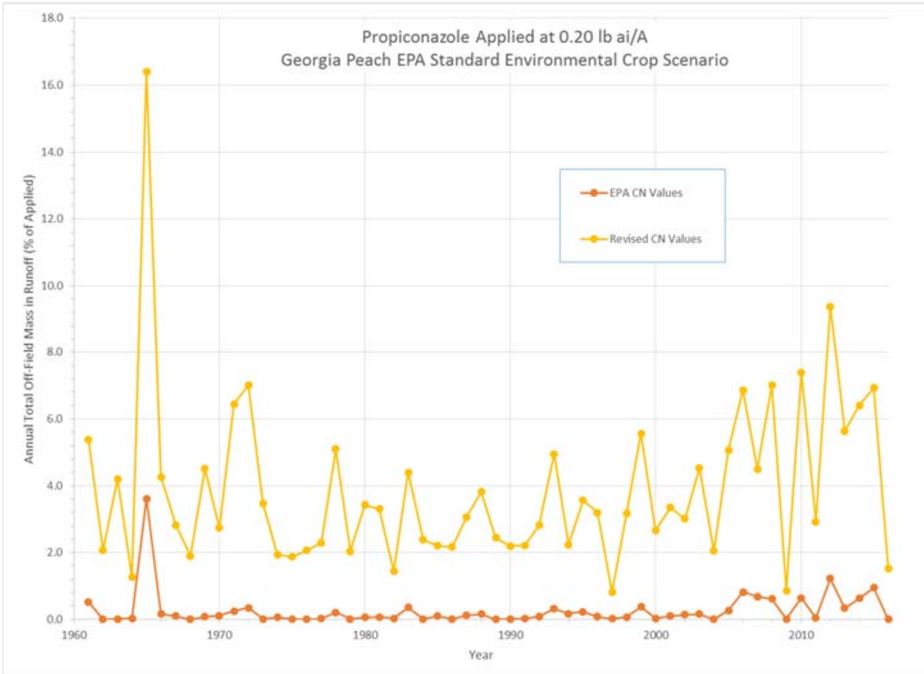

Figure 4. 12 PRZM5.0 Propiconazole – Georgia Peach EPA Standard Environmental Crop Scenario – Predicted Annual Dissolved Off-field Mass (% of Applied)

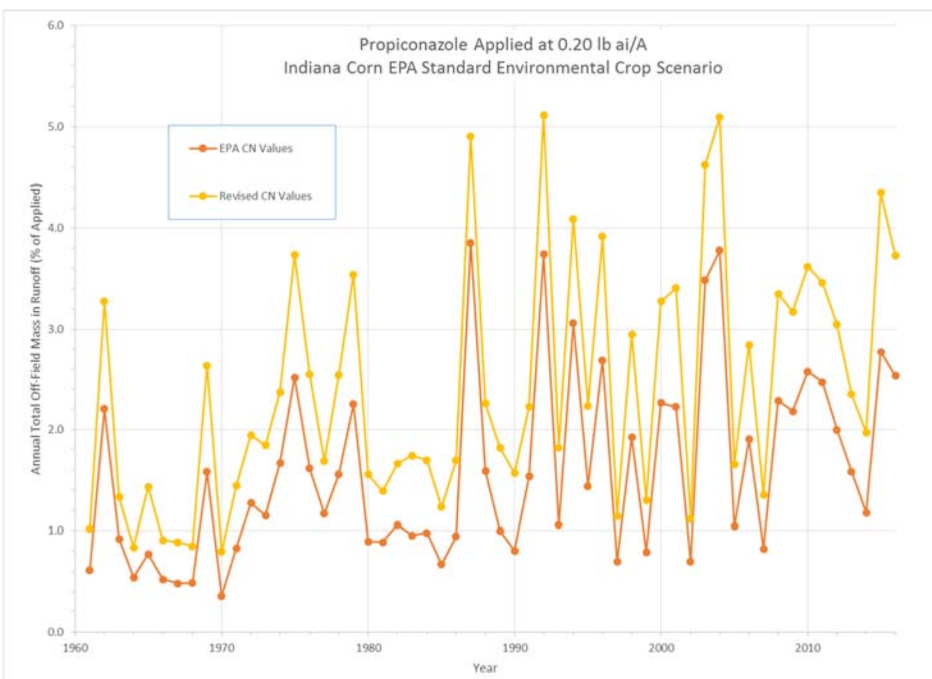

Figure 4. 13 PRZM5.0 Propiconazole – Indiana Corn EPA Standard Environmental Crop Scenario – Predicted Annual Dissolved Off-field Mass (% of Applied)

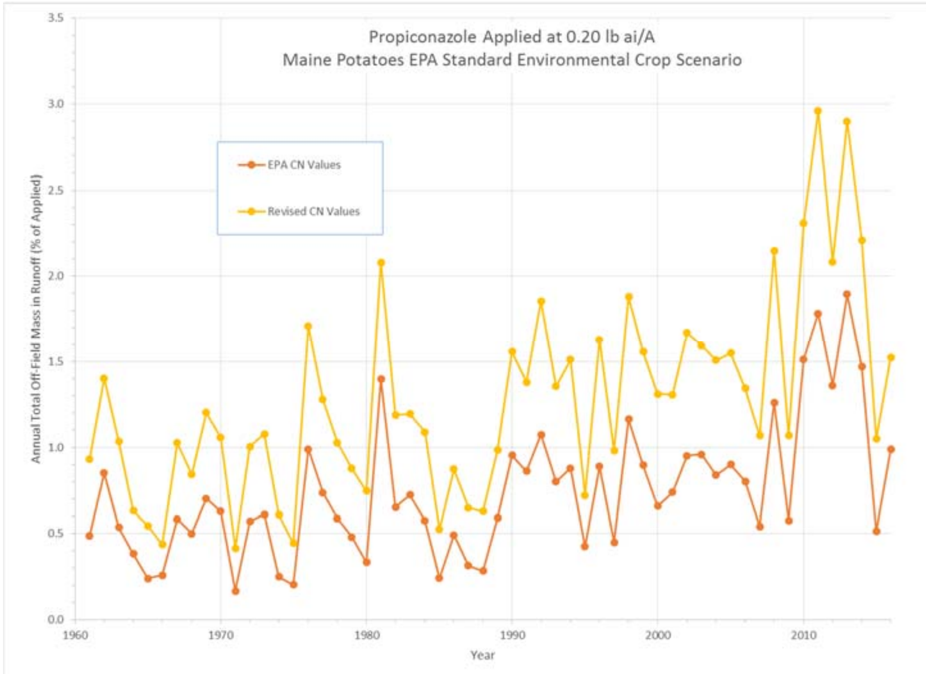

Figure 4. 14 PRZM5.0 Propiconazole – Maine Potatoes EPA Standard Environmental Crop Scenario – Predicted Annual Dissolved Off-field Mass (% of Applied)

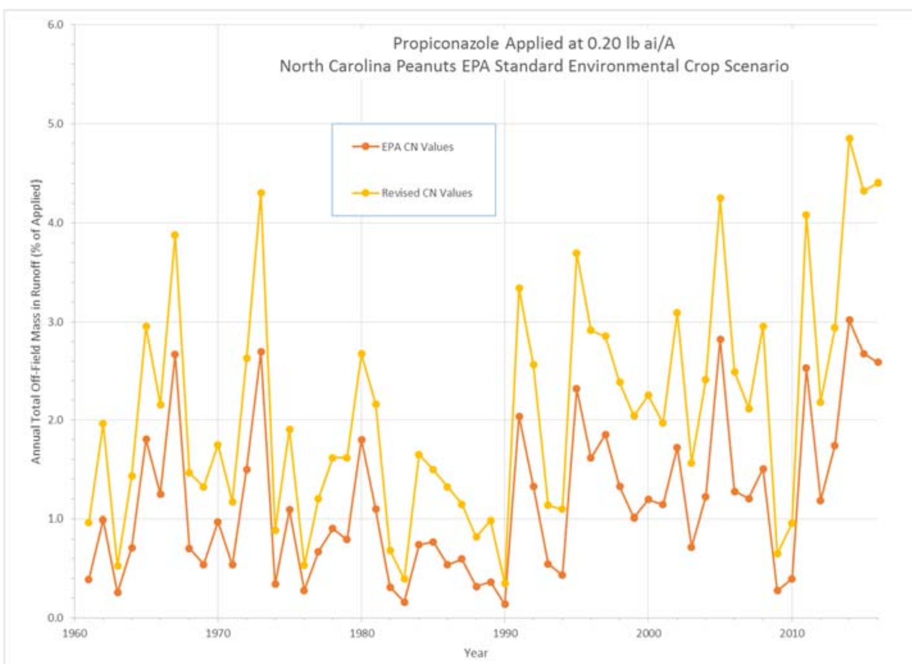

Figure 4. 15 PRZM5.0 Propiconazole – North Carolina Peanuts EPA Standard Environmental Crop Scenario – Predicted Annual Dissolved Off-field Mass (% of Applied)

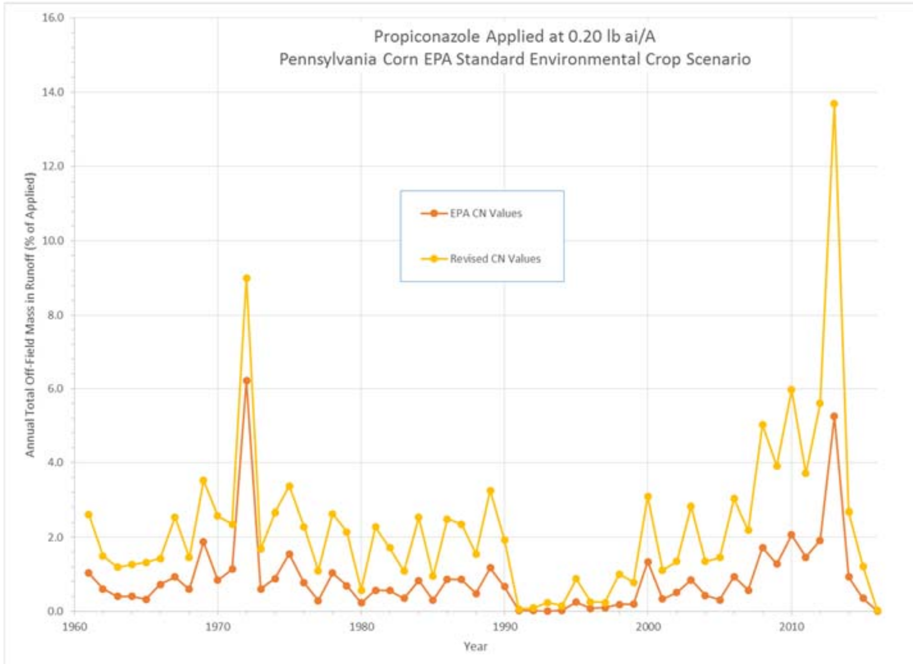

Figure 4. 16 PRZM5.0 Propiconazole – Pennsylvania Corn EPA Standard Environmental Crop Scenario – Predicted Annual Dissolved Off-field Mass (% of Applied)

