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Recommendations of the Best Management Practice (BMP) Expert Panel for
Cropland Irrigation

Chesapeake Bay Program
Science. Restoration. Partnership.

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Executive Summary

This Expert Panel was charged to determine the water quality benefit associated with the practice of irrigation on cropland, a practice of specific importance on the Delmarva Peninsula region of the Chesapeake Bay watershed (CBW). This region is characterized by unpredictable rainfall patterns and wide-spread course-textured sandy soils with low water retention capacity. The primary intention of cropland irrigation is to increase crop yield and consistency. The literature review process revealed limited research directly addressing the impacts of irrigation systems on respective local or regional water quality, in contrast to other partnership-approved Best Management Practices (BMPs), such as cover crops and conservation tillage. The fates of field-applied nitrogen (N) and phosphorus (P), or sediment loss due to erosion are of specific concern in regard to water quality. Taking into account the agricultural practices relevant to the CBW, the Panel narrowed its focus to center-pivot, lateral move and traveling gun irrigation systems on corn (grain or silage). The panel was also limited to addressing N leaching, as there is not sufficient data available addressing P and sediment related to cropland irrigation at this time.

The Chesapeake Bay Program's (CBP) Agriculture Workgroup (AgWG) asked the panel to consider several aspects of cropland irrigation when reviewing the research findings. Primary among them was to refine the current CBP interim BMP [1] definition and N efficiency value for cropland irrigation, accounting for possible deviations in efficiency values based on weather variability across growing seasons. The panel determined that it cannot refine the estimated interim N efficiency value at this time. The research currently available does not sufficiently substantiate a water quality benefit associated with cropland irrigation. The panel was also asked to consider creating separate efficiency values based on decreased variation in yields with irrigation, water management of irrigated systems, and fertigation. The panel determined that these factors are not mutually exclusive. All are interrelated in influencing potential loss of N from irrigated fields. For this reason, they are not considered as separate systems in this report.

The panel elected the Delmarva Peninsula portion of the watershed as the focus of this report due to the prevalence of cropland irrigation in that region. However, much of the literature related to irrigation comes from the mid-west United States, where irrigation of cropland has been ubiquitous across the agricultural landscape for some time, due to climate conditions that leave crops regularly subject to moisture stress. Additionally, most of the research is focused on comparing various irrigation systems to each other, with the goal of defining the system that provides the greatest yields, water use efficiency (WUE), nitrogen use efficiency (NUE), and/or economic benefits. Few studies consider the impacts, either beneficial or deleterious, of irrigated cropland on surrounding water quality. Among the limited publications addressing

[1] CBP interim BMPs are requested by CBW state jurisdictions for use in planning scenarios used to determine a path forward to achieve USEPA-assigned TMDL goals. Interim BMPs should have scientific justification but cannot be submitted for annual progress toward achieving these goals. In contrast, CBP BMPs submitted for progress toward TMDL goals have first been considered by a BMP Expert Panel and subsequently approved by the CBP partnership.

nutrient transport beyond the root zone, some found greater loss of N from irrigated conditions in comparison to dryland conditions, indicating a potential detriment to local water quality. Within the CBW where irrigation is a growing practice, the baseline condition remains dryland agriculture. While many studies compared center-pivot irrigation to other systems (e.g., furrow, drip), there was seldom a control dryland condition.

The Expert Panel agreed that there is not sufficient science-based research available to indicate a reduction in N losses due to irrigation of corn, therefore an N efficiency value cannot be established at this time. This does not preclude the possibility of revisiting cropland irrigation as a BMP for a future expert panel, should a more robust catalogue of scientific research literature addressing cropland irrigation management and its water quality impacts emerge. In that vein, the panel strongly endorses further research on the impacts of cropland irrigation on nutrient and sediment loss and encourages the reader to review the *Ancillary benefits and unintended consequences* (p.38) and *Future research and management needs* (p.40) sections of this report.

Contents

Acronyms and Abbreviations

AgWG	Agriculture Workgroup
BMP	Best Management Practice
CBP	Chesapeake Bay Program
CBW	Chesapeake Bay Watershed
CBWM	Chesapeake Bay Watershed Model
EP	Expert Panel
EPA	Environmental Protection Agency
EPEG	Expert Panel Establishment Group
HUC	Hydrologic Unit Code
LSD	Least Significant Difference
N	Nitrogen
NRCS	Natural Resource Conservation Service (Division of USDA)
NUE	Nitrogen Use Efficiency
P	Phosphorus
SD	Standard Deviation
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
USGS	United States Geological Survey
USDA	United States Department of Agriculture
USDA-NASS	United States Department of Agriculture- National Agricultural Statistics Service
USDA-NRCS	United States Department of Agriculture-Natural Resource Conservation Service
USEPA	United States Environmental Protection Agency
WQGIT	Water Quality Goal Implementation Team
WTWG	Watershed Technical Workgroup
WUE	Water Use Efficiency

Background: Charge and Membership of the Expert Panel

In the Phase 5.3.2 Chesapeake Bay Watershed Model, cropland irrigation was recognized as an interim best management practice (BMP) for planning purposes. Interim BMPs can be used for planning scenarios but are not credited in annual progress scenarios as part of net management actions or BMP implementation until the BMP has been reviewed and approved by the Chesapeake Bay Program (CBP) partnership. The process to review and approve BMPs for this purpose is described in the Water Quality Goal Implementation Team's (WQGIT) *Protocol for the Development, Review, and Approval of Loading and Effectiveness Estimates for Nutrient and Sediment Controls in the Chesapeake Bay Watershed Model,* aka the "BMP Review Protocol" or "BMP Protocol."[2]

In 2015 the Agriculture Workgroup (AgWG) identified cropland irrigation as a BMP that should be considered by a BMP Expert Panel (EP) under the BMP Protocol. The AgWG formed an ad hoc group – or Expert Panel Establishment Group (EPEG) – to formulate the scope of work and suggested expertise for the subsequent panel. The EPEG's recommendations were approved by the AgWG in April 2015 (see Appendix B) and when staff resources were available a group of experts were identified for partnership consideration in May 2016. The panel convened following AgWG approval of the membership in July 2016 (Table 1). The panel met eight times from August 2016 to December 2018 .

Table 1 – Cropland Irrigation Panel membership and support

Panel Member Name	Affiliation
Tim Sexton, Panel Chair	Virginia Department of Conservation and Recreation
James Adkins	University of Delaware
Judy Denver	US Geological Survey (retired)
Greg McCarty, PhD	US Department of Agriculture – Agriculture Research Service
Cory Whaley, PhD	University of Delaware
Support to the panel provided by: Jerry Lewis (USDA-NRCS), Loretta Collins (U. of MD), Jeremy Hanson (VA Tech), Mark Dubin (U. of MD), Matt Johnston (U. of MD), Dr. Brian Benham (VA Tech) and Lindsey Gordon (Chesapeake Research Consortium); Tyler Monteith (DE DNREC). With acknowledgment: Mark Nardi (USGS); Amy Shober (U. of Delaware)	

[2] https://www.chesapeakebay.net/documents/CBP_BMP_Expert_Panel_Protocol_WQGIT_approved_7.13.15.pdf

Scope of Work

The Cropland Irrigation Management Expert Panel was asked to develop definitions and loading or effectiveness estimates for cropland irrigation management practices, including effectiveness estimates for N, P, and sediment, where possible based on available data.

The panel was instructed to work with the AgWG and WTWG to develop a report that includes information as described in the WQGIT's BMP Protocol.

Specifically, the Cropland Irrigation Management EPEG recommended the following four charges with associated tasks to be completed by the Cropland Irrigation Management EP (See Appendix B):

1. Refine interim BMP definition and efficiency values for cropland irrigation under average hydrologic conditions, taking into account how efficiencies might deviate from average values during wet or dry years.
2. Consider developing BMP definitions and efficiency recommendations for three categories of cropland irrigation:
   - Cropland irrigation (i.e., decreased variation in yields between dry land and irrigated cropland production)
   - Irrigation water management (i.e., soil moisture management and water conservation practices)
   - Fertigation (i.e. utilization of irrigation systems to irrigate as well as apply supplemental organic or inorganic nutrients)
3. Consider establishing a baseline condition that addresses irrigation system operation and management.
4. Consider regional variations in irrigation practices and BMP efficiencies.

The first charge was necessary because the interim definition and efficiency values for Cropland Irrigation Management remain preliminary. The interim BMP for Cropland Irrigation included a preliminary total nitrogen (TN) reduction efficiency based on the difference in corn grain yields between dryland and irrigated commodity grain corn yields from the United States Department of Agriculture (USDA) Census of Agriculture for 2002 and 2007; the only two such reports that provided this separation of data at the time the interim BMP was formulated. The census analysis results identified a smaller range in crop yields for irrigated agriculture than dry land crops. The EP was instructed to gather additional information to either refine or replace the interim BMP definition for improved targeting of nutrient applications based on more consistent yields for irrigated systems. The EP was also requested to consider including P and sediment reduction efficiencies if appropriate based on available data.

The second charge addressed the range of variation in cropland irrigation practices and their effects on potential nutrient and sediment loss pathways. The Expert Panel was asked to consider developing definitions and effectiveness values for three potential categories of cropland irrigation, as described in the EPEG report (Appendix B):

1. **Cropland irrigation**. This category is comparable to the refinement of the interim BMP definition under the first charge. It addresses efficiencies to be gained through targeting of nutrient application rates to more predictable crop yields based on decreased annual yield variations.
2. **Irrigation water management**. This category addresses potential reductions in nutrient and sediment loss from improved management of the volume of water applied. The EP will consider potential efficiencies from reductions in both runoff and leaching past the root zone with enhanced water management.
3. **Fertigation**. This category addresses differences in crop yield response variation and surface and subsurface nutrient losses for irrigation systems that are used to deliver supplemental organic or inorganic nutrients. The EP should consider definitions and efficiencies based on cropland irrigation systems as a basis (i.e., analogous to the first category) and water management under fertigation systems (i.e., analogous to the second category). The EP will also consider whether to establish BMP definitions and efficiencies based on various types of irrigation systems (e.g., drip irrigation versus center pivot versus traveling gun irrigation). Finally, the EP will consider how to address acres where irrigation and fertigation are combined. Collaboration with the Nutrient Management EP on fertigation will be critical to ensure that recommendations are complementary as well as to avoid double-counting and ensure effective reporting of practices.

The EP was asked to develop N, P, and sediment efficiencies for all categories of the BMP definition, to the extent possible based on available data.

The third charge acknowledged the potential variation in pollutant reduction efficiency based on irrigation type selection, operation and maintenance, and overall management of the irrigation system. Selection of type and management of irrigation systems dictates, to a high degree, the effect of irrigation on crop yields. Proper system design, operation, and maintenance are critical to achieving consistent yields in dry years and optimizing water use to achieve the desired crop yield response. Furthermore, improperly managed irrigation and fertigation systems can be pollutant sources rather than providing a pollution reduction benefit, especially in wet years. The EP was asked to consider establishing a baseline condition for system management that would guide the identification of systems which would qualify for the practice. The EP would consider factors such as appropriate system selection and design, proper system installation and operation, and adequate system maintenance. In considering these and other appropriate factors, the EP would seek to balance improved confidence in the efficiency values for a well-managed system, with potential limitations in identifying BMP applicability for a specifically-defined baseline condition. The EP would consider whether a baseline condition is appropriate for all categories of the BMP and, if so, whether the same baseline should apply to all categories. Finally, the EP was asked to articulate how baseline conditions will be tracked, reported, and verified.

The fourth charge was necessary to address the potential differences in BMP efficiencies for different hydrologic, geomorphic, agricultural crop production, and other conditions that vary throughout the watershed. To the extent that adequate supporting data are available, the EP was instructed to address variations in BMP efficiencies for all categories based on physiographic region or other locational considerations. The EPEG noted that some of the previously approved CBWM BMPs have chosen to treat karst geology the same as coastal plain physiography to avoid the need to add karst as a separate category.

In addressing these charges, the EP was asked to refer to the practices documented in EPA's National Management Measures for the Control of Nonpoint Pollution from Agriculture, chapter 4F, Irrigation Water Management (EPA, 2003). The EP was advised of ongoing research by the U.S. Geological Survey (USGS) under the Small Watershed Studies project. USGS was investigating small watersheds in Delaware and Maryland to document the effects of irrigation and other conservation practices on hydrology and shallow groundwater quality. The results of the project conducted in the Bucks Branch watershed were published in August 2018 (Denver et al. 2018). A contemporaneous four-year study was also conducted investigating water-use efficiency and NUE on a University of Delaware research farm nearby in Harbeson, DE (Shober et al., 2018).

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Background: Agricultural cropland irrigation in the Chesapeake Bay Watershed

Extent of irrigation and context for the region

Irrigation is the addition of water to lands via artificial means. While irrigation is essential to agricultural systems in arid regions, it is also practiced in humid and sub-humid climates – such as the Mid-Atlantic – to protect crops against periods of drought and to maximize production and the farmer's profit by applying water when needed by the crop. Water used for irrigation can be from either groundwater or surface water sources. Some irrigation systems use reclaimed wastewater from treatment facilities, but those systems are not considered for the purposes of this report.

Nationally, irrigation represents one-third of all water use; the majority of water used for irrigation occurs in 17 western states, with those states accounting for 83 percent of total irrigation water withdrawals and 74 percent of irrigated acres based on 2010 data (Maupin et al., 2014). Altogether the six Bay states account for only about three-tenths of one percent of the total water withdrawals and nine-tenths of one percent of the total irrigated land nationwide. These estimates, summarized in Table 2, are state-wide values and are not adjusted to the portion of the states within the Chesapeake Bay Watershed. Furthermore, they include all irrigation uses, not just agriculture. However, they still illustrate the relative importance of irrigation in the comparatively smaller states of Delaware and Maryland, whose estimated water withdrawals for irrigation are larger than that of the other states and account for over half of the total water use (194,800 acre-feet out of 373,000 acre-feet in 2010).

The 2012 Census of Agriculture reinforces the relative importance of irrigation in Delaware and Maryland. Proportionally speaking, approximately 1-in-5 Delaware farms and 1-in-10 Maryland farms have irrigation (see Table 3). Consistent with Maupin et al. (2014), these two states account for over half the total irrigated land on a statewide basis, despite their relatively small size. Large portions of these two states are located within the Chesapeake Bay watershed (CBW), whereas irrigated land in New York State is mostly outside the CBW.

Census of Agriculture data for the Mid-Atlantic watershed provides additional clarity to statewide estimates. Table 4 summarizes farms and irrigated land at a HUC-6 scale, with only the Mid-Atlantic watersheds associated with the CBW. The Upper and Lower Chesapeake watersheds – which include the entire Delmarva Peninsula as well as some lower Bay and Western shore areas – clearly represent the large majority (77 percent) of irrigated land in the CBW even though those areas only account for about 25 percent of farms with irrigation. Since irrigated land in the CBW is concentrated primarily on the Delmarva Peninsula the panel focused its attention on the factors and available data most applicable in that context, particularly the Maryland and Delaware portions.

Table 2 - Estimated irrigated land and water use in 2010, irrigation water withdrawals. Data adapted from Table 7 in Maupin et al. (2015). Note: These estimates include all irrigated water uses and irrigation systems, not just agricultural crop production, e.g., golf courses, parks, nurseries, cemeteries and other landscape-watering.

	Irrigated land (thousands of acres) by type				**Withdrawals (in thousands of acre-feet) by source**			
	Sprinkler	**Micro-irrigation**	**Surface-water**	**Total**	**Ground-water**	**Surface-water**	**Total**	**Avg rate (acre-feet per acre)**
Delaware	132	1.11	0	133	96.5	17.1	114	0.85
Maryland	102	3.43	0	105	59.9	20.9	80.8	0.77
NY	81.1	24.6	2.77	108	33.9	45	78.9	0.73
PA	53	15.1	0	68.1	8.28	22.1	30.4	0.45
VA	102	14.6	0	117	18	50.8	68.8	0.59
WV	2.52	0	1.09	3.61	0.06	0.04	0.1	0.03
Bay state total (whole states, not CBW-only)	473	59	4	535	217	156	373	0.70
National totals	31,600	4,610	26,200	62,400	55,400	73,900	129,000	2.07

Understanding irrigation and water dynamics of the Delmarva

The Maryland portion of physiographic region known as the Coastal Plain is effectively bisected by the Chesapeake Bay and are nominally described as the Western and Eastern Shores, depending on which side of the Bay one is referring to. The Eastern Shore Coastal Plain (synonymous with Delmarva for the purposes of this report) is less than half the area of the Western Shore Coastal Plain, but a significantly higher proportion of land use is agricultural, and its sandy sediments favor the transport of nitrate into groundwater (Denver et al., 2014), which finds its way to surface water in variable time scales. More than half of groundwater discharging to streams on the Delmarva Peninsula may be older than 13 years by some recent estimates (Sanford and Pope, 2013). The Western Shore has more fine-grained aquifer sediments, more developed and forested areas and less agriculture. Altogether, Eastern Shore tributaries deliver nearly eight times more nitrate (27,300 pounds per day) to the Chesapeake Bay than Western Shore tributaries originating in the Coastal Plain (3,500 pounds per day) (Denver et al., 2014). The United States Environmental Protection Agency (USEPA) Total Maximum Daily Load (TMDL), and therefore CBP, communicates nutrient reduction goals in terms of total elemental concentrations, in this case total nitrogen (TN). Nitrate loads supplied by regional groundwater discharge to tributaries of the Eastern and Western Shores represent 70% and 5% of TN loads reaching the Bay from these opposing shores, respectively (Denver et al., 2014), demonstrating the importance of groundwater quality, particularly on the Eastern Shore (Delmarva).

Table 3 – From USDA-NASS. 2012b. Estimates of farms with irrigation and irrigated land, 2012 and 2007.

	Farms with irrigation # of farms % of farms (in state)		**Irrigated land** # of acres (Avg. acres per irrigated farm)	
State*	**2012**	**2007**	**2012**	**2007**
Delaware	533 21.7%	560 22%	127,272 (239)	104,562 (187)
Maryland	1,220 10%	1,326 10.3%	104,910 (86)	92,805 (70)
New York	3,404 9.6%	3,036 8.4%	59,807 (18)	68,010 (22)
Pennsylvania	4,539 7.7%	3,958 6.3%	38,990 (9)	37,786 (10)
Virginia	2,456 5.3%	2,347 5.0%	68,651 (28)	82,187 (35)
West Virginia	466 2.2%	457 1.9%	2,064 (4)	2,189 (5)
Six-state total	12,618 -	11,684 -	401,694 (32)	387,539 (33)
*Statewide totals from 2012 Census of Agriculture, Table 10 for each respective state. Not adjusted for the counties/area within the Chesapeake Bay watershed.				

Table 4 – From USDA-NRCS. 2012a. 2012 Census of Agriculture, total farms and irrigated land from HUC-6 Chesapeake Bay watershed areas.

	Upper and Lower Chesapeake*		**Everywhere else****		**Total**	
	2012	**2007**	**2012**	**2007**	**2012**	**2007**
Farms with irrigated land	1,558	1,651	4,646	4,056	6,204	5,707
% of CBW total	25	29	75	71	-	-
Acres, irrigated land	187,599	187,739	56,620	56,406	244,219	244,145
% of CBW total	77	77	23	23	-	-
*Composed of Upper Chesapeake (H020600) and Lower Chesapeake (H020801) includes the Delmarva but also large areas on the western shore. There are some discrepancies in the HUC6 watersheds, in particular the boundaries of H020600 changed significantly between 2007 and 2012. **Composed of Upper Susquehanna (H020501), West Branch Susquehanna (H020502), Lower Susquehanna (H020503), Potomac (020700), and James (020802)						

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Key terms, definitions and concepts

Irrigation is the addition of water to lands via artificial means, as opposed to strictly natural means (i.e., rain).

There are multiple methods for irrigation, and many more types of irrigation systems, summarized below. However, only a subset of irrigation systems are currently applicable to the Chesapeake Bay region and the Delmarva Peninsula.

The basic methods of applying irrigation water include (1) surface (or flood) irrigation by gravity, (2) sprinkler, (3) trickle (micro-irrigation), and (4) subsurface. Those four methods include multiple types of irrigation systems (See Table 5).

Surface (or flood) irrigation is an irrigation method that encompasses furrow, basin, border, contour-levee or contour ditch types of irrigation systems. Also commonly referred to as **irrigation by gravity**. Irrigation by gravity is uncommon in the Chesapeake Bay watershed.

The other three methods are **pressure-based irrigation**, as opposed to irrigation by gravity. There are many types of sprinkler irrigation systems, but the most common ones are: self-propelled lateral move or center-pivot systems and traveling gun or other traveling single- or multi-sprinkler systems portable by hand or tractor. **Micro-irrigation or trickle irrigation** includes a variety of irrigation systems that generally apply water through frequent, low-volume and low-pressure systems of porous tubing with uniformly spaced emitter points. These systems are typically associated with orchards, vineyards, or other cropping systems that are not considered for the purposes of this EP. **Subsurface irrigation** methods involve systems that manage the water table by providing subsurface and controlled drainage, irrigating via buried laterals; these systems are not applicable to the crop types and Chesapeake Bay watershed and are therefore also not considered for purposes of this expert panel.

Irrigation scheduling is the use of water management strategies to prevent over-application of water while avoiding yield loss due to water shortage. Long-term decisions on water use are particularly salient in regions in which known limitations on seasonal water supply have been determined based on historical data. Short-term decisions are more appropriate in humid regions where there is significant weather variation on a daily basis.

Nitrogen Use Efficiency (NUE) is a term used to indicate the ratio between the amount of plant-available N removed from the field by a crop and the amount of plant-available N applied. It describes the efficiency of N fertilizer utilization in crop production.

Variable rate irrigation is an emerging technique that accounts for site-specific variability within a field by applying different rates of irrigation across identified management zones. This technology is not evaluated in this report, as its implementation is extremely limited, and no relevant or applicable research is available.

Table 5- General Irrigation System Definitions.

Method	Irrigation system type(s)	Features/description	Applicable to CBW?
Surface (Flood)	Furrows, basin, border, contour levee, contour ditch	ponding of water ground surface to allow for infiltration/percolation through the soil profile	No
Sprinkler	self-propelled center-pivot and lateral-moving systems, traveling boom systems, fixed (solid set systems), traveling gun	typically a pressure-based system; gravitational system possible in regions with sufficient elevation drops	Yes
Micro-irrigation	drip, trickle, bubbler emmitters; point-source and surface line source	frequent low-volume, low-pressure localized water delivery to root zones	orchards, vineyards, horticultural crops
Subsurface	buried subsurface drip tubes or drip tape line sources	low-pressure porous tubing buried beneath the surface, potential for increased water use efficiency compared to above-surface micro-irrigation through reduced evaporation	No. Technology directed toward water-limited regions. Limited in scope nationally due to cost.

Water Use Efficiency (WUE) is generally defined as the unit of crop yield per unit of water applied, either by natural or mechanized means. A variety of mathematical expressions have been used to account for WUE, some accounting for water specifically attributed to irrigation. WUE efficiency can vary significantly across different irrigation methods.

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Review of science and literature

Editor's note for the reader about units and unit conversions: The literature discussed in this section generally reports values in International System of Units (SI), i.e. metric units, such as kilograms per hectare (kg/ha) or millimeters (mm). The Chesapeake Bay Program typically uses US customary units such as pounds (lbs), acres (ac) and inches (in). Many figures below cited from the original sources still have original labels in SI units. To reduce confusion this section presents values in units consistent with the literature. For in-text data references, units are presented per original literature with conversions in parentheses. For the readers' convenience, here are some common conversion factors:

Multiply	**by**	**To obtain**
kilograms per hectare (kg/ha)	0.893	pounds per acre (lbs/ac)
pounds per acre (lbs/ha)	1.121	kilograms per hectare (kg/ha)
megagrams (i.e., metric tons) per hectare (Mg/ha)	15.93	Bushels per acre (bu/ac), for corn, assumes 56 lbs per bushel
millimeters per year (mm/yr)	0.03937	inches per year (in/yr)
inches per year (in/yr)	25.4	millimeters per year (mm/yr)
milligrams per liter (mg/L)	1.0	parts per million (ppm)

Introduction

After a review of available research and accounting for agriculture practices in the Chesapeake Bay watershed, the Expert Panel decided to focus their review on center-pivot, lateral move and traveling gun sprinkler irrigation on corn for grain and silage. Other crops irrigated in the region (e.g. wheat, tobacco and cotton) were unlikely to meet an annual region-wide threshold minimum of 10,000 irrigated acres that would warrant consideration of an irrigation BMP for those crop types. Although wheat in the CBW hovers near the minimum threshold, available research for wheat and the other crop types was even more limited than for corn.

The EP spent considerable time looking for and reviewing existing published research on cropland irrigation. ~~that did not strictly deal with engineering design.~~ Very limited research was available that addressed water quality and nutrient transport ~~studies under~~ on irrigated land. Published research related to other BMPs (e.g., cover crops and conservation tillage) has considered nutrient removal efficiencies based upon loss of nutrients by leaching past the root zone, thus informing the recommendation of previous CBP BMP Expert Panels. As the panel identified and assessed available research, it became apparent that there is limited N leaching data in the research. Even less published research is available for P and sediment. Accordingly, the panel narrowed its focus to N, though this chapter does include brief summaries of other related research, thus providing an overview of the type of irrigated corn research data that is presently available.

To consider an N efficiency, the panel needed to assess the difference in N removal of the crop between irrigated and non-irrigated (baseline condition) management systems. This was a major barrier in making informed determinations. The few available published studies that did assess N losses from farm fields were conducted in regions of the United States where irrigation has a long history and comparisons were typically made between different irrigation management strategies, rather than between irrigated and non-irrigated treatments. In other words, the baseline for comparison in these regional studies tends to be a commonly used irrigation management program in that region, rather than non-irrigated conditions. Additionally, the climatic and soil characteristics in these regions (primarily the midwestern U.S.) are substantially different from those of the Delmarva Peninsula. In general, the studies obtained and reviewed by the panel looked at crop yields, water use efficiency (WUE), economic factors and sometimes NUE under different irrigated management methods without comparisons to similarly managed non-irrigated plots. Furthermore, the irrigation methods studied were often not applicable to the systems or approaches in the CBW. Among those published, peer-reviewed articles that did address N losses or residual N, the potential for increased N losses from inefficiently managed irrigated fields was a common discussion item (Alva et al. 2005; Gehl et al. 2005; Green et al. 2008; Maharjan et al. 2014; Schepers et al. 1995). Recent research efforts on the Delmarva peninsula provide some new insight into the impacts of irrigation on N leaching (Denver et al., 2018; Shober et al., 2018). The two studies were conducted between years 2013-2016, a time in which crop moisture stress was not an issue due to adequate to above-average regional precipitation. Therefore, this time period was not an ideal basis from which to contrast irrigated versus non-irrigated fields. These studies are described in detail in a later section.

The Expert Panel agreed that there is not sufficient science-based research available to indicate a reduction in N losses due to irrigation of corn, therefore a N efficiency value cannot be established at this time. The research reviewed by the panel consistently indicated that irrigated lands had more or greater risk of N leakage past the root zone versus non-irrigated lands. With this decision, the panel acknowledges the need for additional research, as well as further exploration of nutrient transport associated with irrigation via modeling and monitoring efforts due to the complexities of the intersection between surface water, groundwater, and flowing water (tributary systems). The inability to define a N reduction estimate due to cropland irrigation at this time does not preclude defining a nutrient efficiency value(s) in the future, if more information is available. This chapter describes key relevant information and findings from the literature.

Overview of the available science and literature

Due to the fact that in the U.S. there is considerable research on corn, most of the research the EP was able to find and access addressed corn under irrigation. Another portion of the literature is based on furrow or related surface irrigation systems, including research into partial root-zone and alternating partial root-zone irrigation methods. The EP understands that furrow or surface irrigation systems are not applicable to the CBW, although some lessons from those studies regarding N transport or NUE may have limited relevancy to the focus of this report. Therefore, the EP primarily focused on corn production and relevant sprinkler irrigation systems (center pivot, lateral move, and traveling gun).

Nitrogen in irrigated systems

The research available relating information on fate of N in irrigated cropland systems included consideration of NUE, N leaching through the root zone across different types of irrigation and crop management systems. Few studies compared irrigation systems to a dryland control, as most research was conducted in regions where irrigation systems are ubiquitous for grain crops.