Graphs displaying the comparison of PRZM5.0 predicted annual sorbed off-field propiconazole mass (% of applied) for the four parameter combinations (EPA "look-up" table runoff curve number (CN) method with "IREG" storm intensity coefficients method; EPA "look-up" table runoff curve number (CN) method with "NOAA-14" storm intensity coefficients method; Revised runoff curve number (CN) method developed for this research with "IREG" storm intensity coefficients method; and Revised runoff curve number (CN) method developed for this research with "NOAA-14" storm intensity coefficients method) are displayed in Figures 4.17-4.22

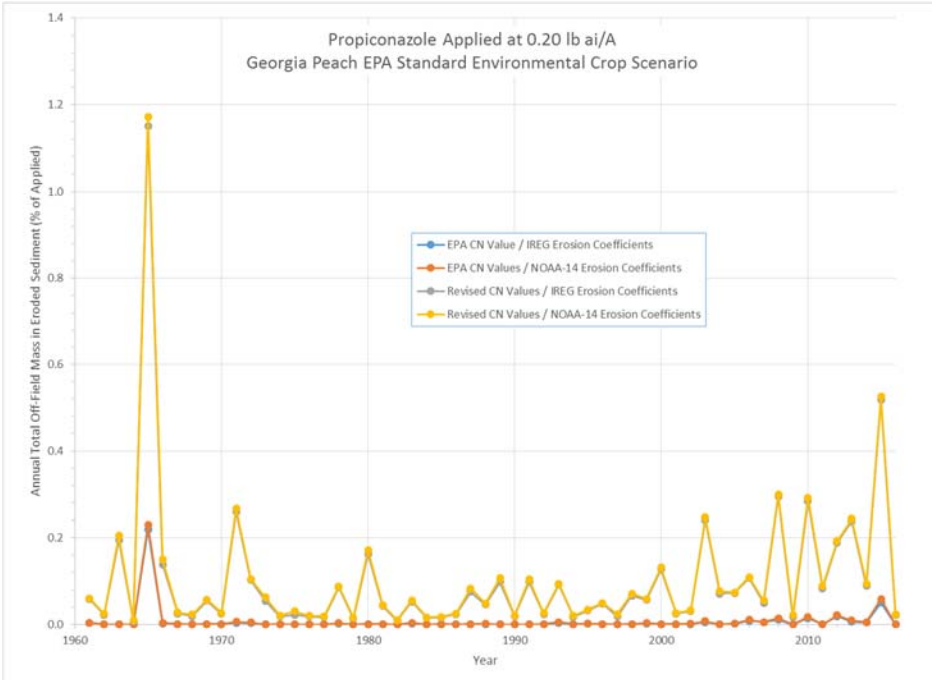

Figure 4. 17 PRZM5.0 Propiconazole – Georgia Peach EPA Standard Environmental Crop Scenario – Predicted Annual Sorbed Off-field Mass (% of Applied)

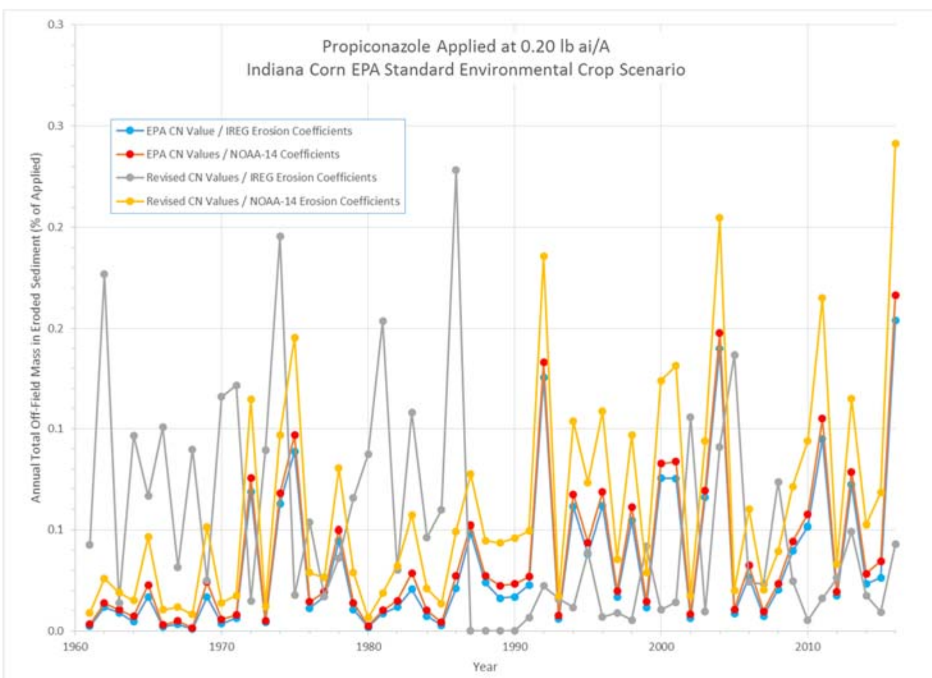

Figure 4. 18 PRZM5.0 Propiconazole – Indiana Corn EPA Standard Environmental Crop Scenario – Predicted Annual Sorbed Off-field Mass (% of Applied)

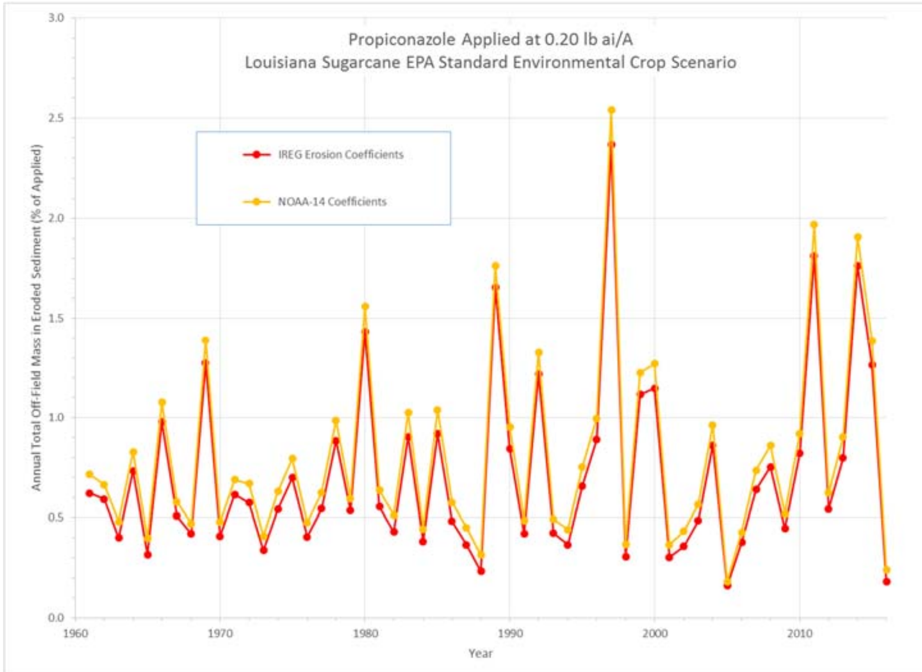

Figure 4. 19 PRZM5.0 Propiconazole – Louisiana Sugarcane EPA Standard Environmental Crop Scenario – Predicted Annual Sorbed Off-field Mass (% of Applied)

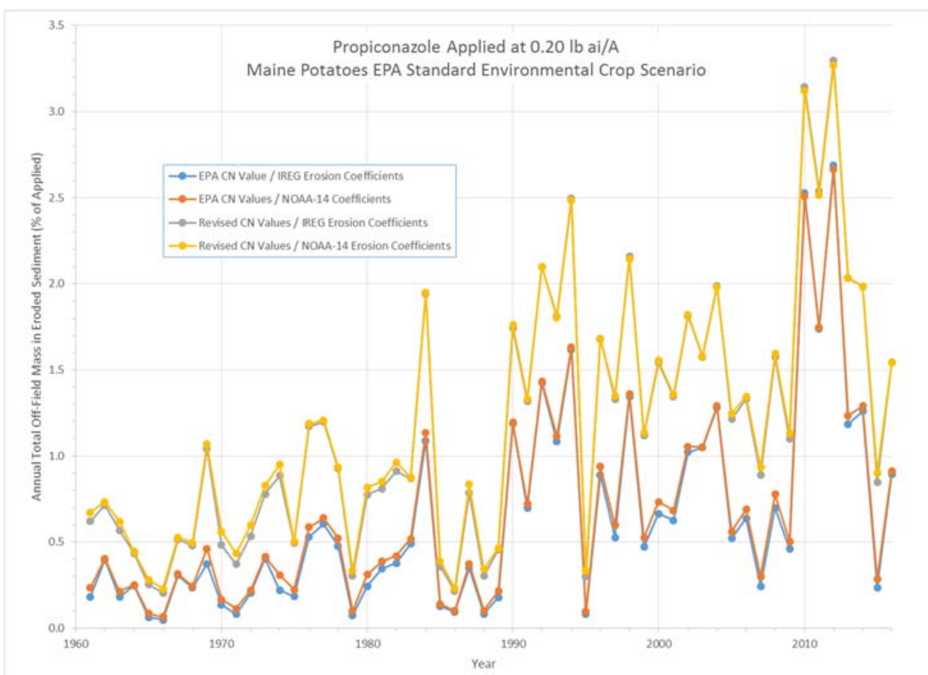

Figure 4. 20 PRZM5.0 Propiconazole – Maine Potatoes EPA Standard Environmental Crop Scenario – Predicted Annual Sorbed Off-field Mass (% of Applied)