A study of five agricultural research sites (including an irrigated site in California and non-irrigated site on Maryland's Eastern Shore) demonstrated the impact of soil characteristics on N leaching. Soils consisting of sandier unsaturated zone sediments tended to have greater fractions of N leaching to the deep unsaturated zone than finer-textured soils (Green et al., 2008). At heavily irrigated sites (including CA), water applications during the growing season were associated with large and rapid fluxes of N, whereas the other sites (including MD without irrigation) displayed more gradual fluxes that occurred during the fall and spring.

Nitrogen leaching

For all types of irrigation, N leaching has the potential to reduce NUE, thus increasing pollution of ground water. It is well established in the literature that irrigation management is critical to control the risk of N leaching below the root zone in a variety of systems. Application of too much irrigation water after N fertilization with the purpose of improving N uptake can dissolve fertilizer N into irrigation water and transport it into deeper soil layers, and even to ground water directly (Barton et al., 2006; Brown et al., 1977; Ebrahimian et al., 2013; Fu et al., 2014; Han et al., 2016; Morton et al., 1988; Snyder et al., 1984; Zhang et al., 2014). The result can be a lower NUE and water pollution. Proper irrigation management is therefore critical in both agronomic, and environmental contexts.

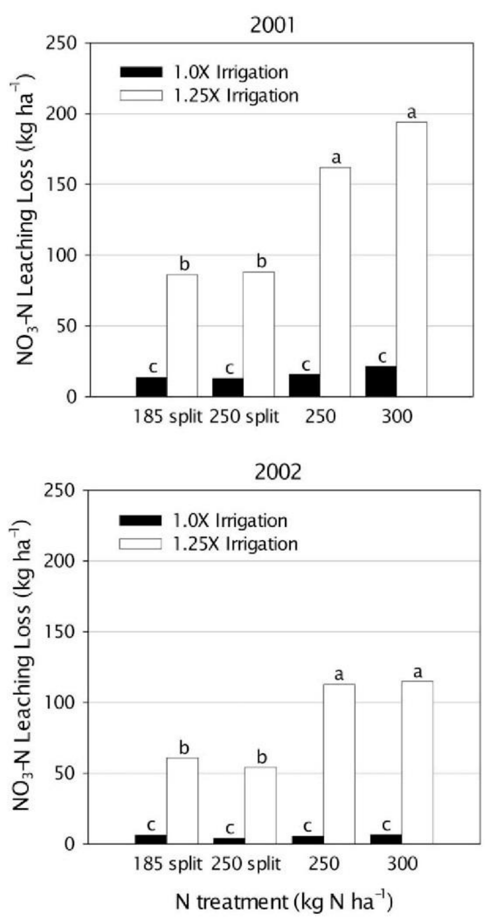

Figure 1. From Gehl et al. 2005. Seasonal leaching losses of NO_3^-–N for four N treatments and two water treatments in 2001 and 2002. Bars labeled with the same letter for a given year are not different as determined by LSD at α = 0.10.

Even if N is applied incrementally with sound management practices ~~(split application of N is now commonplace on the Delmarva Peninsula)~~, nitrate leaching can be substantial if sandy soils are over-irrigated, as demonstrated by ~~(~~Hergert (~~,~~1986) in a Nebraska study. While efficient irrigation is important to minimize N leaching from irrigated corn fields, it is especially critical if N is applied in excess of crop need. Gehl et al. (2005) tested two irrigation treatments – using a sprinkler system, irrigation rates at optimal water rate and +25% of the optimal water rate – and four N application treatments on corn fields established on sandy soils in Kansas. For some N treatments the additional 25% irrigation water above the optimal rate resulted in as great as 16-fold increase in observed nitrate leaching, while there were no significant observed differences in leaching among the N treatments at the optimal water rate (see Figure 1). The results suggest that excess irrigation can indeed be problematic for water quality, but exponentially so if N is not applied based on crop need or in conjunction with appropriate nutrient management planning, emphasizing the importance of a well-managed irrigation program.

Kessavalou et al. (1996) used bromide and N tracers to track nitrate leaching under center-pivot irrigation on an alluvial fine-silty and silt-loam Mollisol soil in Nebraska and found that split

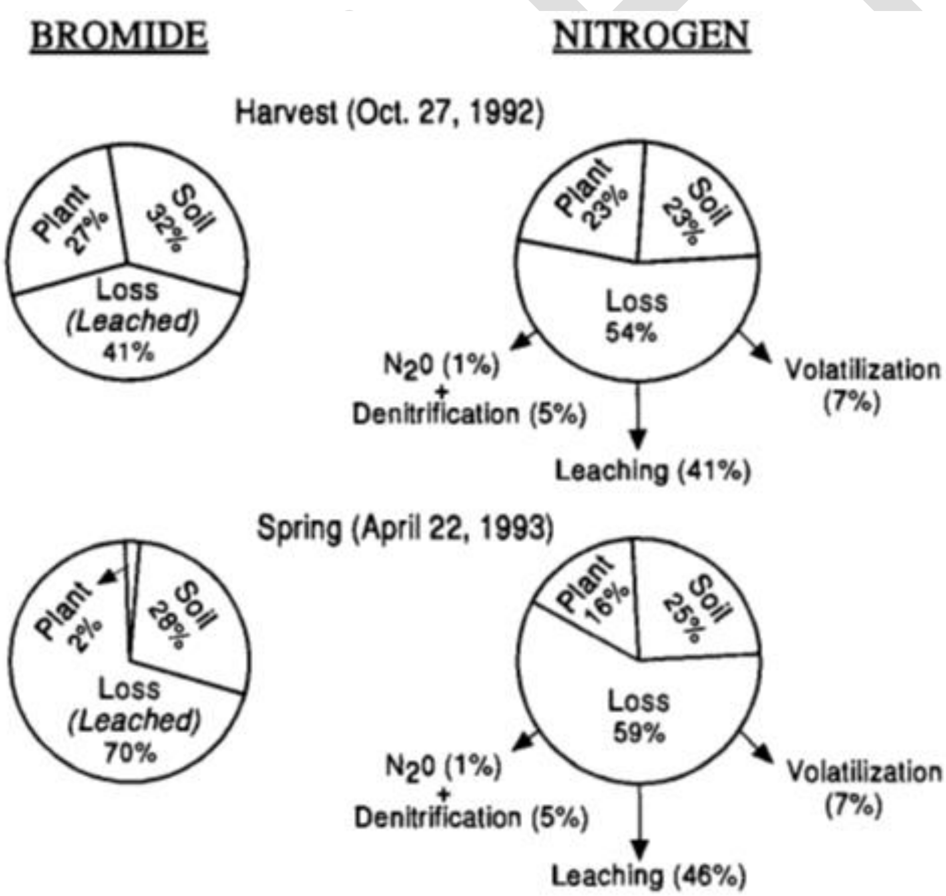

Figure 2. From Kessavalou et al. 1996. Fate of Br and 15N-labeled fertilizer N applied to irrigated corn at the Management System Evaluation Area (MSEA) near Shelton, NE, 1992-1993.

applications of N fertilizer (starter and 3 applications via fertigation, adjusted based on N content in irrigation water), considered a best management practice in the region, still allowed for significant loss of nitrogen (See Figure 2), particularly on course-textured soils. This study also did not have a dryland comparison condition.

Another study in Nebraska by Spalding et al. (2001) focused specifically on nitrate leaching by comparing several different irrigation systems. The authors collected groundwater quality data from 16 depths and 31 multi-level samples three times annually from 1991-1996 under furrow-irrigated corn, surge-irrigated corn, center pivot-irrigated corn, and center-pivot alfalfa. The data indicated that center-pivot sprinkler irrigation combined with a fertigation program significantly reduced nitrate leaching in comparison to furrow- and surge-irrigated corn with only minor reductions (6%) in crop yield. As with most mid-west U.S. field studies, it did not include a dryland condition, minimizing the usefulness of this study to the charge of the Expert Panel.

Klocke et al. (1999) followed up on an emerging concern regarding increased nitrate concentration in aquifers in the Midwest with a look at N leaching from corn and corn-soybean rotations on Nebraska loamy soils under sprinkler irrigation over six growing seasons. They found that careful irrigation scheduling in conjunction with appropriate BMPs such as nutrient management did result in environmental benefits. On average 27% of N applied was lost in corn and 105% of N applied in corn-soybean rotation was lost. There was no dryland condition in this study and the primary driver for the study was to quantify N loss in standard continuous corn and corn-soybean rotation management schemes in their region of Nebraska. They did not study alternative irrigation systems.

At a University of Minnesota research farm with loamy-sand soil subject to excessive drainage, Maharjan et al. (2014) found that solid-set sprinkler irrigation, managed with guidance from daily soil water mass balances (fully irrigated), significantly increased nitrate leaching compared to a minimal irrigation (irrigation limited to mid-season) schedule during the growing season. The fully irrigated site leached 30.6 kg/ha (27.3 lbs/ac)-, approximately twice as much nitrate per unit area as the minimal irrigation system 15.5 kg/ha (13.8 (lbs/ac), a statistically significant difference ($p<0.01$). However, after accounting for significantly increased yields with irrigation, N losses expressed on a yield basis did not differ and in some cases decreased with full irrigation. Specifically, the authors concluded that to grow the same amount of corn, the fully irrigated system leached about 9% less nitrate on a yield-adjusted basis, though the difference was not statistically significant for the yield-adjusted calculations. The authors concluded that assuming similar grain yield across limited and full irrigation, the limited irrigation condition can be expected to have greater N loss in the spring. Post-harvest soil N and soil-water nitrate in spring showed the potential for greater N leaching in minimal-irrigation than fully irrigated plots. The fully irrigated and limited irrigation conditions were fertilized at the same rate in this study. Generally, however, it is expected that irrigated corn will have significantly higher yields and coinciding higher rates of fertilizer application to accommodate those potential yields. Even a well-managed system can experience N leaching due to the many factors that impact crop cultivation from one growing season to the next. The proportional increase in N application on a high-yield irrigated field could negate the benefits of reduced leaching due to proportional N uptake and loss.

A Wisconsin study (Kraft and Stites, 2003) on course-textured soils under humid climate conditions investigated sweet corn under irrigation and concluded that well-managed irrigation, in conjunction with proper nutrient management, is not likely to substantially reduce nitrate leaching if profitability must also be maximized. The authors suggested focusing efforts on BMPs that manage mineralized N from crop residue and other BMPs that might avert N loss (e.g., cover crops), rather than improvements on irrigation management. Similar to most Midwest studies, there was no dryland control and the focus of this study was to quantify nitrate-N loading to groundwater under typical management scenarios in that region, rather than comparing irrigation to a dryland scenario.

A four-year lysimeter study in Minnesota (Timmons and Dylla, 1981) on a sandy loam soil in a region subject to drought is among the few studies found that did compare irrigated and non-irrigated sites under corn production over the course of five growing seasons. The first two years of the study utilized sprinkler irrigation, while the last three seasons utilized drip irrigation. In the non-irrigated treatment, all N was applied in granular form and disked pre-planting. Irrigated treatments received either granular N applied once at pre-planting or liquid N via fertigation during multiple irrigation events over the course of the growing season. Overall, the authors found that average annual nitrate losses from the irrigated systems were 17%-62% greater than the losses from non-irrigated systems across N-fertilized treatments. There was limited evidence of improved N retention under fertigation compared to granular application.

A lab study (Peng et al., 2015) demonstrated the importance of choice of N source on nitrate leaching. Several N fertilizer types were applied to a course-textured Nebraska soil under incubation and it was found that coated urea products resulted in reduced N leaching under simulated rainfall. Timing, duration, and intensity of irrigation cycles were also factors in determining nitrate leaching. This study again emphasizes the importance of management decisions on potential for N leaching.

Techniques to mitigate N leaching potential via precision agriculture were considered by Delgado and Bausch (2005) on center-pivot irrigated corn fields in Colorado over two consecutive growing seasons. The goal of the study was to evaluate the use of geographic information systems (GIS), global positioning systems (GPS), modeling and remote sensing for reducing residual soil nitrate-N and nitrate-N leaching. Soil and plant samples from the corn fields were analyzed for N content and used to identify differences in residual soil nitrate and N leaching potential across the fields. It was demonstrated that GIS, GPS, and modeling technologies can be used to identify and simulate the spatial residual soil nitrate-N patterns. Lower residual soil nitrate-N was found on the lower productivity sandier areas, which also had a higher nitrate-N leaching potential.

Marinov and Marinov (2014) proposed a model describing physical transport and biogeochemical dynamics of water and N in the soil-water-plant-groundwater system. Their specific objective was to use model simulations to investigate the effects of soil type, irrigation rate, and N fertilizer application rate on N leaching toward groundwater and on the behavior of a pollutant plume in an aquifer in the European country of Romania. Simulations indicated that in order to achieve high crop yields while minimizing N loading to soils and groundwater there needed to be an optimal balance between the amount of chemical fertilizers and water applied to crops on the one hand, and the amount of nitrate and water used by plants on the other. The conditions used to define the model were based on a region in Romania, but the proposal offers some bottom-line insights regarding N transport: if certain parameters related to groundwater recharge are known, such as soil water retentive capacity, hydraulic conductivity of the soil, and velocity and longitudinal dispersity for groundwater, better predictions of N fate can be made. Their findings indicated that medium-textured soils are superior for corn production, since such texture restricts downward movement of water and nitrate, ensuring more plant uptake and greater yield, in addition to less aquifer pollution. Additionally, intensely fertilized and irrigated coarse soil areas with shallow aquifers are especially prone to groundwater contamination. They demonstrated that higher rates of irrigation resulted in lower N concentrations in both soil and aquifer, but much larger net leaching to the aquifer. The authors concluded that an irrigation strategy that emphasizes water management in addition to optimizing N fertilization is necessary to reduce N leaching.

Water Use Efficiency

This section is included in this report due to the reasonable assumption that better WUE correlates with minimizing over-irrigation. Reducing over-irrigation can be a significant factor in reducing N loss from crop fields (Gehl et al., 2005).

A field study in Nebraska (Schepers et al., 1995) on alluvial silty Mollisol soils, further demonstrated the important of choice in irrigation management system on reduction of nitrate leaching, when comparing center-pivot irrigation to conventional furrow irrigation. Water application was reduced by 60 to 72% when a center-pivot system was chosen over furrow irrigation. The authors also indicated unpublished data demonstrating that three years of center-pivot irrigation resulted in reduced concentrations of nitrate-N leaching beneath the root zone (compared to furrow irrigation). This study did not include a dryland condition for comparison and furrow irrigation in corn cultivation is not common practice on the Coastal Plain, nevertheless the results indicate the consequences of management choices on WUE.