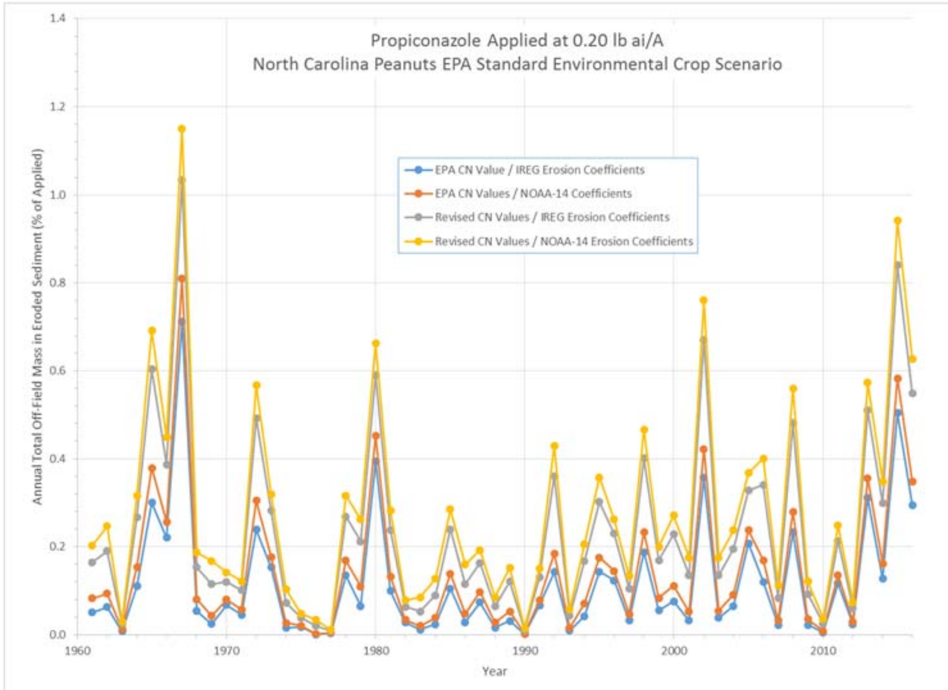

Figure 4. 21 PRZM5.0 Propiconazole – North Carolina Peanuts EPA Standard Environmental Crop Scenario – Predicted Annual Sorbed Off-field Mass (% of Applied)

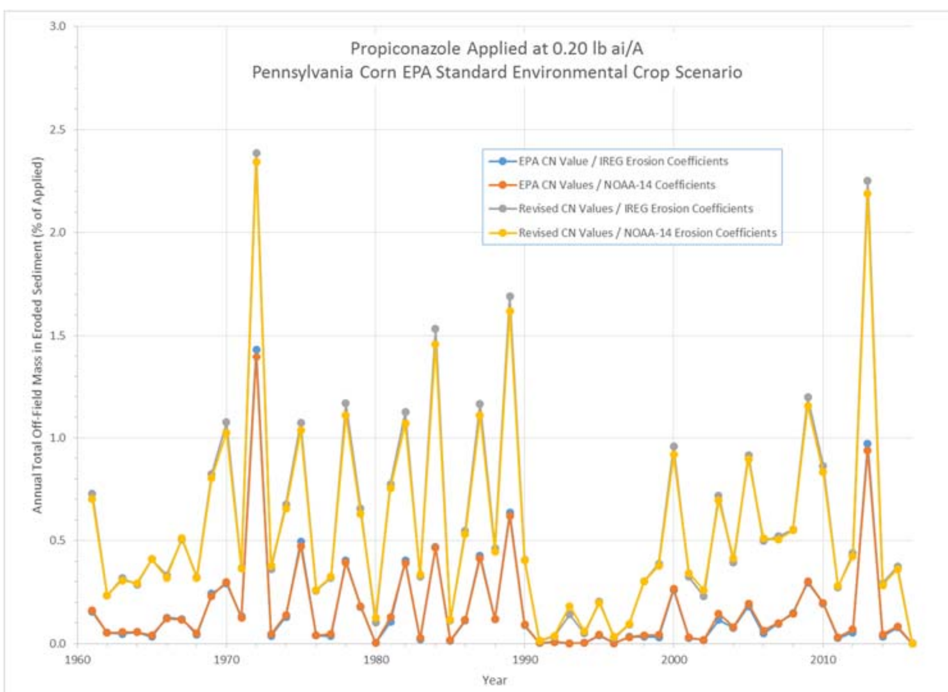

Figure 4. 22 PRZM5.0 Propiconazole e – Pennsylvania Corn EPA Standard Environmental Crop Scenario – Predicted Annual Sorbed Off-field Mass (% of Applied)

4.4.3 Chlorpyrifos Results

The annual average chlorpyrifos PRZM5.0 predicted off-field mass (% of applied) for 1961-2016 for the four parameter combinations are detailed in Tables 4.6 and 4.7 below.

Table 4. 6 Chlorpyrifos Average Annual PRZM5.0 Predicted Dissolved Off-Field Mass (% Applied)

EPA Standard Environmental Crop Scenario	EPA Table "Look-Up" Method CN Value IREG storm intensity Coefficients	EPA Table "Look-Up" Method CN Value NOAA-14 storm intensity Coefficients	Revised Runoff Curve Number Method CN Values IREG storm intensity Coefficients	Revised Runoff Curve Number Method CN Values NOAA-14 storm intensity Coefficients
	Average Annual % of Applied (Standard Deviation)	Average Annual % of Applied (Standard Deviation)	Average Annual % of Applied (Standard Deviation)	Average Annual % of Applied (Standard Deviation)
GA Peach	0.404 (0.421)	0.404 (0.421)	3.157 (1.205)	3.154 (1.205)
IN Corn	1.010 (0.508)	1.009 (0.507)	1.077 (0.500)	1.076 (0.499)
LA Sugarcane	1.043 (0.305)	1.037 (0.303)	N/A	N/A
ME Potatoes	0.219 (0.100)	0.218 (0.100)	0.324 (0.133)	0.324 (0.133)
NC Peanuts	0.800 (0.382)	0.795 (0.379)	1.103 (0.495)	1.100 (0.496)
PA Corn	0.370 (0.500)	0.370 (0.500)	0.674 (0.776)	0.675 (0.777)

Table 4. 7 Chlorpyrifos Average Annual PRZM5.0 Predicted Sorbed Off-Field Mass (% Applied)

EPA Standard Environmental Crop Scenario	EPA Table "Look-Up" Method CN Value IREG storm intensity Coefficients Average Annual % of Applied (Standard Deviation)	EPA Table "Look-Up" Method CN Value NOAA-14 storm intensity Coefficients Average Annual % of Applied (Standard Deviation)	Revised Runoff Curve Number Method CN Values IREG storm intensity Coefficients Average Annual % of Applied (Standard Deviation)	Revised Runoff Curve Number Method CN Values NOAA-14 storm intensity Coefficients Average Annual % of Applied (Standard Deviation)
GA Peach	0.053 (0.172)	0.061 (0.181)	0.621 (0.525)	0.644 (0.528)
IN Corn	0.332 (0.233)	0.362 (0.240)	0.386 (0.213)	0.419 (0.219)
LA Sugarcane	2.601 (0.535)	2.765 (0.530)	N/A	N/A
ME Potatoes	2.175 (0.853)	2.231 (0.828)	2.921 (0.793)	2.946 (0.769)
NC Peanuts	0.845 (0.605)	0.986 (0.645)	1.330 (0.721)	1.425 (0.721)
PA Corn	0.990 (0.760)	0.988 (0.746)	1.909 (0.973)	1.881 (0.951)

Graphs displaying the comparison of PRZM5.0 predicted annual dissolved off-field chlorpyrifos mass (% of applied) for the current EPA environmental standard crop scenario method of identifying runoff curve numbers (CN) which involves using table "look-up" versus the revised runoff curve number (CN) method from this research are displayed in Figures 4.23-4.27.

Note: There is not a graph for the Louisiana Sugarcane EPA standard environmental crop scenario because the revised method resulted in the same CN value identified using the table "look-up" method, thus, no change in predicted runoff.

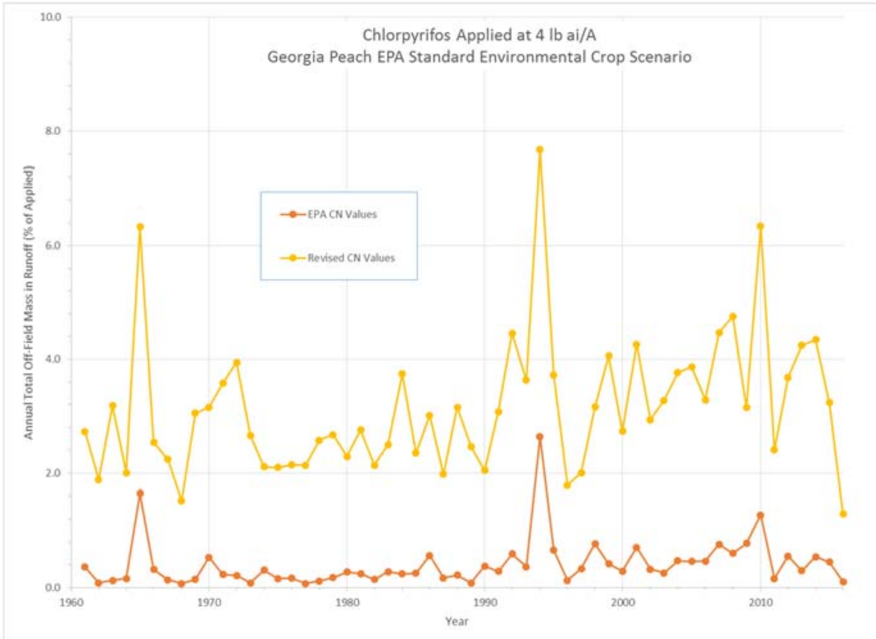

Figure 4. 23 PRZM5.0 Chlorpyrifos – Georgia Peach EPA Standard Environmental Crop Scenario – Predicted Annual Dissolved Off-field Mass (% of Applied)

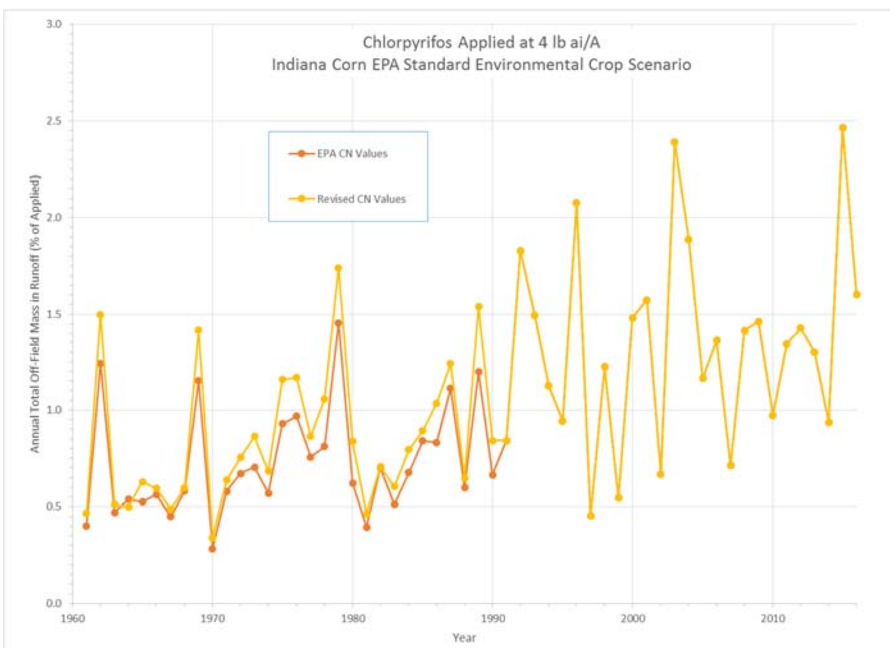

Figure 4. 24 Chlorpyrifos – Indiana Corn EPA Standard Environmental Crop Scenario – Predicted Annual Dissolved Off-field Mass (% of Applied)

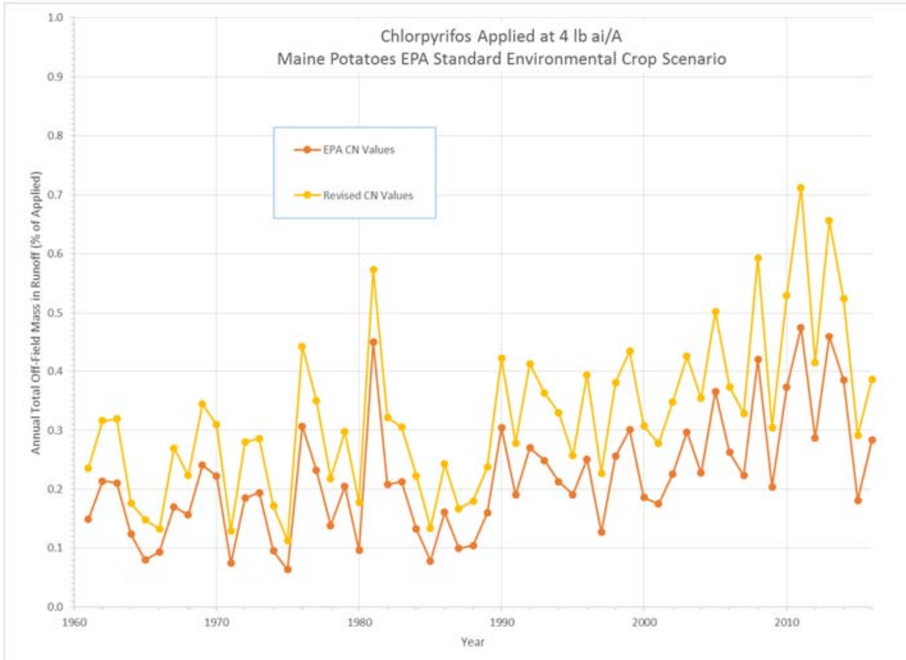

Figure 4. 25 PRZM5.0 Chlorpyrifos – Maine Potatoes EPA Standard Environmental Crop Scenario – Predicted Annual Dissolved Off-field Mass (% of Applied)

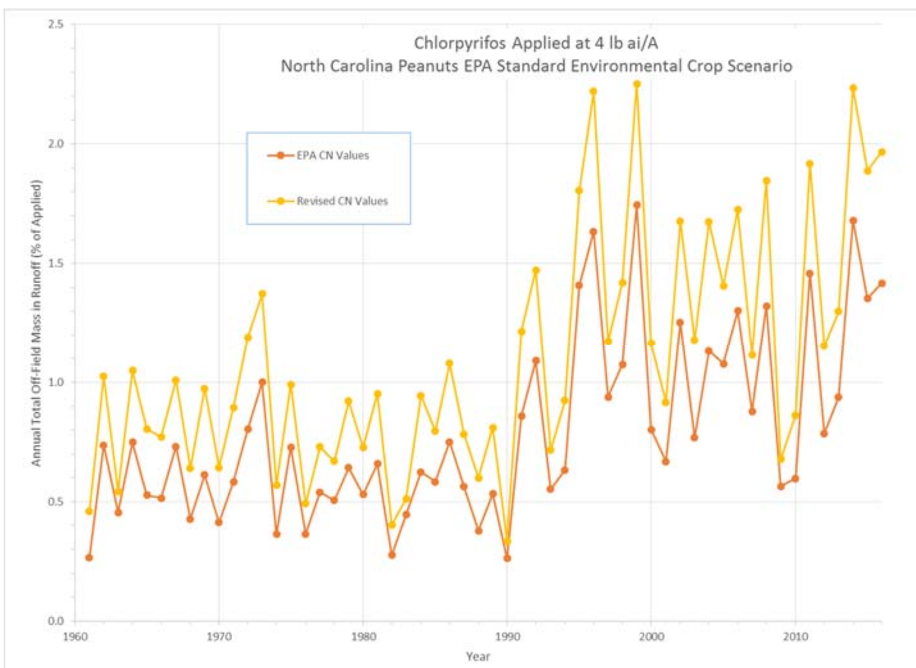

Figure 4. 26 PRZM5.0 Chlorpyrifos – North Carolina Peanuts EPA Standard Environmental Crop Scenario – Predicted Annual Dissolved Off-field Mass (% of Applied)

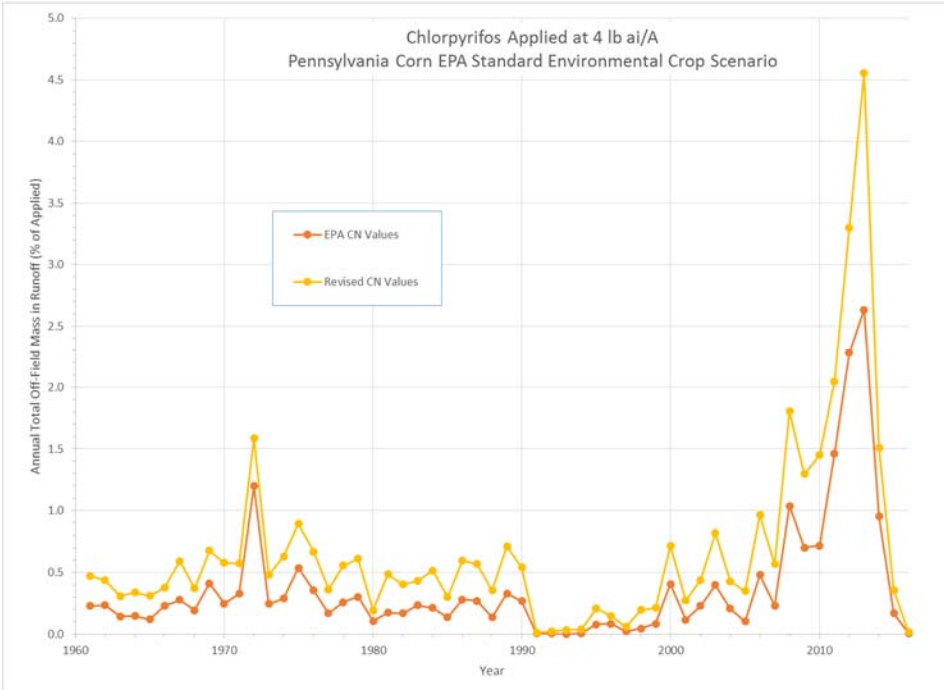

Figure 4. 27 PRZM5.0 Chlorpyrifos – Pennsylvania Corn EPA Standard Environmental Crop Scenario – Predicted Annual Dissolved Off-field Mass (% of Applied)

Graphs displaying the comparison of PRZM5.0 predicted annual sorbed off-field chlorpyrifos mass (% of applied) for the four parameter combinations (EPA "look-up" table runoff curve number (CN) method with "IREG" storm intensity coefficients method; EPA "look-up" table runoff curve number (CN) method with "NOAA-14" storm intensity coefficients method; Revised runoff curve number (CN) method for this research with "IREG" storm intensity coefficients method; and Revised runoff curve number (CN) method for this research with "NOAA-14" storm intensity coefficients method) are displayed in Figures 4.28-4.33.

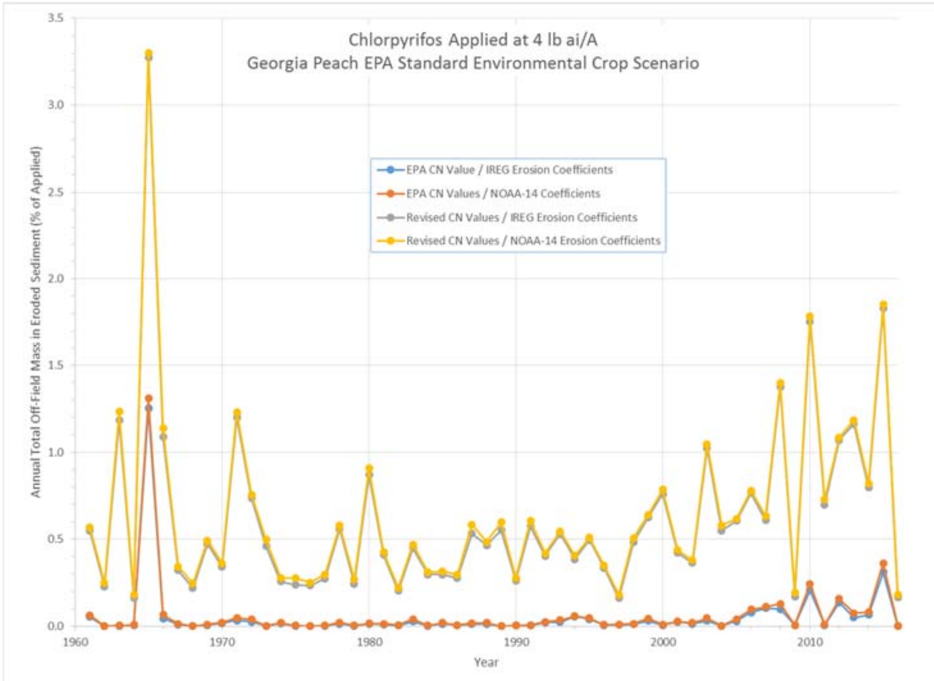

Figure 4. 28 PRZM5.0 Chlorpyrifos – Georgia Peach EPA Standard Environmental Crop Scenario – Predicted Annual Sorbed Off-field Mass (% of Applied)