A review of literature on cropland irrigation practices in Bushland, Texas by Howell (2001) suggested that WUE can be maximized by slight under-irrigation (commonly referred to as deficit irrigation and defined here as 0.75-0.8 of full irrigation or withholding early vegetative irrigation), perhaps by promoting deeper extraction of stored soil water. If the rooting system is encouraged to search deeper into the soil profile for water there is potential for reduction in N leaching beyond the root zone under limited irrigation.

Irmak (2015) collected data on various irrigation WUE metrics for four irrigation levels and a dryland treatment over multiple years in an effort to study deficit/limited irrigation management on corn (less than 100% of crop water requirement is provided for by means of precipitation, soil water, and irrigation combined). Timing and magnitude of potential plant stress must be considered carefully with this approach. Providing limited irrigation has the potential to decrease N leaching below the root zone, but the authors collected no N data to support this potential. Research on these limited irrigation management strategies are a means of addressing current and predicted future water shortages in the mid-west U.S. (in this case Nebraska), an issue that is not at the forefront of agricultural research on the Mid-Atlantic Coastal Plain at this time. The study emphasized the importance of management in South Central Nebraska on center-pivot irrigated corn.

Another Nebraska study (Rudnick and Irmak, 2013) considered data on grain yield and WUE factors under various N application rates for full irrigation, 75% irrigation (deficit irrigation) and a dryland control over two consecutive growing seasons. The goal of the study was to compare irrigated corn to rain-fed corn and determine how to maximize the effects of irrigation and WUE as a compliment to yield and evapotranspiration. The authors observed that irrigation water was most effective at improving grain yield above dryland conditions when N application rates were increased and that N fertilization rates were more impactful on grain yield outcomes than evapotranspiration. The impact of factors such as weather conditions and management practices influenced the efficacy of irrigation WUE primarily due to their effects on dryland grain yield. Grain yield responses to irrigation were greater during the drier of the two growing seasons. Essentially, they concluded that optimal N applications for maximum productivity varied not by irrigation regime, but within irrigation regimes across seasons, indicating the importance of weather conditions on not only WUE, but NUE as well. Soil moisture was measured, but no water quality samples were taken from any sites that could provide insight on the fate of N under different irrigation management and N application rates, as N loss was not a consideration in this study.

Grassini et al. (2011b) conducted a data analysis to quantify and improve water productivity in irrigated corn. Data collected from private farms in a Nebraska natural resources district was evaluated for yield, fertilizer, and irrigation water. As with other studies cited here, this study compared different types of irrigation to each other and concluded that center-pivot irrigation resulted in significantly greater WUE compared to surface systems, such as furrow irrigation. There was no discussion of N leaching risk from irrigation, although the authors identified fine-tuned water management as a means to reduce water and energy usage without significant yield loss.

Yield Consistency in Irrigated Systems

Among the advantages of irrigated farmland systems is the potential not just for increased yields, but improved yield consistency across growing seasons by lessening the impact of water as a limiting factor for plant growth. Yield consistency leads to better informed yield goals, and therefore the potential for fertilizer applications that are more closely aligned with actual crop need during the growing season. If NUE is improved, one would expect reduced N leaching from the root zone. Unfortunately, research considering yield consistency is usually geared towards maximum yield and profit, without consideration of water quality, resulting in a lack of hard evidence to affirm water quality benefits associated with improved yield consistency.

Boyer et al. (2014) demonstrated that center-pivot irrigation on a silty Alfisol soil in Tennessee can result in better corn yield stability over-time compared to non-irrigated corn in a semi-humid climate (See Figure 3). Both the irrigated and dryland plots received identical fertilizer rates. Nitrogen leaching was not measured in the study, but increased NUE due to a fertilization program based on reliable yield goals has the potential to reduce N loss below the root zone.

As discussed in the *Nitrogen Leaching* section above, the Maharjan et al. (2014) study in

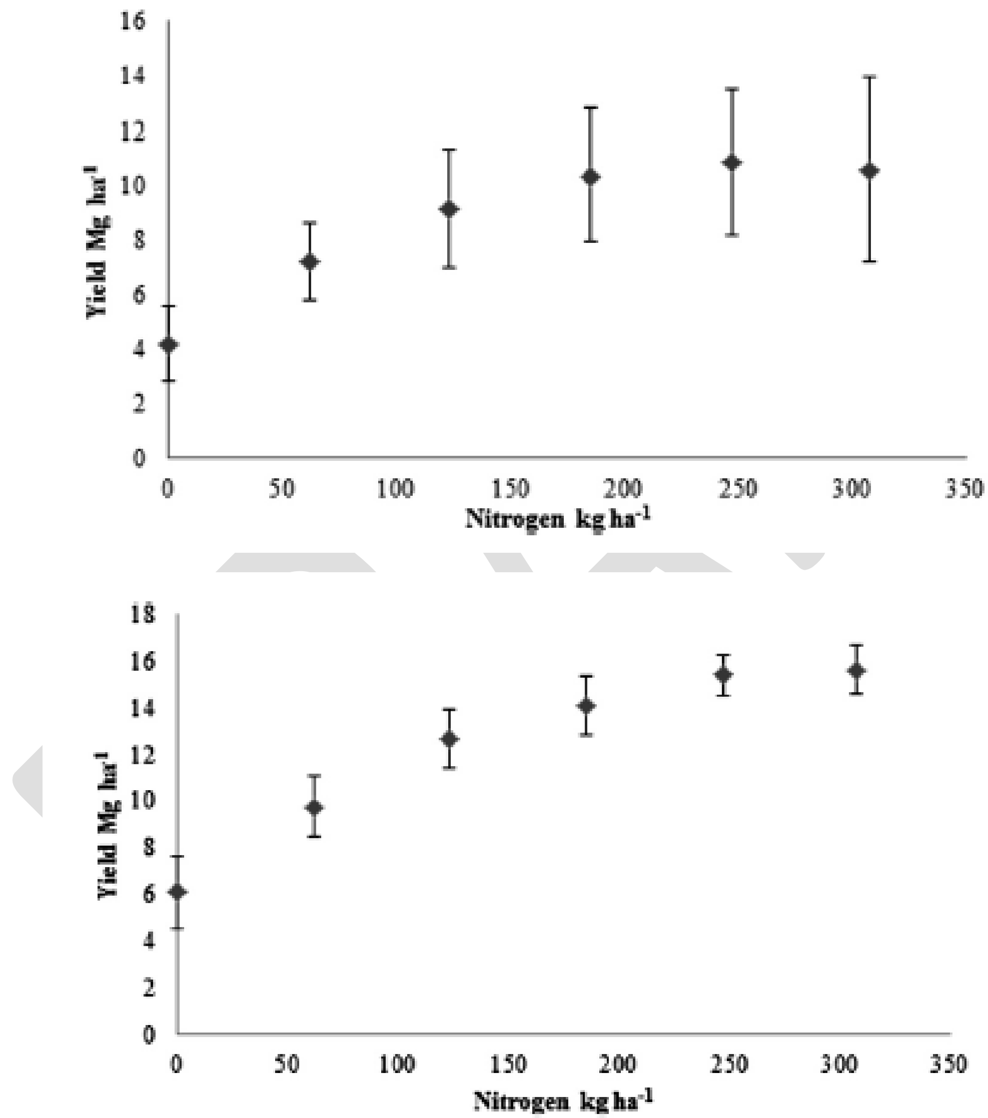

Figure 3. From Boyer et al. 2014. Above: Non-irrigated corn yields (Mg/ha) by nitrogen rates (kg N/ha) from 2006 to 2011 at Milan, TN. Below: Irrigated corn yields (Mg/ha) by nitrogen rates (kg N/ha) from 2006 to 2011 at Milan TN.

Minnesota predicted less potential for N leaching on a yield-adjusted basis under full irrigation, compared to a minimal irrigation scenario, based on post-harvest soil N and soil water nitrate data available in the spring. Nitrogen leaching potential was presumably high under minimal irrigation due to less efficient N uptake (reduced NUE). An important consideration with this research is the applied N fertilizer rates. Across both full and minimal irrigation plots, N was applied at the same rate, regardless of expected yield differences across irrigation treatments. ~~on a per-acre basis, rather than per-expected yield.~~ In a typical irrigated corn scenario on the Mid-Atlantic Coastal Plain, N fertilizer rates are planned based on expected yield at the on-set of planting. Since irrigated corn is expected to result in substantially greater yield due to the removal of water as a limiting factor, it is expected that the rate of N applied per acre will be higher under irrigated conditions.

Grassini et al. (2011a) studied quantifying yield gaps (average yield versus yield potential) and impact of agronomic practices on irrigated corn in Nebraska. They presented data culled from the state's natural resource districts and analyzed the correlation of yield with N fertilizer rate, applied irrigation, and planting date, but did not consider N losses. The three former factors were considered in the context of identifying major management constraints to actual productivity. Rotation, tillage system, sowing date, and plant population density were identified as most sensitive factors affecting current yields on irrigated lands. Although the authors were clear that there is a need to increase crop production due to global demand, they concede that the top reported yields in Nebraska are unlikely to be economically or environmentally sustainable on a commercial scale. They conclude that improving standard irrigation practices in Nebraska through water management and nutrient management may help to reduce excessive N inputs and help protect environmental quality through improved input efficiency (NUE), ideally with a negligible impact on yield.

~~Schlegel et al. (2016) conducted a long-term field study on a silt loam soil in Kansas to determine effect of limited irrigation on yield, water use and profitability of several crops (corn, sorghum, soybean, sunflower). Data was collected on grain yields, crop water productivity (calculated as kg/ha grain yield divided by mm of crop water use and synonymous with WUE for this report), and available soil water by crops and by irrigation level. The authors found that corn responded better (up to 33%) to higher levels of irrigation than other crops. Irrigated corn in rotation (some combination of wheat, soybean, and/or sorghum) resulted in higher yields than continuous corn, although WUE was greater for continuous corn, as was the corn yield equivalent (a calculation that normalizes yields for economic comparability across different growing seasons). There was no difference between the lowest level of irrigation (177 mm/yr; 6.97 in/yr) and dryland plots regarding yield response in corn. Averaged over years, the yield of corn was greater than that of all other crops at all irrigation levels. For corn, WUE was higher at the higher irrigation levels compared with the lowest irrigation level. Residual soil nitrate- N was measured post-harvest to compare across crops, indicating the least amount of residual nitrate-N following corn, and the most following wheat. The authors did not consider N leaching from the root zone, but the study did confirm the high relative value of irrigation and N fertilization on corn.~~

Schlegel et al. (2016) conducted a six-year field study on a silt loam soil in Kansas to determine the effect of limited irrigation on yield, water use and profitability of several crops (corn, sorghum, soybean, sunflower) in a region where the main source of irrigation water is depleting, and judicious use of water resources is a necessity. There was no dryland treatment condition, but they did find a relative yield advantage for corn at higher levels of irrigation over other crops. The mean grain yield for corn was greater than the three other crops and within the corn plots, grain yield increased by 49% from the lowest irrigation treatment (127mm per season) to the next (254 mm per season) and increased an additional 17% at the highest treatment (381 mm per season). For each increase in irrigation treatment level, the initiation date was earlier and termination date of irrigation was later in the season. Averaged over years, the yield of corn was greater than that of all other crops at all irrigation levels. The authors found that at higher levels of irrigation, corn is the most profitable crop, while with limited irrigation any of the four crops studied would produce similar results, demonstrating a significant advantage to corn yield under irrigated conditions.

Farmaha et al. (2016) compared N, water inputs and other site properties for corn fields with small and large differences (yield gap) between potential and actual yields, based on data from 3,000 privately owned Nebraska farm fields. They defined yield potential (Yp) as "the yield of a crop cultivar with nutrients and water non-limiting, and pests and diseases effectively controlled." Yield gap (Yg) was defined as the difference between Yp and actual yield. The goal of the report was to create a framework relating the factors that help to determine end-of-season Yg. These factors were split into persistent (consistent over years, such as producer skills and soil quality) and non-persistent (year-to-year changes, such as weather and pest outbreaks). Estimating field Yg is challenging due lack of field-specific high-quality data on yield collected from a large population of fields over enough years to infer trends. However, better understanding of what contributes to Yg can better inform water and nutrient management decisions. Their analysis suggested that roughly 30–50% of Yg of irrigated maize in Nebraska can be attributed to factors that are persistent over time, such as soils and non-adaptive operator management. The authors demonstrated that high-resolution satellite data combined with crop models to measure field persistent factors can reasonably predict Yg, particularly at the regional level. They suggested that in regions where Yg proved to be persistent over time, it is useful to differentiate between those persistent factors that are manageable (e.g., early sowing, crop sequence, N and water management) versus non-manageable (e.g., soil type). They concluded "that well-managed irrigated fields can achieve high yields with higher than average inputs, without sacrificing input-use efficiency" and that soil plays a key role in determining the magnitude of yield gaps. The greatest Yg values and variation in Yg were associated with regions that have the largest variation in soil properties across fields.

Water quality of irrigation water source

An irrigation program geared towards reducing potential N leaching should include nutrient management as part of the management decision process. For this reason, irrigated management systems may want to account for the N in the irrigation water, especially if the farm's water source has significant nitrate concentrations and is applied at a greater rate to ensure yield goal achievement.

For example, a study of 79 irrigated corn sites in Nebraska found that while 19 lbs N/acre (21 kg/ha) were accounted for as contributions to total available nitrogen, another 42 lbs N/acre

(47 kg/ha) from groundwater was not accounted for; this average value of unaccounted water N suggested that fertilizer rates could be reduced by 40 lbs N/acre (45 kg/ha) with no significant reductions in yield (Ferguson et al. 1991). The average for all site-years in the Ferguson et al. (1991) study was 20.5 inches (521 mm) of annual irrigation water application (range: 6.3 in - 48 in; 160 mm-1200 mm) and groundwater nitrate concentrations ranged from 0.5 to 46.1 ppm NO^{-}_{3}-N.