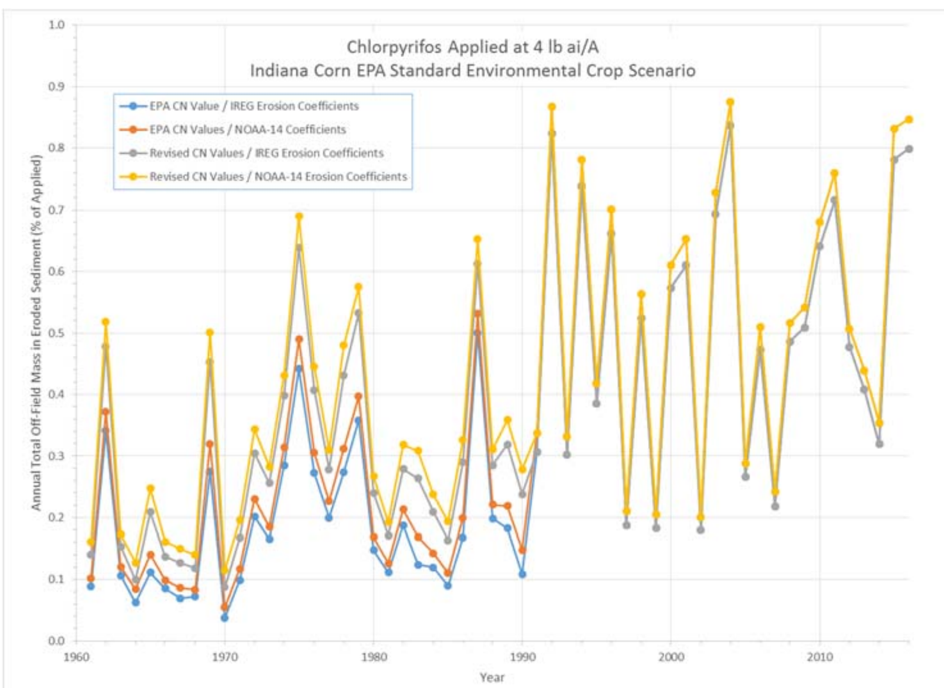

Figure 4. 29 PRZM5.0 Chlorpyrifos – Indiana Corn EPA Standard Environmental Crop Scenario – Predicted Annual Sorbed Off-field Mass (% of Applied)

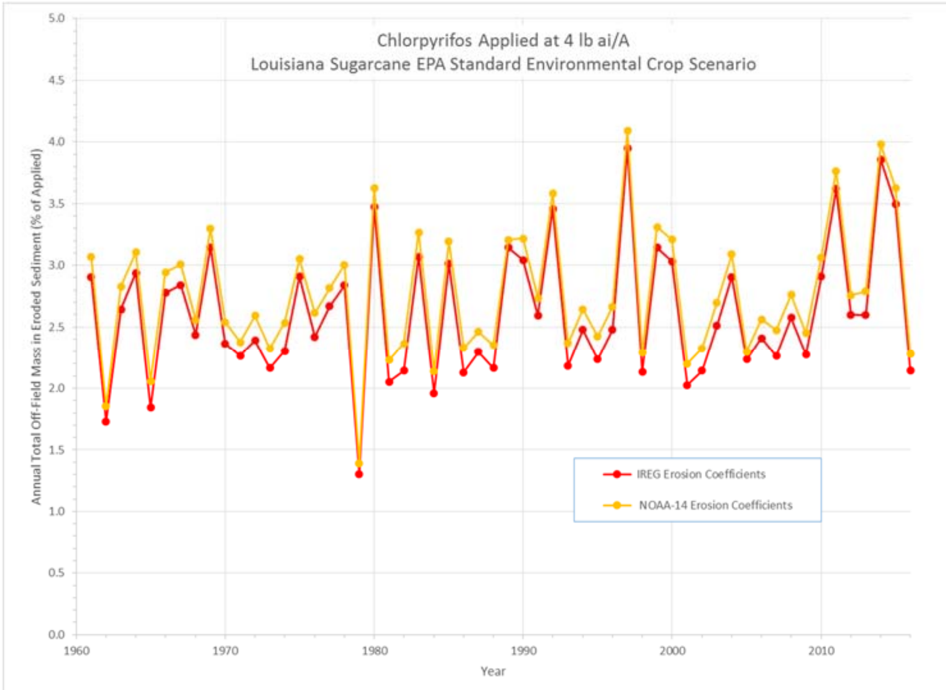

Figure 4. 30 PRZM5.0 Chlorpyrifos – Louisiana Sugarcane EPA Standard Environmental Crop Scenario – Predicted Annual Sorbed Off-field Mass (% of Applied)

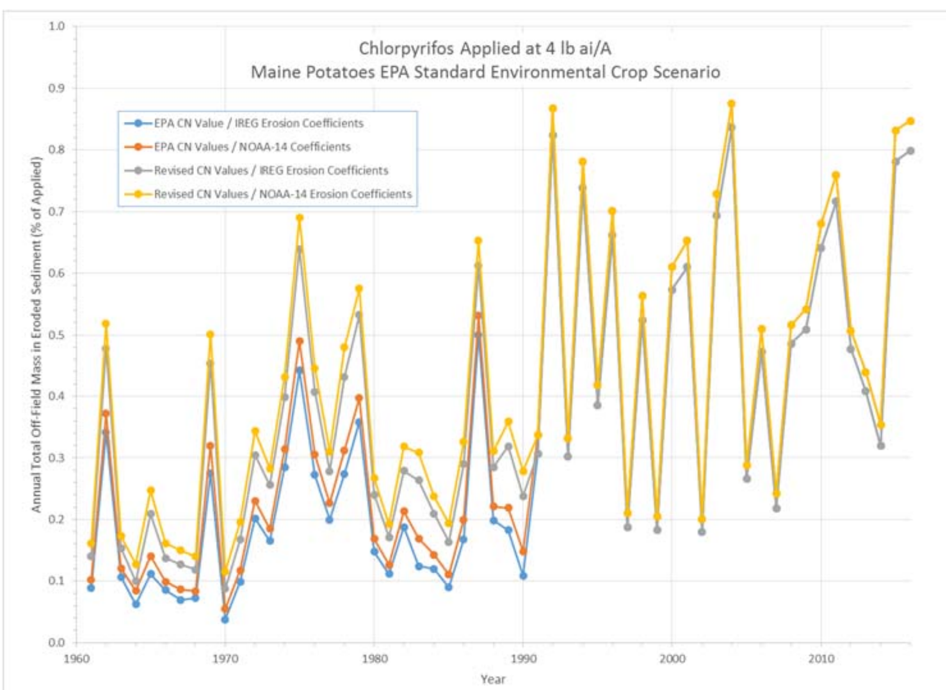

Figure 4. 31 PRZM5.0 Chlorpyrifos – Maine Potatoes EPA Standard Environmental Crop Scenario – Predicted Annual Sorbed Off-field Mass (% of Applied)

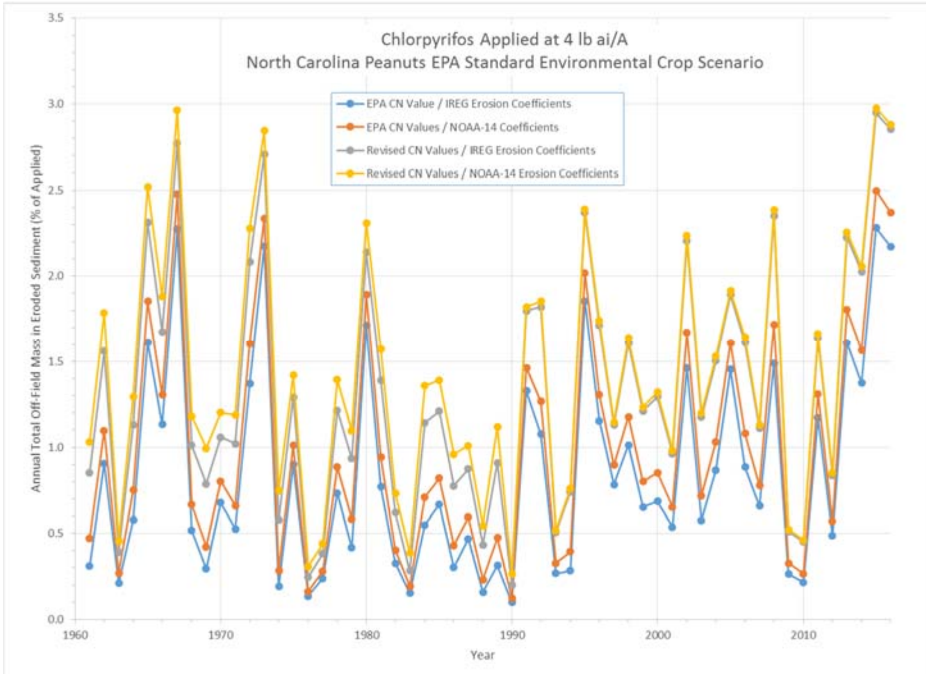

Figure 4. 32 PRZM5.0 Chlorpyrifos – North Carolina Peanuts EPA Standard Environmental Crop Scenario – Predicted Annual Sorbed Off-field Mass (% of Applied)

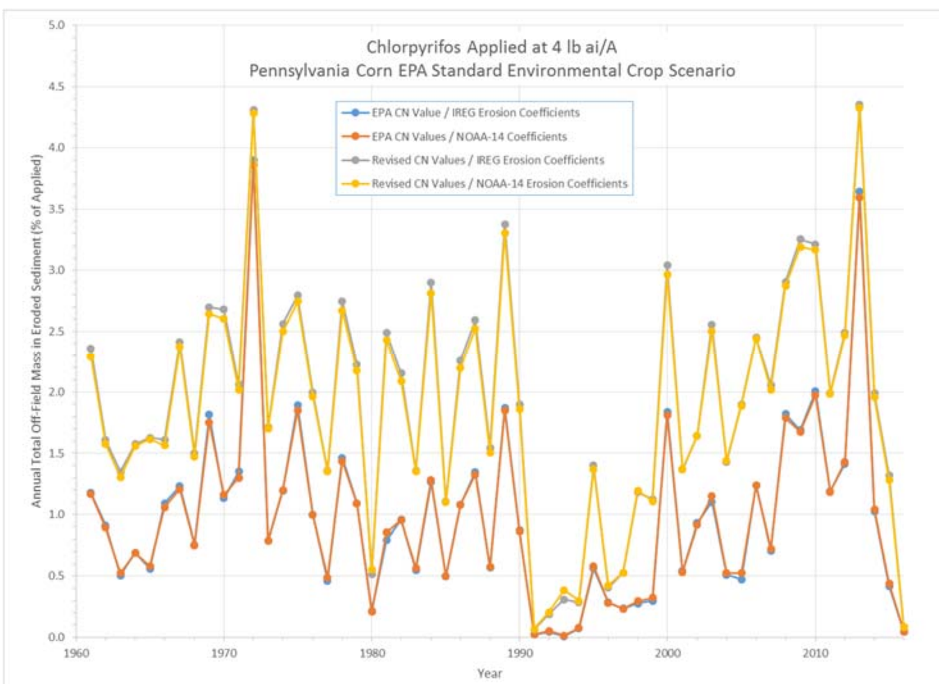

Figure 4. 33 PRZM5.0 Chlorpyrifos – Pennsylvania Corn EPA Standard Environmental Crop Scenario – Predicted Annual Sorbed Off-field Mass (% of Applied)

4.5 Conclusions

The objective of this research was to evaluate the effect of the current EPA “look-up” table method for estimating runoff curve numbers (CN) versus the revised runoff curve numbers (CN) method developed for this research and to evaluate the effect of the “IREG” storm intensity coefficients method versus the “NOAA-14” storm intensity coefficients method identified in this research on off-field pesticide mass predictions by PRZM5.0. Three pesticides: atrazine, propiconazole, and chlorpyrifos were selected for the PRZM5.0 modelling.

The major findings of this work found the following results:

(1) PRZM5 predicted off-field pesticide mass is highly sensitive to the user input runoff curve number. This is similar to finding of Estes and Hendley for model sensitivity of PRZM3.12.2 (Estes and Hendley, 2000).

(2) For all three pesticides, both predicted dissolved and sorbed off-field pesticide masses were higher for simulations with runoff curve numbers generated with the revised runoff curve number (CN) developed for this research compared to the current EPA “look-up” table method for estimating runoff curve numbers (CN). This was also true over the entire 1961-2016 weather time series period and for all six EPA standard environmental crop scenarios. The results in Chapter 3 showed that the PRZM5.0 simulations run with revised method estimated runoff curve numbers (CN) both over-estimated observed runoff depths as well demonstrated improved fit to the observed runoff data when compared to results from PRZM5.0 simulations run with the EPA table “look-up” method runoff curve number. Since runoff is the carrier for dissolved pesticide and a key parameter in the erosion algorithm, this

indicates that PRZM5.0 may potentially be under-estimating off-field pesticide mass in runoff and eroded sediment.

(3) The % of applied dissolved pesticide mass increased by 1.6%-14.4% for atrazine; 1.4%-15.0% for propiconazole; and 1.1%-7.8% for chlorpyrifos as a result of change from the EPA "look-up" table method for estimating runoff curve numbers to the revised runoff curve number (CN) method developed for this research. The % of applied sorbed pesticide mass increased by 1.7%-10.0% for atrazine; 1.6%-14.7.0% for propiconazole; and 1.3%-1.7% for chlorpyrifos, a result of change from the EPA "look-up" table method for estimating runoff curve numbers to the revised runoff curve number (CN) method developed for this research. This pattern is expected where the low K_{OC} pesticide, atrazine, would increase more in the dissolved phase and the high K_{OC} pesticide, chlorpryifos, would increase more in the sorbed phase.

(4) Investigation into the increases in predicted off-field sorbed pesticide masses from the revised runoff curve number (CN) method developed for this research compared to the current EPA "look-up" table method for estimating runoff curve numbers indicate that the runoff curve number (CN) assignment is more sensitive to increasing predicted off-field sorbed pesticide mass in off-field eroded sediment compared to internal PRZM5.0 equation for rainfall intensity. The internal erosion algorithm in PRZM5.0 uses the daily calculated runoff quantity in its formula for calculating daily off-field loading of erosion. Thus, the user-supplied runoff curve number affects not only the daily off-field predicted runoff quantity, but also, the daily off-field erosion quantity. This results in the user supplied runoff curve number

affecting both the PRZM5.0 prediction of off-field dissolved and sorbed pesticide quantities (Young and Fry, 2014).

(5) The "NOAA-14" storm intensity coefficients generally resulted in slight increases in PRZM5.0 predicted off-field sorbed pesticide compared to the "IREG" storm intensity coefficients method.

Given the results of this study, the revised runoff curve number (CN) method developed for this research combined with the "NOAA-14" storm intensity coefficients showed potential for improving predictions of off-field pesticide mass, both dissolved and sorbed, for use with EPA PRZM5.0 standard environmental crop scenarios, especially if used with updated weather time series.

4.6 Future Work

Potential Future Work may include the following:

(1) Revise the runoff curve numbers, CN, for the remaining EPA PRZM5.0 standard environmental crop scenarios using revised method of calculating CN values based on time series of streamflow data developed for this thesis.

(2) Improve the NRCS Runoff Curve (CN) method to better fit contemporary observed runoff data, and subsequently, better simulate off-field pesticide mass.

(3) Conduct agricultural field runoff studies with runoff quantities that better match contemporary runoff quantities. Measurements of pesticide mass could be made to verify dissolved and sorbed quantities for various compounds.

(4) Extension of this research to other pesticide, hydrology or nutrient models to evaluate how the new revised runoff curve number (CN) method or "NOAA-14"

storm intensity coefficients perform for runoff, erosion and off-field contaminant prediction.

4.7 References

(1) Burns, L.A. (2006). User Manual for EXPRESS, the EXAMS-PRZM Exposure Simulation Shell -Version 1.03.02, July 20, 2007. U. S. Environmental Protection Agency, Office of Research and Development, Washington D.C. 20460. EPA/600/R-06/095 September 2006.

(2) EPA (2006). Pesticide Root Zone Model Field and Orchard Crop Scenario Metadata. U. S. Environmental Protection Agency, Office of Pesticide Programs, Environmental Fate and Effects Division. April 5, 2006.

(3) EPA. 2009. Guidance for Selecting Input Parameters in Modelling the Environmental Fate and Transport of Pesticides, Version 2.1. U. S. Environmental Protection Agency, Office of Pesticide Programs, Environmental Fate and Effects Division. October 22, 2009.

(4) Estes, T.L., N. Pai, M.F. Winchell (2015). "Comparison of Predicted Pesticide Concentrations in Groundwater from Sci-Grow and PRZM-GW Models with Historical Monitoring Data. Pest Management Science No. 72, pp. 1187-1201 2015.

(5) Estes, T.L., and P. Hendley (2000). "The Sensitivity of PRZM-EXAMS to Key Assumptions – Implications for Pesticide Aquatic Risk Assessments". Poster: 21st Annual Meeting of the Society of Environmental Toxicology and Chemistry, Nashville, Tennessee.

(6) Jones, R. D., S Abel, W. Effland, R Matzner, and R. Parker (1998). An Index Reservoir for Use in Assessing Drinking Water Exposure. Chapter IV in Proposed Methods for Basin-Scale Estimation of Pesticide Concentrations in Flowing Water and Reservoirs for Tolerance Reassessment., presented to the FIFRA Science Advisory Panel, July 29, 1998.

(7) Knisel, W.G., ,F.M. Davis, and R.A. Leonard (1994) GLEAMS Version 2.0 –Part III: User Manual. USDA-ARS, Coastal Plain Experiment Station. Southeast Watershed Research Laboratory. Tifton, Georgia, 31793.200 pp.

(8) Suarez, L.A. (2005). PRZM-3, A Model for Predicting Pesticide and Nitrogen Fate in the Crop Root and Unsaturated Soil Zones: User's Manual for Release 3.12.2. US EPA. Office of Research and Development. Athens Georgia.

(9)Young, D.F. and M.M. Fry (2014). PRZM5, A Model for Predicting Pesticide in Runoff, Erosion and Leachate: User Manual. USEPA: Office of Pesticide Programs, Washington, D.C. USEPA/OPP 734F14002.

CHAPTER 5 CONCLUSIONS

The focus of this research was to develop updated approaches to estimating rainfall storm intensity modelling by the EPA field-scale model PRZM5.0 for use with the EPA standard environmental crop scenarios for both ecological and drinking water risk assessment of pesticide contamination in surface water. Two separate environmental processes, erosion and runoff, in PRZM5.0 needed to be evaluated for updating.

Chapter one focused on the background of the objective of this research, literature, and overall research objective. Chapter two focused on a potential revision to the storm intensity algorithm to the 1986 NRCS internal empirical algorithm, “IREG” storm intensity distribution system built into PRZM5.0. NRCS is in the process of creating a new replacement system, “NOAA-14”, which is more temporally current and spatially representative of the varying geographical conditions in the U.S. Chapter three focused on developing a revised method for calculating runoff curve (CN) numbers as an alternative to the EPA table “look-up” method for use in surface water risk assessment modelling. Chapter 4 focused on evaluating the effect of the current EPA “look-up” table method for estimating runoff curve numbers (CN) versus the revised runoff curve numbers (CN) from this research and evaluated the effect of the “IREG” storm intensity coefficients method versus the “NOAA-14” storm intensity coefficients method for off-field pesticide mass predictions for three pesticides with differing sorption behavior.

For the erosion component, a custom version of PRZM5.0 was developed which allows the user to simulate the “NOAA-14” storm distribution systems. This custom version was tested to evaluate and compare the off-field eroded sediment loads for six EPA PRZM5.0 standard environmental crop scenarios and two weather time series, 1961-1990 and 1991-2016. Results found that for the majority of the simulations, the “NOAA-14” storm intensity distribution

predicted statistically higher off-field loadings of eroded sediment than the “IREG” storm intensity distribution, with increase in off-field eroded sediment loadings increasing by 0.3% to as high as 69. These findings indicate that if the PRZM5.0 internal storm intensity coefficients are not updated, the model may be under-estimating off-field eroded sediment and, consequently, sorbed pesticide residues for use with surface water models for risk assessment.

Results from the runoff algorithm and runoff curve (CN) statistical analyses showed very little variation between nearby streamflow locations. Variability appeared to be temporal rather than spatial. The EPA PRZM5.0 standard environmental crop scenarios run with runoff curve numbers identified using the table “look-up” method resulted in under-estimation of the observed off-field runoff. Simulations run with runoff curve numbers calculated using the revised runoff curve number (CN) method biased toward over-estimation. Given these results, the revised runoff curve number (CN) method based on time series of streamflow data showed potential improvement in predicting off-field runoff, especially for updated weather time series.