Natural groundwater on the Delaware Coastal Plain rarely exceeds 0.4 ppm, but due to cumulative anthropogenic impacts nitrate concentrations are often much higher in the surficial aquifer, with a median concentration of 4.95 ppm in samples from 48 wells (min. 0.34 ppm, max 41.47 ppm); Fleming et al. (2017) found that the group of wells associated with the highest percentage of agricultural lands had the highest median nitrate concentration at 10.15 ppm (min. 3.0 ppm, max 41.47 ppm). Though the expected application rate of irrigation water is lower on the Delmarva Peninsula than the average Nebraska site monitored in Ferguson et al. (1991), the comparable nitrate concentrations suggest that the nitrate load in irrigation water may be worth considering as part of the nutrient management planning process when the farmer and technical assistance providers can test the groundwater quality. Currently, it is not required, nor standard practice, for nutrient management planning in the Coastal Plain regions of Maryland and Delaware to test nitrate levels in irrigation water for consideration when planning N-based fertilization for the cropping season. Incorporating irrigation water crediting into corn fertilization plans in the Delmarva region poses a challenge for two reasons: timing and weather conditions. All N fertilization should be applied prior to the tasseling stage, but a significant proportion of irrigation is applied after this stage, at which point nitrate in the irrigation water will not be efficiently used by the plant. Additionally, the timing and rate of irrigation prior to tasseling varies on a year-to-year basis due to varying weather conditions, making it difficult to adapt pre-season nutrient planning to account for nitrate in the irrigation water, but this early season irrigation presents a possible benefit to water quality as the crop will certainly take up dissolved nitrate with the irrigation.

Recent irrigation research in the Chesapeake Bay watershed

As indicated above, results of two contemporaneous research studies conducted on the Delmarva Peninsula were recently published (Shober et al., 2018; Denver et al., 2018). Due to the lack of regionally relevant research related directly to the aims of this panel, these two publications are of particular influence on the conclusions of this report. Both are current, regionally appropriate, and address irrigation management and N loss in a manner relevant to water quality, rather than solely yield performance. Three additional sources, including a Master's thesis (Soroka 2016), doctoral dissertation (Hanna 2006) and a report to DNREC (Sims et al., 2012) were provided by Delaware during the CBP review and approval process; summaries of these sources are included below.

Hanna dissertation (2006)

Hanna (2006) applied the Soil and Water Assessment Tool (SWAT) model to study the economic benefits of irrigation in the Pocomoke River basin on the Maryland Eastern Shore. The modeling scenarios isolated effects of irrigation versus non-irrigation to estimate the yield and economic benefits, while holding other factors such as fertilizer applications constant. The author concluded, based on his model analysis, that the use of irrigation can reduce the total quantity of nitrogen export from an agricultural field. He also concluded, however, that the higher average soil moisture content levels from irrigation result in higher runoff volumes and thus increased phosphorus export and total sediment yield. The author calls for further modeling and field validation to verify or refute those conclusions, noting that such study could illuminate full impact of irrigation on fertilizer utilization and the potential reduction in fertilizer. Such a study, he concludes, could validate the use of irrigation as a BMP to control and reduce excess nutrients.

University of Delaware: Sims et al. (2012)

Sims et al. (2012) conducted a comprehensive overview of the state of irrigation for crop production in Delaware and among many objectives analyzed the potential for irrigation to improve NUE, particularly for corn, and therefore decrease residual N left in soils after harvest. The report examined the clear benefits of irrigation on crop yield, due to the presence of sandy soils with low organic matter and low moisture holding capacities in the region, combined with an unpredictable and large inter-annual variability in precipitation. The authors provided four theoretical situations and the formula to calculate unaccounted for N after corn harvest, based on assumptions specific to the region. The scenarios clearly demonstrate the advantage of irrigation in reducing the potential for residual applied N to be left in the soil after harvest under typical summer drought conditions. Shober et al. (2018), described below, tested the field applicability of these scenarios. They were unable to test the benefits of irrigation under typical summer drought conditions, but were able to compare irrigated and non-irrigated corn under fairly ideal precipitation conditions, finding yields to be comparable across treatments in contrast to the Sims et al. (2012) proposition that irrigated corn yield would surpass dryland corn even in ideal weather conditions. Sims et al. (2012) recommends three areas for future research: 1) updating UD recommendations for irrigated corn based on reports of high yielding corn at application rates lower than 1 lb N/bu; 2) more reliable estimates of soil N availability, and; 3) more accurate data on the availability of ammoniacal and organic N in animal manures (particularly poultry).

University of Delaware: Soroka (2016)

Soroka (2016) also conducted research at the UD Warrington Irrigation Research Farm over the course of two years to investigate the effects of N application rate and timing on corn grain yield and NUE. The master's thesis also reviewed historical yield data in Delaware to investigate the impact of irrigation on yield and NUE in corn. Data from the two-year plot study showed that increased quantities of unaccounted for N (residual N) post-harvest aligned with higher rates of N application and that increased NUE on irrigated corn could result in the capability of achieving higher grain yield at lower N rates than currently recommended by UD. Trends in yield data over 35 years indicated that non-irrigated plots were 80-85% as efficient as irrigated plots in converting applied N to grain yield. These results led to two primary recommendation from the author. The first recommendation was a reduction in UD nitrogen application recommendations by 15% for high yielding irrigated corn in order to account for improved NUE. The second recommendation for this thesis was to further evaluate the modeling of improved NUE for irrigated corn as either a separate crop category or a BMP, as characterized by the Chesapeake Bay Program watershed model. Suggestions for engaging these recommendations included field research to further refine NUE on a regional scale, as well as collection and analysis of leachate and groundwater samples to explore correlations between irrigation management conditions and risk of N loss.

University of Delaware: Shober et al. (2018)

Shober et al. (2018) conducted a four-year (2013-2016) field study in Sussex County, DE observing the effects of irrigation on WUE and NUE in corn. The years during which the study was conducted were not ideal for observing potential differences between irrigated and dryland corn, because rainfall during the growing season did not appear to limit crop production (See Figure 4). This is not typical for the region (Sims et al., 2012). It is generally understood that the benefits of irrigation are most observable during dry to drought conditions that would contribute to moisture stress in a dryland scenario. Nevertheless, use of irrigation has been expanding in Delaware due to its potential to stabilize yields and increase profitability during less-than-ideal cropping years.

Center-pivot irrigation on corn, managed based on sensor measurements for soil matric potential or evapotranspiration estimates, were compared to a non-irrigated (dryland) control on a University of Delaware (UD) Research Farm in Sussex County. Nine-meter wide buffers between treatment plots ensured no confounding of treatment effects on neighboring plots. Soil moisture data was monitored daily to optimize irrigation treatments. All plots received poultry litter and N fertilizer at the same total PAN rate to meet crop need based on realistic yield goals. In-season N applications to these plots were applied via sidedress application at the same total N rate for all treatments, based on realistic yield goals.

When NUE was calculated based on grain yield and fertilizer applied (partial factor productivity for N), NUE of irrigated corn was not significantly different than non-irrigated corn in 2013 or 2014. In 2015 and 2016 this measure of NUE was lower for non-irrigated corn (30.8 and 31.0 kg grain per kg [0.65 and 0.66 bu/lb] N applied in 2015 and 2016, respectively) than for most irrigated treatments (42.3 and 35.8 kg grain per kg [0.89 and 0.76 bu/lb] N fertilizer applied in 2015 and 2016, respectively); 7 of the 10 irrigation treatments resulted in improved NUE in 2016 when compared to the non-irrigated control.

However, when NUE was calculated using a mass balance approach, the results suggested lower NUE overall when compared to the partial factor productivity measurement. Mass balance based NUE of the non-irrigated crop was only significantly different than irrigated plots in 2015, where the estimated efficiency of the non-irrigated crops was 21% compared with 40% for the three of the 11 irrigation treatments evaluated. Seven irrigation treatments resulted in mass balance NUE that was not statistically different than the non-irrigated control in 2015. Notably though, the authors concluded that under both irrigated and non-irrigated conditions, 40% or more of N available to growing crops (including N from poultry litter, fertilizer, soil residual N, atmospheric deposition, or irrigation water) was potentially at risk for loss to the environment. The authors suspected that differences in NUE between irrigated and non-irrigated corn would be more drastic (in favor of irrigation) if water had been yield limiting.

As indicated above, the four years during which the study was conducted had good-to-ideal precipitation and temperature conditions. As such, there was often no significant irrigation effect on WUE; WUE was not significantly higher WUE in non-irrigated plots over the course of the study (See Figure 5). Nitrogen uptake by irrigated corn was significantly greater than dryland corn only when irrigation resulted in significantly greater corn yield. However, in 2013 and 2014 no significant difference in yield was observed between corn grown under irrigated or dryland conditions (See Figure 6).

Shober et al. (2018) supplemented work conducted by USGS, described below.(Denver et al., 2018) by calculating NUE for the irrigated and non-irrigated fields at Bucks Branch using farmer indicated management information for the 2015 growing season; management data was not available in other years. Statistical analysis could not be completed on the results due to lack of replication. Data suggested that yield and N uptake (in grain and stover) was higher for the irrigated field than for the non-irrigated field. Yield was 12.6 Mg/ha (238 lb/ac) in the irrigated field and 8.7 kg/ha (164 lb/ac) in the non-irrigated field. Similarly, grain and stover N uptake were 174 and 81 kg/ha (155 and 72 lb/ac) for the irrigated field, respectively and 126 and 64 kg/ha (112 and 57 lb/ac) for the dryland field, respectively. When evaluated using the partial factor productivity method, NUE was similar for both fields (46 and 49 kg grain per kg [0.97 and 1.03 bu/lb] N fertilizer applied for irrigated and dryland, respectively). However, when evaluated using the mass balance approach, there was a trend for lower NUE in the irrigated field than the non-irrigated field (61 and 79%, respectively). Upon review of the data, the authors noted that most of the decline in NUE using the mass balance approach was due to higher estimated soil N mineralization in the irrigated field (73 vs. 52 kg/ha [65 vs. 47 lb/ac] for the irrigated and non-irrigated fields, respectively) and N applied in irrigation water (19 vs. 0 kg/ha [17 vs. 0 lb/ac] for the irrigated and non-irrigated fields). As such, the lower NUE for the irrigated field using the mass balance approach was due to higher inputs of N from other sources (namely soil and irrigation water) and not from over-fertilization. If the other N sources were held at the same rate as in the non-irrigated field, the mass balance based NUE would improve to 75% in the irrigated field. In sum, the authors did not find conclusive evidence of a beneficial effect of irrigation on NUE, but they were also unable to conclude that irrigation has a negative effect on these factors. The results highlight the need for better estimation of “other” N sources when making N fertilizer rate recommendations.

USGS

Denver et al. (2018) recently published results from a two-year study (2014 and 2015 growing seasons) concerned with the impacts of conservation practices on water quality within the Bucks Branch sub watershed of the Nanticoke River basin. The study site consisted of the same set of private farm fields indicated above in the Shober et al. (2018) publication. Rainfall frequency and intensity over the two years of the study were described as average, with no major rainfall events. Water monitoring was conducted across both the irrigated (irrigation management began in year 2000) and dryland corn field. Bucks Branch has been identified by USGS as having among the highest nitrate-N surface water concentrations within the Nanticoke River basin. Although both residential and agricultural land-uses have contributed to the high levels of nitrate, geochemical analysis by USGS determined that agriculture is the predominant source of nitrate to Bucks Branch.

In studying the effects of irrigation on nutrient transport to groundwater, compared to dryland conditions, the authors found that movement of nitrate to groundwater was enhanced under irrigated conditions even with the presence of cover crops and nutrient management. Nitrate was present in all groundwater samples, with a median of 9 mg/L as N in the dryland condition and 14 mg/L as N in the irrigated condition. Younger groundwater (recharge <10 years) had higher nitrate concentrations under both dryland and irrigated conditions, with 10 mg/L as N and 18 mg/L as N, respectively (See Figure 7). Additionally, water beneath the irrigated field that recharged the aquifer more than 15 years prior to the USGS study (before irrigation was installed) had lower nitrate concentrations than the younger water under the same field. According to the authors, the majority (90%) of flow in Bucks Branch comes from groundwater, and the chemistry of the groundwater reflects the chemistry of the surface water subject to agricultural use.

In sum, Denver et al. (2018) determined from data collected at this site, that when soil moisture was high, either after significant rainfall or irrigation, nutrients were carried through the root zone and soil zone via infiltration of water. Water infiltrating into the soil zone shortly after fertilizer application resulted in the highest nitrate concentrations (often greater than 50 mg/L). This has the potential to be a significant pathway for nitrate to reach groundwater, from which there is a high likelihood of that nitrate reaching Bucks Branch. The authors also estimated, however, that somewhere between 12 to 22% of nitrate in the groundwater would be lost to denitrification before discharge into Bucks Branch. The authors suggest that cover crops planted in standing corn can pull nitrate from below the root zone to the top layer of soil to limit potential nitrate leaching to groundwater. They also note that irrigation management that lowers average soil moisture conditions could also potentially limit nitrogen transport. They conclude that limiting the leaching of nitrate will remain a challenge in sandy soils of the Mid-Atlantic Coastal Plain, as soil moisture capacity is low and accounting for rainfall is difficult.

Virginia Tech

Unpublished data (W. Thomason, personal communication, 2017) presented to the panel by Dr. Wade Thomason, Extension Grain Specialist at Virginia Tech, indicated that both irrigated and non-irrigated corn often remove more N than what is land-applied during the growing season. The data comes from several years of field trials conducted at a research facility located within the Virginia coastal plain region of the Chesapeake Bay watershed. Nitrogen content in the form of crude protein (CP) often exceeded the one pound per bushel fertilization rate. Up to 15% more CP was removed by irrigated corn that non-irrigated in paired trials. ~~There were~~ Nno data were collected to determine ~~indicate~~ the impact of irrigation on the amount of N leaching past the root zone in any of the field trials, although greater concentrations of CP in irrigated corn could indicate that less N would be available to leach below the root zone. Additionally, no data were collected to determine other possible pools of N available for uptake. While the panel discussed where the N might come from (e.g., mineralization of organics in the soil, ammonium in the soil, N conversion from the atmosphere during respiration), all of which we believe contribute, the panel found no research to directly support this theory. On sites that have a long history or manure application, there is research that shows continued mineralization of organic N exceeding 3 or 4 years after the last application of nutrients.

Regardless, tThere is clear indication of greater yield stability in corn under irrigation over 21 years of continuous field trials at this Virginia Tech site (See Figure 8).