Finally, the “NOAA-14” storm intensity coefficients and the revised runoff curve number (CN) method were compared to the established “IREG” storm intensity coefficient distribution system and EPA table “look-up” method for simulating three pesticides of differing sorption behaviors using EPA PRZM5.0 standard environmental crop scenarios. The major findings are that predicted off-field pesticide mass is highly sensitive to the user input runoff curve number. Additionally, for all three pesticides, both predicted dissolved and sorbed off-field pesticide masses were higher for simulations with runoff curve numbers generated with the revised runoff curve number (CN) method compared to the current EPA “look-up” table method for estimating runoff curve numbers (CN). Additionally, since runoff is also a variable in the erosion algorithm, the user-supplied runoff curve number was found to affect not only the daily off-field predicted

runoff quantity, but also, the daily off-field erosion quantity. This results in the user supplied runoff curve number affecting both the prediction of off-field dissolved and sorbed pesticide quantities. Finally, this research found that the “NOAA-14” storm intensity coefficients generally resulted in slight increases in predicted off-field sorbed pesticide compared to the “IREG” storm intensity coefficients method.

The overall results of combined research for this dissertation is that the revised runoff curve number (CN) method developed for this research combined with the “NOAA-14” storm intensity coefficients showed potential for improving predictions of off-field pesticide mass, both dissolved and sorbed, for use with EPA PRZM5.0 standard environmental crop scenarios, especially if used with updated weather time series. Moreover, these revised methods may show potential for use with other models, such as SWAT or LEACHP.

A final important finding was that regulatory models need to be periodically reviewed to assure that internal algorithms are still applicable and current. This is especially true for algorithms based on empirical equations.

APPENDIX A – MODIFIED PRZM5.0 EROSION SUBROUTINE

```
module erosion
    implicit none
    contains

    SUBROUTINE EROSN(julday)
     !Determines loss of pesticide due to erosion by a variation of USLE and
an enrichment ratio.
      use
constants_and_Variables,ONLY:NAPP,NC,NCMPTS,precip,spt,itflag,AFIELD,USLEK,US
LELS,USLEP,cfac, &
                                       DELX,runof,erflag,sedl,ELTT,
julday1900,model_erosion,data_date
      use utilities
      implicit none

      integer,intent(in) :: julday  !used to determine the rainfall
characteristics

      REAL ::  Q,QQP,SLKGHA,ENRICH
      REAL ::  EC0,EC1,EC2,TC,QP,QU



      ELTT = 0
      !check to see if first compartment frozen
      IF((ITFLAG.EQ.1).AND.(SPT(1).LE.0.0)) Return

      ! Get Coefficients from Table F-1 in TR-55
      CALL TMCOEF(EC0,EC1,EC2, julday)


      CALL TMCONC_PRZM5(TC)

      !if (FLAG4) then
      !    CALL TMCONC_PRZM5(TC)
      !else
      !    CALL TMCONC_PRZM3(TC)
      !end if

      QU=EC0+EC1*ALOG10(TC)+EC2*(ALOG10(TC)**2)
      QU=10.0**QU
      QP=(QU*(AFIELD*.00386)*(RUNOF*.3937))*0.02832
      QP=(QP/AFIELD)*360
      write(*,*) TC
      Q=RUNOF*10.
      QQP=Q*QP




      ! ERFLAG=2: MUSLE
      ! ERFLAG=3: MUST
      ! ERFLAG=4: MUSS
```

```
      IF(ERFLAG.EQ.2)THEN
        SEDL=1.586*(QQP**0.56)*(AFIELD**0.12)
      ELSEIF(ERFLAG.EQ.3)THEN
        SEDL=2.5*(QQP**0.5)
      ELSEIF(ERFLAG.EQ.4)THEN
        SEDL=0.79*(QQP**0.65)*(AFIELD**0.009)
      ENDIF

!     Compute enrichment ratio
      SEDL   = (SEDL* USLEK* USLELS* CFAC* USLEP)*AFIELD


      SLKGHA = (SEDL* 1000.)/AFIELD



      where (data_date == julday1900)   model_erosion = SLKGHA



      IF(SLKGHA.EQ.0.0)THEN
        ENRICH=1.0
      ELSE
        ENRICH = 2.0- (0.2* log(SLKGHA))
        ENRICH= EXPCHK(ENRICH)
      ENDIF

      !Compute loss term for pesticide balance
      !delx(1) is in here nd will cause problems later when declining erosion
extraction is used

      ELTT=  (SLKGHA/(100000.*DELX(1)))*ENRICH   !grams/cm3


    END  SUBROUTINE EROSN




!*****************************************************************************
****
    SUBROUTINE TMCONC_PRZM5(TC)
      !PRZM5 Corrects an error in the sheet flow calculation where Rain
should be used rather than runoff
      !Calculate time of concentration based on TR-55 method
      !TC = time of concentration (hrs)

       use  constants_and_Variables, ONLY:
NC,NCMPTS,PRECIP,HL,SLP,N1,effective_rain
       implicit none
       real, intent(out) :: TC
       REAL S1,S2,HL1,HL2,WATER,TT1,V2,TT2

!     ASSUME S2=S1, R2=0.4 FT, N2=0.05.  LIMIT HL1 TO 300'
      S1=SLP/100.
      S2=S1
!      R2=0.4
```

```
!       N2=0.08

      HL1=AMIN1(HL*3.28,300.)           !ft 300 max for sheet
      HL2=AMAX1(0.0,(HL*3.28)-300)      !remainder for conc flow


      water = effective_rain /2.54  !PRZM5 repair



     ! WATER=(RUNOF)/2.54                !inches but this is Runoff and it 
should be rain

      TT1=(0.007*(N1*HL1)**0.8) / ((WATER**0.5)*(S1**0.4))
      V2=16.1345*(S2)**0.5
      TT2=HL2/(3600.*V2)
      TC=TT1+TT2




    END SUBROUTINE TMCONC_PRZM5



!***********************************************************************
****
!    SUBROUTINE TMCONC_PRZM3(TC)
!
!!      Calculate time of concentration based on TR-55 method
!!      TC = time of concentration (hrs)
!
!        use  constants_and_Variables, ONLY: NC,NCMPTS,PRECIP,HL,SLP,N1,runof
!        implicit none
!
!       REAL S1,S2,HL1,HL2,WATER,TT1,V2,TT2,TC
!
!!      ASSUME S2=S1, R2=0.4 FT, N2=0.05.  LIMIT HL1 TO 300'
!       S1=SLP/100.
!       S2=S1
!!       R2=0.4
!!       N2=0.08
!
!       HL1=AMIN1(HL*3.28,300.)           !ft 300 max for sheet
!       HL2=AMAX1(0.0,(HL*3.28)-300)      !remainder for conc flow
!
!       WATER=(RUNOF)/2.54                !inches but this is Runoff and it 
should be rain
!
!       TT1=(0.007*(N1*HL1)**0.8) / ((WATER**0.5)*(S1**0.4))
!       V2=16.1345*(S2)**0.5
!       TT2=HL2/(3600.*V2)
!       TC=TT1+TT2
!
!       END SUBROUTINE TMCONC_PRZM3
!
!
```

```
!
! ********************************************
  SUBROUTINE TMCOEF(EC0,EC1,EC2,julday)
      !Gets Coefficients fro Table F-1 in TR-55
      use  constants_and_Variables, ONLY: NC,
NCMPTS,PRECIP,thrufl,ireg,inabs,smelt

      implicit none

      integer,intent(in) :: julday
       real, intent(out) :: EC0,EC1,EC2

      INTEGER  IFND,J,IREGOLD
      INTEGER  NBG(10),NEN(10)
      REAL     CC(62),CC0(62),CC1(62),CC2(62)
      REAL     CTEMP,IAP


      DATA NBG /1,9,17,25,33,38,43,48,53,58/
      DATA NEN /8,13,22,30,33,38,43,48,53,58/
      DATA CC
/0.10,0.20,0.25,0.30,0.35,0.40,0.45,0.50,0.10,0.20,0.25,0.30,0.50,0.00,0.00,0
.00, &

0.10,0.30,0.35,0.40,0.45,0.50,0.00,0.00,0.10,0.30,0.35,0.40,0.45,0.50,0.00,0.
00, &

0.10,0.25,0.30,0.40,0.50,0.10,0.25,0.30,0.40,0.50,0.10,0.25,0.30,0.40,0.50, &

0.10,0.25,0.30,0.40,0.50,0.10,0.2,0.30,0.40,0.50,0.10,0.25,0.30,0.40,0.50/
      DATA CC0
/2.30550,2.23537,2.18219,2.10624,2.00303,1.87733,1.76312,1.67889,2.03250,&
                1.91978,1.83842,1.72657,1.63417, &

0.0,0.0,0.0,2.55323,2.46532,2.41896,2.36409,2.29238,2.20282,0.0,0.0,
&

2.47317,2.39628,2.35477,2.30726,2.24876,2.17772,0.0,0.0,2.4922,2.4485,2.4176,
&
                2.3275,2.1929,2.5796, 2.539, 2.5126, 2.4423, 2.3435, 2.4928,
2.4494, 2.4182, &
                2.3289, 2.1955,
&
                2.5447, 2.5016, 2.473, 2.3917, 2.2743,
&
                2.515, 2.4934, 2.441, 2.354, 2.2249,
&
                2.4928, 2.4494, 2.4182, 2.3289, 2.1955/
      DATA CC1 /-0.51429,-0.50387,-0.48488,-0.45695,-0.40769,-0.32274,-
0.15644,-0.06930,                                &
                -0.31583,-0.28215,-0.25543,-0.19826,-0.09100,0.0,0.0,0.0,-
0.61512,-0.62257,-0.61594,-0.59857,-0.57005,  &
                -0.51599,0.0,0.0,-0.51848,-0.51202,-0.49735,-0.46541,-
0.41314,-0.36803,0.0,0.0, &
                -0.5871, -0.5944, -0.5866, -0.5372, -0.3911, -0.6312, -
0.6368, -0.6315, -0.5887, -0.4789, &
```

```
                -0.585, -0.5928, -0.5857, -0.5381, -0.3952,
&
                -0.6222, -0.6298, -0.6226, -0.5773, -0.4524,
&
                -0.6024, -0.6134, -0.6056, -0.56, -0.4257,
&
                -0.585, -0.5928, -0.5857, -0.5381, -0.3952/
      DATA CC2 /-0.11750,-0.08929,-0.06589,-
0.02835,0.01983,0.05754,0.00453,0.0,-0.13748,-0.07020, &
                 -0.02597,0.02633,0.0,  &
                 0.0,0.0,0.0,-0.16403,-0.11657,-0.08820,-0.05621,-0.02281,-
0.01259,0.0,0.0,                             &
                 -0.17083,-0.13245,-0.11985,-0.11094,-0.11508,-
0.09525,0.0,0.0, &
                 -0.13, -0.1073, -0.093, -0.0647, -0.0933, &
                 -0.1451, -0.1203, -0.1087, -0.0921, -0.1246,
&
                 -0.137, -0.1154, -0.1018, -0.0754, -0.1077,
&
                 -0.1332, -0.1071, -0.0947, -0.0694, -0.0948,
&
                 -0.1344, -0.1226, -0.0986, -0.0725, -0.0996,
&
                 -0.1370, -0.1154, -0.1018, -0.0754, -0.1077/


      IREGOLD=IREG

!      IF(IREG.NE.2)THEN
!        IF((JULDAY.LE.121).OR.(JULDAY.GE.258))THEN  !May 1 to Sep 16,  IREG
= IREG, else IREG =2
!          IREG=2
!        ELSEIF(PRECIP.GT. 5.08)THEN  !not sure what this is about
!          IREG=1
!        ENDIF
!      ENDIF

      IFND=0
      IAP=INABS/(THRUFL+SMELT)



      IF(IAP.LE.CC(NBG(IREG)))THEN
        EC0=CC0(NBG(IREG))
        EC1=CC1(NBG(IREG))
        EC2=CC2(NBG(IREG))
      ELSE
        do J=NBG(IREG),NEN(IREG)
          IF((IAP.LE.CC(J)).AND.(IFND.EQ.0))THEN
            CTEMP=(IAP-CC(J-1)) / (CC(J)-CC(J-1))
            EC0=CTEMP * (CC0(J)-CC0(J-1)) + CC0(J-1)
            EC1=CTEMP * (CC1(J)-CC1(J-1)) + CC1(J-1)
            EC2=CTEMP * (CC2(J)-CC2(J-1)) + CC2(J-1)
            IFND=1
          ENDIF
        end do
```

```
        IF(IFND.EQ.0)THEN
          EC0=CC0(NEN(IREG))
          EC1=CC1(NEN(IREG))
          EC2=CC2(NEN(IREG))
        ENDIF
      ENDIF


      IREG=IREGOLD

  END SUBROUTINE TMCOEF


end module erosion
```

APPENDIX B - SOURCE CODE FOR REVISED METHOD FOR CALCULATING RUNOFF CURVE NUMBERS

```
PROGRAM   Runoff


   integer i, j, ct, yr, yrA(10000), pyr

   Character*10 dum1, dum2
   character*20 date1, mdate, dateA(10000)
   real*8 disc, prec, pdisc, maxd, mind, abay, abayin, &
           storm, discA, S, CN, tcn, ct2, maxCN(10000), mCN,
&
           indisc, disck(10000), tprecp, precA(10000)
   character*1  inflow
   open(5,status="old",file="PA11.prn")
   open(6,status="unknown",file="PA11.dat")
   write(6,19)
19 format('Max Date ,  Total P , Storm ft^3/s , Storm in , Q
ft^3/s , Q in , S , CN , Year')

! Initial condition of flow - flow go up and down file
either starts going up or down U for up D for Down
   inflow = 'd'
! Initialize values
   tprecp = 0.0
   pdisc=100000.0
   ct=0
   mind=0.0
   maxd=0.0
   abay=0.0
   abayin = 0.0
!   s = 0.0
   indisc = 0.0
   storm = 0.0
   discA = 0.0

   do 12 i=1,10000,1
      discK(i) = 0.0
      precA(i) = 0.0
12 continue

!  Read in values
    read(5,1) dum1
1   format(a10)
20  continue
```

```
    Read(5,10,end=50) dum1, dum2, date1, disc, prec, yr
    write(*,*) date1, disc
10  format(a10,a10,a20,f10.0,f10.0,i10)

!   If discharge is less than previous value then flow is
still decreasing continue processing
!  if discharge is greater than or equal then flow and end
of downflood is new set output and start anew

    if (inflow.eq.'u') then
      if (pdisc.lt.disc) then

           if (mind.lt.disc) mind = disc
           if (maxd.ge.disc) maxd = disc
           if (maxd.ge.disc) mdate = date1
           pdisc = disc
           ct = ct + 1
           dateA(ct) = date1
           discA = discA + disc
           discK(ct) = disc
           precA(ct) = prec
           goto 20
       endif
       if (pdisc.ge.disc) then
           if (mind.lt.disc) mind = disc
           if (maxd.ge.disc) maxd = disc
           if (maxd.ge.disc) mdate = date1
           pdisc = disc
           ct = ct + 1
           discA = discA + disc
           discK(ct) = disc
           dateA(ct) = date1
           precA(ct) = prec
           yrA(ct) = yr
           inflow = 'd'
           goto 20
       endif
    endif

    if (inflow.eq.'d') then

      if (pdisc.lt.disc) then

      mind = discK(1)
      mdate = dateA(1)
      maxd = discK(1)
```

```
      do 65 i=2,ct,1
        if (discK(i).lt.mind) mind= discK(i)
        if (discK(i).gt.maxd) then
          mdate = dateA(i)
          maxd = discK(i)
        endif

 65   continue


! Calculate storm runoff in ft^3/s and in
      storm = discA
      indisc = (storm*0.03719)/35.0

! Calculate Direct runoff for an annual flood in ft^3/s and
in

      abay = storm - (((discK(1) + discK(ct))/2.0)*(ct-1))
      abayin = (abay * 0.03719)/35.0

! Calculate S

      tprecp = 0.0
      Do 75 i=1,ct,1
        tprecp= tprecp + precA(i)
75    continue
      if (abayin.gt.0.0) then
         S = 5.0 * (tprecp + 2.0 * abayin  -
((4.0*abayin*abayin + 5.0*tprecp*abayin)**0.5))
      endif
      if (abayin.le.0.0) S = 0.0
      CN = 1000.0 / (10.0 + S)


! Write output
      if ((S.gt.0.0).and.(tprecp.gt.0.0)) then
         write(6,77) mdate, tprecp, storm, indisc, abay,
abayin, S, CN, yrA(ct)
      endif
77    format(a20,7(' , ',f10.3),' , ',i10)

!  reinitialize everything
   discK(1) = disc
   discA = disc

   dateA(1) = date1
   precA(1) = prec
```

```
   yrA(1) = yr

   do 41 i=2,10000, 1
     discK(i) = 0.0
     dateA(i) = ' '
     precA(i) = 0.0
     yrA(i) = 0
41 continue
   pdisc=disc
   ct=1
   mind=0.0
   maxd=0.0
   abay=0.0
   abayin = 0.0
   s = 0.0
   indisc = 0.0
   storm = 0.0
   inflow = 'u'
   goto 20
   endif

   if (pdisc.ge.disc) then
     if (maxd.ge.disc) maxd = disc
     if (maxd.ge.disc) mdate = date1
     pdisc = disc
     ct = ct + 1
     discA = discA + disc
     discK(ct) = disc
     dateA(ct) = date1
     precA(ct) = prec
     yrA(ct) = yr
     go to 20
   endif
   endif

50 continue
   close(5)
   close(6)
!  End of processing daily data.  Now calculate averages and
annual CN values

   open(6,status="unknown",file="PA11.dat")
   open(7,status="unknown",file="PA11_CN.dat")
   write(7,88)
88 format('Year , Rain (in) , Q (in) , S , Average CN, Max
CN ')
```

```
      pyr = 1961
      avgS = 0.0
      tprecp = 0.0
      ct2 = 0.0
      tcn = 0.0
      i = 0
      do 801 j=1,10000
        maxCN(j) = 0.0
801   continue
      read(6,92) dum1
92    format(a10)
307   continue
      i = i + 1
      read(6,107,end=100) mdate, prec, storm, indisc, abay,
abayin, S, maxCN(i), yr
107   format(a20,7(3x,f10.0),3x,i10)
      write(*,*) mdate, i, maxCN(i), yr

      avgS = avgS + abayin
      tprecp = tprecp + prec
      ct2 = ct2 + 1.0
      tcn = tcn + maxCN(i)
! if new year, calculate CN and restart stuff

      if (yr.ne.pyr) then
        avgS = avgs - abayin
        tprecp = tprecp - prec
        tcn = (tcn - maxCN(i-1))/ (ct2 - 1.0)
        mCN = 0.0
        do 901 j=1,i-1
           if (maxCN(j).gt.mCN) mCN = maxCN(j)
 901    continue

        write(7,207) pyr, tprecp, avgS, tcn, mCN
207     format(i10,5(' , ',f10.3))
        avgS = abayin
        tprecp = prec
        ct2 = 1.0
        mCN = 0.0
        maxCN(1) = maxCN(i)
        i=1
        do 501 j=2,10000,1
           maxCN(j) = 0.0
501     continue
        tcn = maxCN(1)
        pyr = yr
        goto 307
```

```
      endif

! Else keep tabulating
      if (yr.eq.pyr) then
          pyr = yr
          avgS = avgS + abayin
          tprecp = tprecp + prec
          ct2 = ct2 + 1.0
          tcn = tcn + maxCN(i)
          goto 307
      endif
100   continue

! At end of file, process last year
      tcn = (tcn - maxCN(i-1))/ (ct2 - 1.0)
        mCN = 0.0
        do 301 j=1,i-1
           if (maxCN(j).gt.mCN) mCN = maxCN(j)
 301    continue

      write(7,207) pyr, tprecp, avgS, tcn, mCN

END PROGRAM Runoff
```

VITA

Tammara Estes has spent over thirty years in the agrochemical industry working in regulatory support, environmental simulation modeling, statistical analysis, and environmental risk assessment of crop protection chemicals in surface water, groundwater, and soils. She is a biomathematician by training with extensive knowledge of the major EPA regulatory models and methods that are in use today in the U.S., Canada, and Europe. She has successfully applied this knowledge to various registration efforts and has designed numerous refined approaches to estimating agrochemical concentrations in surface water and groundwater.

She is a former member of both the FIFRA Exposure Modeling Work Group, a consortium of agrochemical industry scientists formed to address issues concerning the use of environmental fate simulation modeling to estimate pesticide concentrations in groundwater and surface water in the context of the U.S. regulatory framework, and the Spray Drift Task Force, an industry group formed to study drift from agricultural application of pesticides. She also served on numerous additional task forces to evaluate methods for assessing crop protection chemical exposure in surface and groundwater.

Additionally, Ms. Estes taught college mathematics and statistics for ten years. After completion of her Ph.D., she intends to continue working in environmental modeling as well as teaching mathematical and statistical methods for environmental risk assessment.