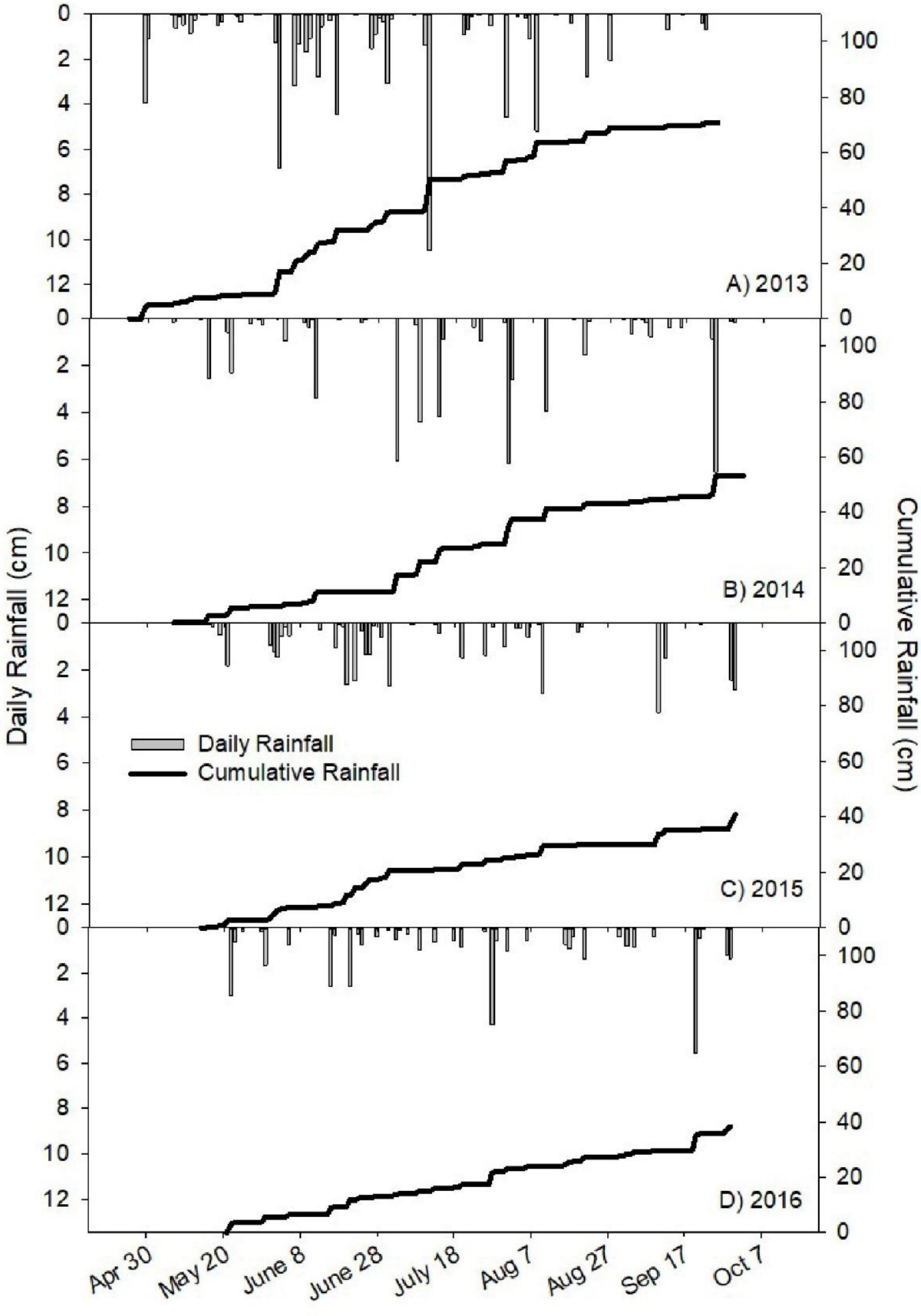

Figure 4. From Shober et al. 2018. Daily and cumulative seasonal rainfall at the University of Delaware (UD) Warrington Irrigation Research Farm in A) 2013, B) 2014, C) 2015, and D) 2016 growing seasons.

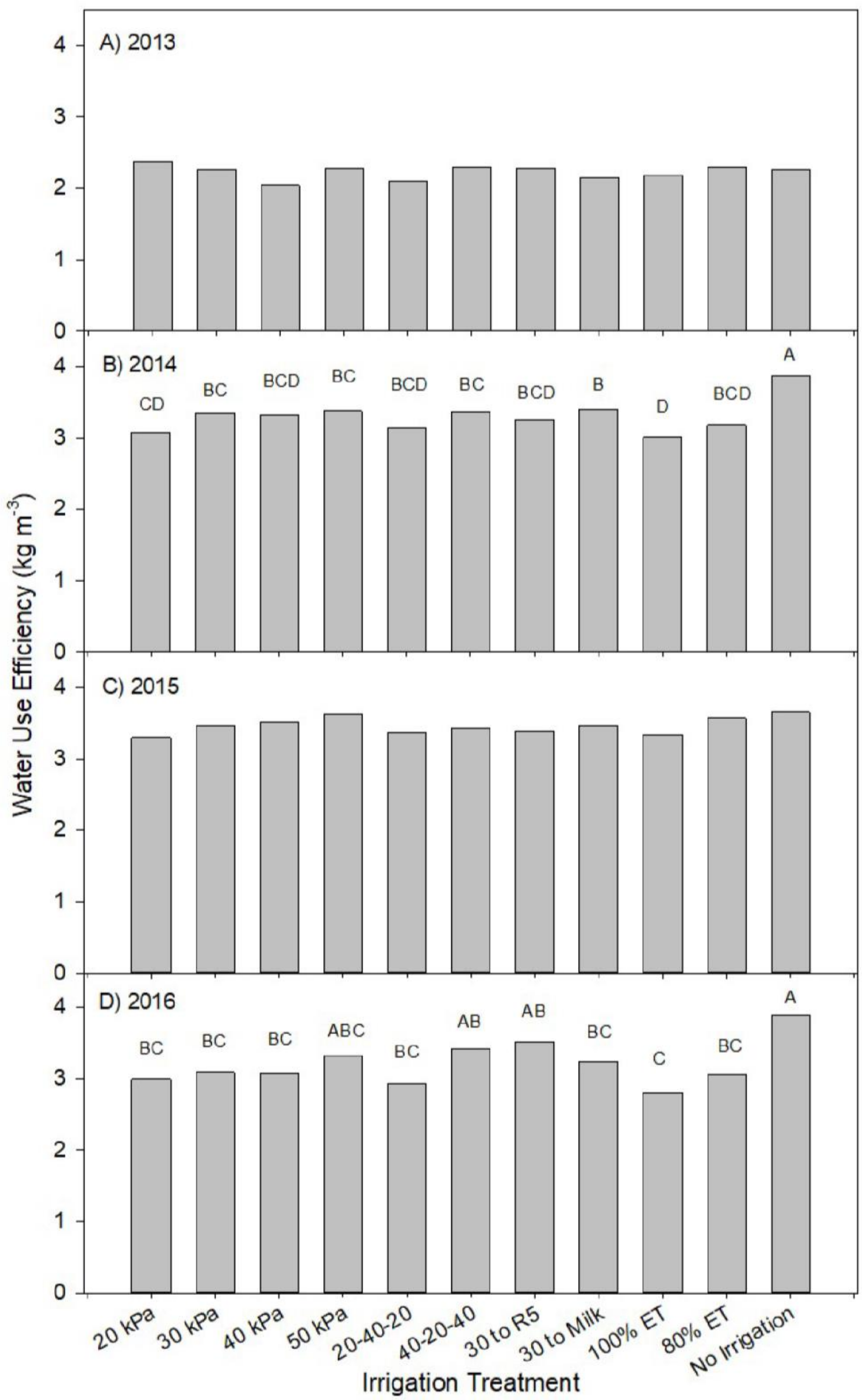

Figure 5. From Shober et al. 2018. Average water use efficiency as affected by center pivot irrigation treatments at the University of Delaware (UD) Warrington Irrigation Research Farm near Harbeson, DE in A)2013, B) 2014, C) 2015, and D) 2016. Letters that are the same indicate no significant differences between treatments using Tukey's HSD test at α=0.05.

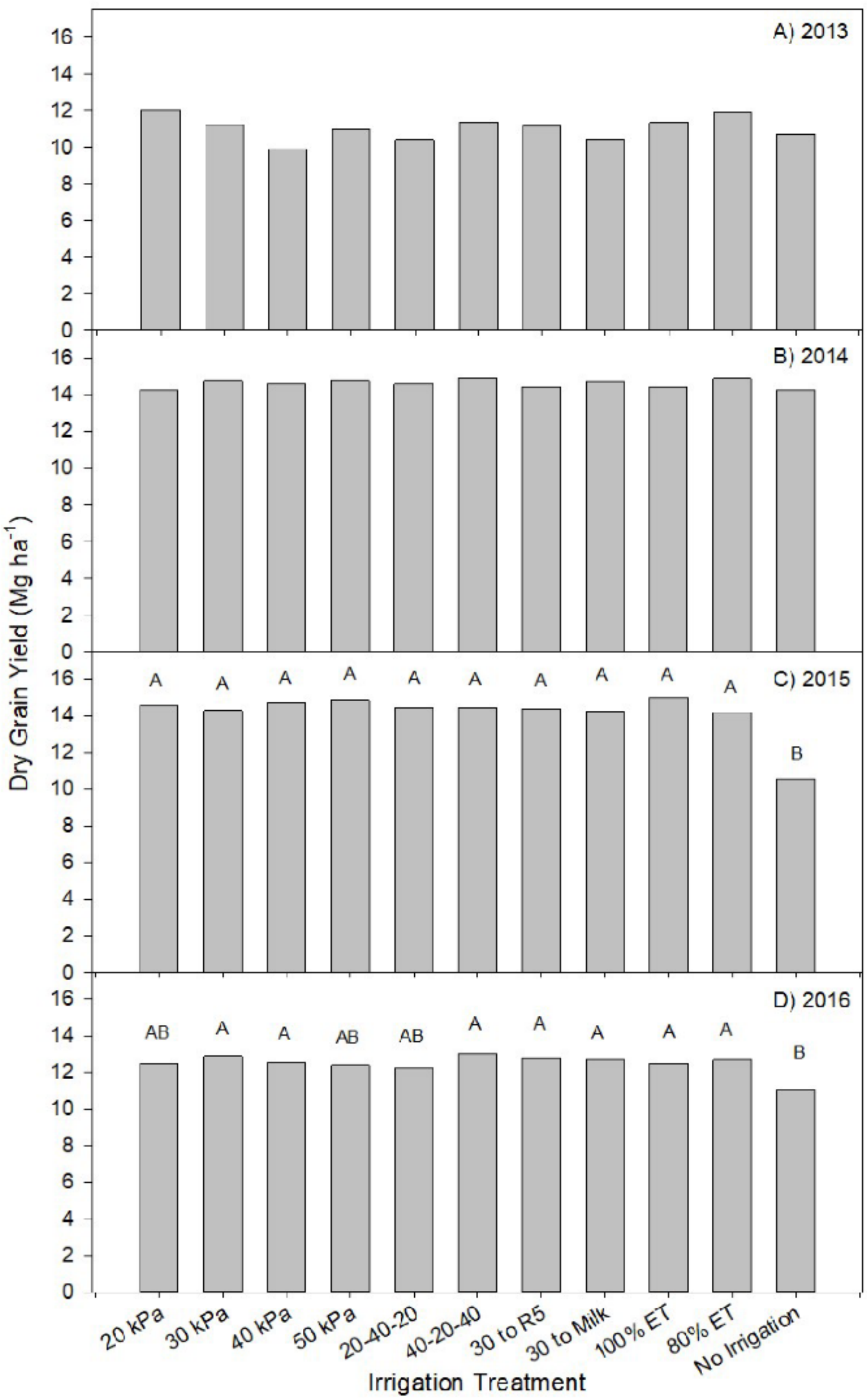

Figure 6. From Shober et al. 2018. Average dry grain yields by center pivot irrigation treatments at the University of DE (UD) Warrington Irrigation Research Farm near Harbeson, DE in A) 2013, B) 2014, C) 2015, D) 2016. Letters that are the same indicate no significant differences between treatments using Tukey's HSD test α=0.05.

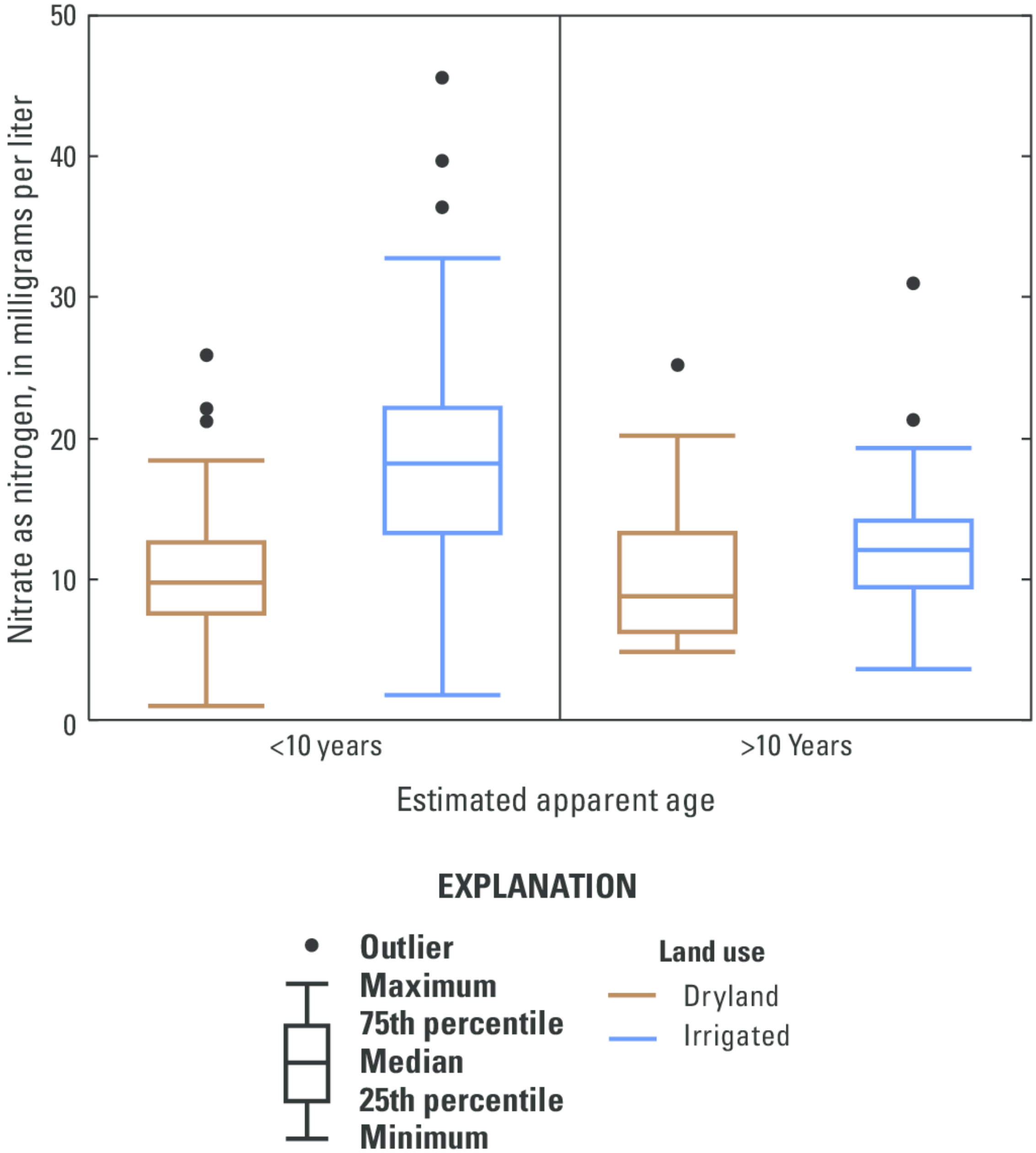

Figure 7. From Denver et al. 2018. Concentration of nitrated as nitrogen in relation to the estimated apparent age of groundwater under the irrigated and dryland fields at the Bucks Branch study site, Sussex County, Delaware.

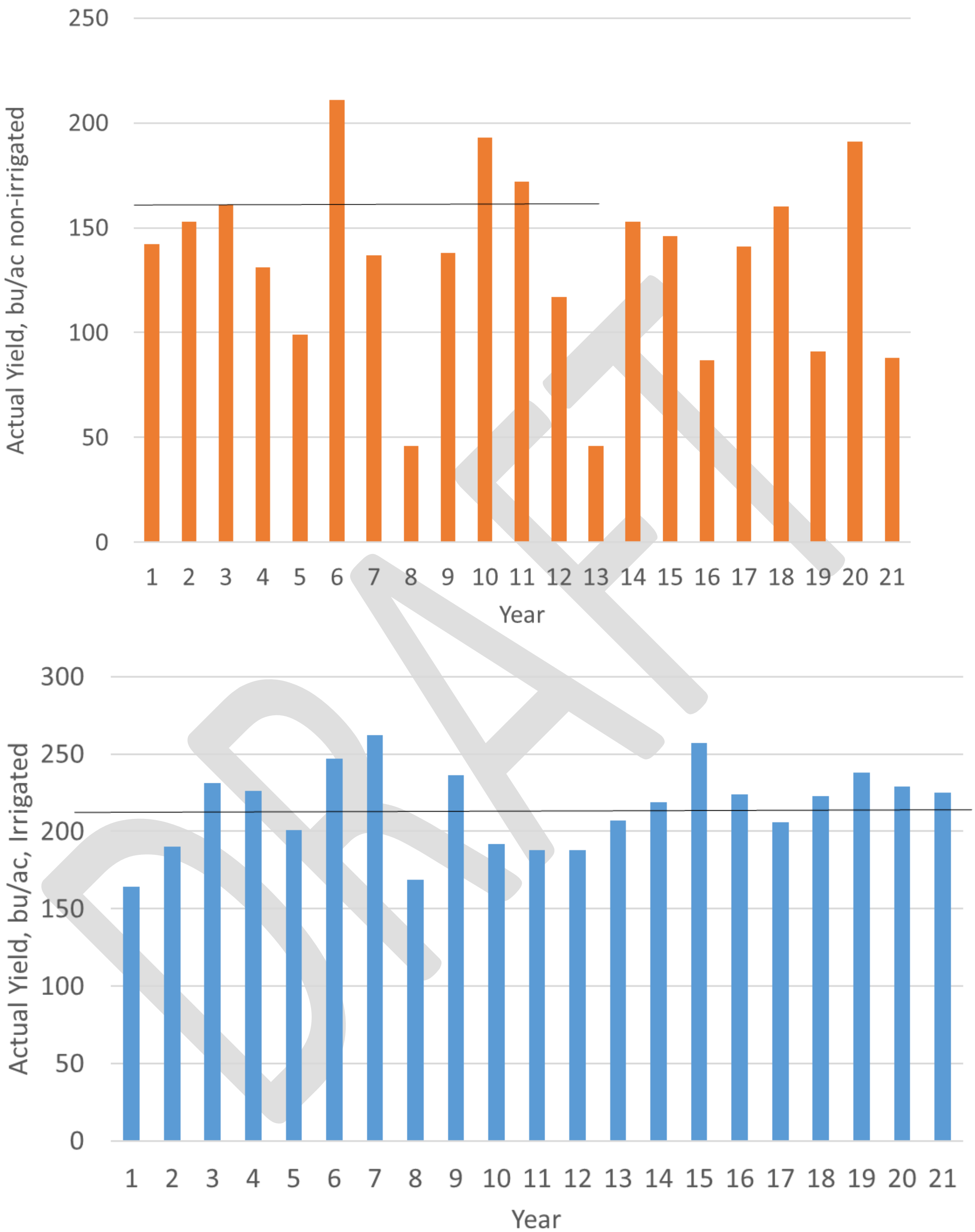

Figure 8. From W. Thomason, personal communication. 2017. Data from 21 consecutive years of paired-corn trials on the coastal plain of Virginia. Unpublished. Above: Corn yield from non-irrigated field trials, SD = 45. Below: Corn yields on irrigated field trials, SD = 27.

Future research need: improved understanding of phosphorus pathways and the potential impact of irrigation

There were no relevant studies that measured loss of P in irrigated and non-irrigated systems. Without empirical studies the panel could not determine if there is a positive or negative effect on P losses due to irrigation on regional cropland. However, observations made regarding P losses on the Delmarva Peninsula are worth noting, since the area is associated with the bulk of the region's irrigated cropland, intensive poultry production and soils with excessive levels of soil-P. As future research is carried out, interactions between irrigation and other BMPs may be of special interest with regard to potential P losses. Surface runoff is the main source of P losses from surface irrigation systems, especially when irrigation water exceeds field infiltration rates (Lentz et al. 1998). However, it is subsurface pathways that are recognized as significant mechanisms of P loss in flat landscapes, especially areas with poorly drained soils (Kleinman et al. 2015). Subsurface P transport is frequently a primary pathway of P loss from agricultural soils to ditches and tile drains (Beauchemin et al. 1998; Djodjic et al. 2000; Kleinman et al. 2007). Due to the high sorptive potential of subsoils, subsurface P transport (via vertical leaching and lateral flow) is likely dominated by preferential flow of P from areas of high P concentrations through macropores (e.g., earthworm burrows, root channels, and particle interstices) that bypass potential sinks for P within the soil matrix (Han et al., 2015; Sharpley and Syers, 1979; Hergert et al., 1981; Djodjic et al., 1999; Simard et al., 2000).

As discussed in Sharpley et al. (2013), widespread adoption of conservation tillage in the Great Lakes region dramatically reduced P loads over the course of two decades. However, this change in tillage management, in combination with long-term broadcast applications resulted in a slow continued buildup of P in the soil, eventually translating into increased dissolved P discharge to Lake Erie. Sharpley et al. (2013) also noted that increased hydrologic connectivity via tile drainage eventually increased the potential of those agricultural lands to contribute P to Lake Erie. Similarly, it has been noted that widespread expansion of no-till on Delmarva soils has the potential to increase P transport through macropore flow compared with conventional tillage (Kleinman et al., 2009). The additive role that irrigation may or may not play should be considered in future research efforts on the Delmarva, including effects of irrigation on soil structure and P transport when combined with other common BMPs like conservation tillage.

There is great interest and a growing body of research regarding soil P, its flow paths and its management on the Delmarva peninsula. The greatest potential for transmission of P from litter applications has been observed with finer-textured soils of the Delmarva; litter-derived P has been observed to contribute to increases in leachate P losses in both "high-P" and "low-P" soils alike (Kleinman et al., 2015), although Han et al. (2015) observed P losses were 10 times higher on high P soils than on low P test soils. Some sand and sandy loam soil types lacked any detectable change in leachate P after application of litter (Kleinman et al., 2015). Site assessment tools addressing P leaching losses need to consider soil structural traits favoring macropore preservation by considering soil texture as a proxy for structural integrity, or by considering management measures related to the continuity of macropores (Kleinman et al., 2015). It is unknown by the EP how often irrigated land coincides with high soil-P levels, however, so further information about soil types and P levels on irrigated land will help inform future research.

Kang et al. (2011) reported on P leaching through sandy soil columns from a North Carolina cotton field after application of different forms of inorganic P or various types of manure at varying application rates. They found type of P source can impact the potential for leaching and water-extractable P in manure can be an important indicator of potential P loss. On fields subject to years of continuous application of manure, leaching can potentially reach the total amount of P in the manure, indicating attention should be given to soil-P levels and potential for crop removal of P.

Findings

Approximately one-hundred and twenty peer-reviewed research articles were reviewed during the panel process, with approximately thirty of these papers relevant to the focus of the EP. Most research cited was conducted outside of the Chesapeake Bay watershed in regions subject to significantly different climatic conditions. The dearth of research relating cropland irrigation directly to water quality created a challenge for the EP in regard to developing an efficiency value for nutrients or sediment. Due to insufficient availability of data regarding P and sediment, only N was considered for this report. The panel set a minimum threshold of 10,000 irrigated acres within the Chesapeake Bay watershed for a specific crop to be considered. Among those that could be considered (corn, wheat, tobacco, and cotton), only corn and wheat meet that minimum threshold. The data that was relevant and available related almost exclusively to corn, therefore the EP chose to focus its attention on corn grown under sprinkler irrigation systems, such as center-pivot or traveling gun.

The EP is in agreement that proper management of short-term irrigation scheduling is critical if maximum N uptake (high NUE) and consequent reduction in N loss from the agroecosystem is to occur. Taking into account the proportional uptake of N on an irrigated field (managed to maximize WUE and NUE) versus a comparable dryland field (under less-than-ideal weather conditions), it is expected that less N would be lost to leaching under the irrigated sprinkler management systems focused on in this report than under dryland conditions. However, as indicated by the AgWG EPEG, nutrient management is also a key component to reducing N loss in an irrigated system. Over-irrigation, coupled with applying N at an appropriate rate may still result in pushing the N below the root zone (Gehl et al., 2005), not only impacting water quality but to the detriment of the crop. Additionally, it is important to consider the basis for fertilizer rates applied to corn. Fertilizer rates in the Delmarva region are generally determined based on expected yield. As irrigated corn yields are expected to be substantially higher than dryland corn yields, irrigated corn typically receives a higher rate of N than dryland corn on a per-acre basis. The proportional rise in fertilizer rate has the potential to negate the impact of increased N uptake or NUE. Although an ideal irrigation management strategy would maximize NUE and WUE, thereby reducing N loss via leaching and in turn benefiting both water quality and the farmer's wallet, the end goal of irrigation is a more profitable crop. In this sense, a management system most beneficial to water quality may not be economically advantageous to the farmer. From an economics standpoint it is not always beneficial to carefully manage irrigation, but from a water quality standpoint it is necessary. A recent research and education project in Delaware, sponsored by Sustainable Agriculture Research and Education (SARE), encountered many challenges in its intended goal to engage farmers in precision management of their irrigation systems with soil moisture monitoring equipment. The most prevalent method to schedule irrigation in Delaware remains the "checkbook" method that relies on daily reference evapotranspiration data from local weather stations adjusted by crop-specific growth coefficients to estimate the amount of water used daily. Many assumptions are necessary to calculate the daily water use, including proper irrigation system calibration. Among the challenges were equipment and labor costs, complexity of data tracking and analysis, calibration and technical malfunctions, and favorable (wet) weather conditions during the three years of the project. The project leads determined that soil moisture monitoring is not a realistic tool in the Mid-Atlantic region and from an economic perspective it is cheaper for farmers to over-irrigate by some measure than invest in soil moisture monitoring equipment. With that said, the final project report also acknowledged contemporaneous cooperative work between the University of Delaware (UD) and USDA-NRCS evaluating over 400 center-pivot irrigation systems for uniformity, efficiency, and application rate. UD and USDA-NRCS found that, "Over 50% of the systems tested in this program applied less than 80% of the water estimated by the system manufacturer's calibration chart," highlighting the need for better equipment calibration, and irrigation scheduling methods (SARE-USDA/NIFA, 2015).

In response to the limited and mixed results related to the impact on cropland irrigation on N leaching it is noted that temporal and spatial variance in agroecosystems can make it difficult to measure relatively small, but perhaps consequential, changes in NUE and nitrate leaching. Additionally, groundwater monitoring may not accurately reflect contemporaneous or relatively recent changes in irrigation management above-ground. Regardless, there is currently a lack of field research definitively pointing to a water quality benefit from cropland irrigation, and in some cases the data shows increased losses of N to the surrounding environment due to irrigation (Denver et al., 2018). Yield stability associated with irrigation seems to be the key to the assumption that irrigated cropland can reliably reduce loss of N to the environment. Relying on expected yield differentials between irrigated and non-irrigated cropland to presume N loss reductions requires careful consideration of proper irrigation management, nutrient management, and yearly variation in seasonal weather factors, as well as reliable measures of N inputs vs outputs on a seasonal basis (i.e., a mass balance approach). Leachate studies and monitoring of nitrate levels in groundwater can provide reasonable assurance that such practices are indeed reducing N losses. Currently, there is very little published research tying such water quality measures to cropland irrigation management.

Conclusion

Taking into account the limited research data currently available and the variable nature of the conclusions to be drawn from that data, the EP has determined that an N efficiency value for cropland irrigation cannot be assigned at this time. Among the research available for review, there is reasonable indication that irrigating cropland can result in increased N leaching past the root zone relative to non-irrigated cropland. Increased N leaching would warrant a negative N efficiency in the context of water quality. The efficiency values associated with past CBP BMP

Expert Panels (e.g., cover crops, conservation tillage) were determined not by nutrient uptake or removal, but by how a practice could reduce nutrient runoff or leakage of nutrients past the root zone. This panel chooses not to deviate from this approach. This recommendation does not prevent the possibility of an N efficiency for cropland irrigation as a CBP BMP at a future date if new research addresses gaps and uncertainties highlighted in this report. At this time, however, the panel's best professional judgment could not be used to fill the gaps, conflicting evidence and uncertainties in the existing available research, especially for nitrate leaching and NUE.

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Ancillary benefits and potential unintended consequences

Irrigation allows Coastal Plain farmers to better control for variable precipitation patterns on the Delmarva Peninsula. Removing the potential for crop moisture stress allows farmers to plan for greater average yields, which clearly has economic benefits and greatly reduces the risk of crop failure. Predictable yields allow for more informed pre-season planning, particularly related to fertilizer and manure applications. However, planning for higher yields also means greater application of nutrients. Current general nutrient application guidelines for corn in both Maryland and Delaware recommend one pound of nitrogen per expected bushel of corn, resulting in a substantially higher rate of N application on irrigated fields. Virginia nutrient management also allows for increased N application rates on irrigated corn. Therefore, assuming N recommendations are based on yield expectations alone, it can be assumed that corn under irrigation would receive higher applications of N than a comparable planting without irrigation. Failure to achieve anticipated yields on irrigated fields could therefore result in greater N leaching than on an equivalent dryland field.

Nutrient management programs in both Maryland and Delaware provide some guidance for N credits related to previous land management, but there is still room for improvement on N crediting measures that could reduce in-season N application from fertilizer or manure (Morris et al., 2018). Additionally, there may be locales where nitrate-N concentrations in the irrigation water source are high enough to warrant consideration as a part of nutrient management planning. Without a well-managed irrigation program that includes close monitoring of weather, field and crop status throughout the growing season, there is potential for greater N loss from irrigated fields.

Sustainable Intensification

Cropland irrigation represents an intensification of agricultural production with increased yields per area of land and increased likelihood of yield stabilization under a varied climate. There is a growing body of literature addressing the concept of Sustainable Intensification (SI) of agricultural production (Garnett et al., 2013; Pretty, 2018). In short, SI comprises agricultural systems in which production is maintained or increased while progressing toward significant enhancement of environmental outcome. One important aspect of the concept is that intensification of production on the most productive land can permit retirement of marginal lands from production. Sustainable intensification emphasizes the importance of taking holistic approaches to implementing BMPs to gain useful synergies (Pretty, 2018). One such approach could couple programs encouraging irrigation on highly productive land and increased implementation of riparian buffers with concurrent removal of marginal lands from production. The findings of Maharjan et al. (2014) suggest increased N uptake by corn on irrigated fields due to increased biomass, and the possibility of decreased nitrate loss on a yield-adjusted basis. Further research looking specifically at N loss from irrigated cropland systems could support the inclusion of irrigation as part of an SI system that includes marginal land retirement for additional reduction in nutrient loss.

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Future research and management needs

The conclusion of this EP is that there is not currently enough evidence to definitively state that irrigation on corn will decrease N loss and thus prevent water quality degradation. On the contrary, there is some research indicating that irrigation may result in increased nitrate concentrations and loads in groundwater. That said, there is agreement among panel members that more research on cropland irrigation impacts to water quality is needed in the CBW and more specifically on the Delmarva Peninsula, where center-pivot irrigation systems are now a mainstay in corn cultivation. For this reason, the EP has several recommendations for further research that could better inform our understanding of cropland irrigation and its interception with nutrient reduction into the future:

- Further research to collect data on crop response to irrigation rate on the Coastal Plain and throughout the humid climate of the CBW. As indicated in this report, published research on deficit irrigation and its impact on crop yields in semi-arid regions is plentiful, but it is lacking in the CBW. The impact of irrigation on crop nutrient uptake and yield on the Coastal Plain would help to better understand water quality impacts. Access to existing unpublished information relating yields to nutrient load reductions would also be useful.
- Further field research to test NUE assumptions regarding non-irrigated vs. irrigated plots under Delaware field conditions (Sims et al. 2012) and the impact of those assumptions on nitrogen loss.
- Further CBW research on variable rate irrigation to address irrigation on fields encompassing wetlands or uneven soil moisture conditions. Blanket irrigation rates across a field with uneven soil conditions can result in significant nutrient transport from characteristically wetter areas.
- Further CBW research on the interaction of irrigation management with other measurable variables (e.g., yields, biomass, soil moisture).
- Further CBW field research on supplemental irrigation. Inconclusive data limits the assertion that increased crude protein in corn is an indication of less nutrients subject to leaching.
- Sensitivity analyses of studies looking at N leaching associated with irrigation to account for potential noise in the observed data.
- Development of model scenarios to address impacts of various environmental conditions on potential for nutrient leaching and transport. Identification of modeling data that does exist that can inform evaluation of irrigation under different environmental conditions.
- Monitoring water and land management practices in a strategic manner to collect the data most critical to informing modeling scenarios that can more definitively demonstrate if better irrigation management can significantly reduce N leachate entering groundwater. A long-term (5-8 year) study with broad participation is needed to get a better sense of average conditions.

- Further research to explore the impact of litter and manure application under irrigated conditions. Irrigation research in the mid-west U.S. primarily considers fertilizer-only cropland. Agriculture on the Delmarva Peninsula relies heavily on the plentiful local supply of poultry litter as a valuable soil amendment due to its organic matter content, N, P and micronutrient constituents. Although there are some published studies that consider litter and manure application under irrigated conditions, they were not relevant to the current report (Feyereisen et al., 2010; Glaesner et al., 2011; Kang et al., 2011).
- Further research and data informing the conditions under which a water quality benefit could be expected from cropland irrigations (e.g., weather, water management, nutrient management, healthy soil practices, soil organic matter content).
- Further research into the most efficient N rates for irrigated corn and other crops to ensure that nutrient application recommendations are based off the latest scientific data.

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Appendix A: Conformity of report with BMP Protocol

1. **Identity and expertise of panel members***:* See Table 1.

- **Practice name or title:** Cropland Irrigation Management

- **Detailed definition of the practice***:* N/A

- **Recommended N, P and TSS loading or effectiveness estimates:** No effectiveness estimates (efficiencies) are recommended at this time.

2. **Justification of selected effectiveness estimates***:* N/A. See above.

3. **Description of how best professional judgment was used, if applicable, to determine effectiveness estimates:** According to the best professional judgement of the panel, there is not enough research evidence to confidently attribute an effectiveness estimate to cropland irrigation on a scientific basis. However, the panel was not ready to definitively state that there is no water quality benefit associated with irrigation on corn, particularly if it is well-managed and in conjunction with a nutrient management plan. Further research into the impacts of irrigation on water quality is strongly recommended by the panel.

4. **Land uses to which BMP is applied:** N/A

5. **Load sources that the BMP will address and potential interactions with other practices:** N/A

6. **Description of pre-practice and post-practice circumstances, including the baseline conditions for individual practices:** N/A

7. **Conditions under which the practice performs as intended/designed:** N/A

8. **Temporal performance of BMP including lag times between establishment and full functioning:** N/A

9. **Unit of measure: Locations in CB watershed where the practice applies:** N/A

10. **Useful life; practice performance over time**: N/A

11. **Cumulative or annual practice:** N/A

12. **Recommended description of how practice could be tracked, reported, and verified:** N/A

13. **Guidance on BMP verification***:* N/A

14. **Description of how the practice may be used to relocate pollutants to a different location:** N/A

15. **Suggestion for review timeline; when will additional information be available that may warrant a re-evaluation of the practice effectiveness estimates:** The panel recommends that further research be conducted both in-field and from a modeling context. Logistically, this may mean re-evaluation of the research and data available five years from publishing of this report (2023).

16. **Outstanding issues that need to be resolved in the future and a list of ongoing studies, if any:** Indicated in *Review of science and literature* and *Future research and management needs* sections.

17. **Documentation of dissenting opinion(s) if consensus cannot be reached:** Full consensus on recommendations was achieved.

18. **Operation and Maintenance requirements and how neglect alters the practice effectiveness estimates:** Although effectiveness values where not determined, it is important to note that it is generally understood that less-than-ideal irrigation management can result in inefficient use of applied nutrients resulting in a larger pool of soluble nitrogen to be lost to the environment or, in the case of over-watering, increased loss of nitrogen via sub-surface or overland flow.

19. **A brief summary of BMP implementation and maintenance costs estimates, when this data is available through existing literature:** N/A, but this information is likely available if a BMP is recommended in the future.

20. **Technical appendix:** N/A, not recommending a BMP at this time.

Appendix B: Cropland Irrigation Management Expert Panel Charge Document

Recommendations for the Cropland Irrigation Management Expert Panel

Prepared for the Chesapeake Bay Program Partnership's Agriculture Workgroup by the Cropland Irrigation Management Expert Panel Establishment Group

Approved by the Agriculture Workgroup on April 16, 2015

Background

In the current version of the Chesapeake Bay Program (CBP) partnership's Watershed Model (version 5.3.2), cropland irrigation management is recognized as an interim practice used for planning purposes only. The potential nutrient reduction benefit stems not from the increased average yield (20-25%) of irrigated versus non-irrigated cropland, but from the greater consistency of crop yields over time matched to nutrient applications. This increased consistency in crop yields provides a subsequent increased consistency in plant nutrient uptakes over time matched to applications, resulting in a decrease in potential environmental nutrient losses. The placeholder effectiveness values are 4% total nitrogen (TN), 0% total phosphorus (TP) and 0% total suspended solids (TSS), based on the range in average yields from the 2002 and 2007 NASS Census of Agriculture data for irrigated and non-irrigated grain corn as a reference.

The Cropland Irrigation Management Expert Panel Establishment Group (EPEG) was formed to:

- Identify priority tasks for the Cropland Irrigation Management Expert Panel (EP),
- Recommend areas of expertise that should be included on the Cropland Irrigation Management EP, and
- Draft the Cropland Irrigation Management EP's charge for the review process.

From March 3, 2015 through April 1, 2015 the EPEG met 4 times by conference call and worked collaboratively to complete this charge for presentation to the Agriculture Workgroup (AgWG) on April 16, 2015. Final approval of the charge was obtained by online polling of all members. Members of the EPEG are listed in Table 1.

Table 6. Cropland Irrigation Management Expert Panel Establishment Group membership and affiliations.

Member	Affiliation
Jen Nelson	Resource Smart, LLC
Jenn Volk	University of Delaware
Judy Denver	United States Geological Survey
Tim Sexton	Virginia Department of Conservation and Recreation
EPEG Support Staff	
Mark Dubin	University Maryland
Emma Giese	Chesapeake Research Consortium

Jennifer Ferrando	Tetra Tech, Inc.

Method

The Cropland Irrigation management EPEG developed its recommendations in accordance with the process specified by the AgWG (AgWG 2014). This process is informed by the strawman proposal presented at the December 11, 2014 AgWG meeting, the Water Quality Goal Implementation Team (WQGIT) Best Management Practice (BMP) protocol, input from existing panelists and chairs, and the process recently undertaken by the AgWG to develop the charge for the Manure Treatment Technologies EP.

The collective knowledge and expertise of EPEG members formed the basis for the recommendations contained herein. The majority of the EPEG members have had experience on BMP expert panels, including the Cover Crops, Nutrient Management, and Wetlands Land Use Definition and Wetlands Restoration BMP Expert Panels as well as the Poultry Litter and Agricultural Modeling Subcommittees. EPEG members and the technical support team also have knowledge and/or expertise in state and federal programs, the Chesapeake Bay model, and cropland irrigation management practices within the Chesapeake Bay watershed.

Communication among EPEG members was by conference call and email. All decisions were consensus-based.

Recommendations for Expert Panel Member Expertise

The AgWG expert panel organization process directs that each expert panel is to include eight members, including one non-voting representative each from the Watershed Technical Workgroup (WTWG) and Chesapeake Bay Program modeling team. Panels are also expected to include three recognized topic experts and three individuals with expertise in environmental and water quality-related issues. One of the six topic or environmental and water quality experts will serve as the panel Chair. A representative of USDA who is familiar with the USDA-Natural Resources Conservation Service (NRCS) practice standards should be included as one of the six individuals who have topic- or other expertise.

In accordance with the WQGIT BMP protocol, EP members should not represent entities with potential conflicts of interest, such as entities that could receive a financial benefit from EP recommendations or where there is a conflict between the private interests and the official responsibilities of those entities. All Panelists are required to identify any potential financial or other conflicts of interest prior to serving on the EP. These conditions will minimize the risk that Expert Panels are biased toward particular interests or regions.

The Cropland Irrigation Management EPEG recommends that the Cropland Irrigation Management EP should include members with the following areas of expertise:

- Expertise in cropland irrigation management and cropping practices in the Chesapeake Bay watershed jurisdiction(s).

- Expertise in fate and transport of nitrogen, and/or phosphorus, and/or sediment in agricultural systems under various irrigation management systems representative of various Chesapeake Bay physiographic provinces.
- Understanding of Chesapeake Bay watershed hydrogeology in the context of chemical transport.
- Knowledge of irrigation system engineering and management requirements, including fertigation systems.
- Experience with carrying out research projects relating to irrigation management.
- Experience with verification of cropland irrigation management practice implementation.
- Knowledge of how BMPs are tracked and reported, and the Chesapeake Bay Program partnership's modeling tools.
- Knowledge of relevant NRCS practice codes or standards, if applicable.

Staff from the Chesapeake Bay Program and Tetra Tech will provide technical support for the Cropland Irrigation Management EP.

Expert Panel Scope of Work

The Cropland Irrigation Management Expert Panel will develop definitions and loading or effectiveness estimates for the cropland irrigation management practice described above. The Expert Panel will develop effectiveness estimates for nitrogen, phosphorus, and sediment, where possible based on available data.

The panel will work with the AgWG and WTWG to develop a report that includes information as described in the WQGIT's *Protocol for the Development, Review, and Approval of Loading and Effectiveness Estimates for Nutrient and Sediment Controls in the Chesapeake Bay Watershed Model*[3] (see Attachment 1).

Specifically, the Cropland Irrigation Management EPEG recommend the following four charges with associated tasks to be completed by the Cropland Irrigation Management EP:

1. Refine interim BMP definition and efficiency values for cropland irrigation under average hydrologic conditions, taking into account how efficiencies might deviate from average values during wet or dry years.
2. Consider developing BMP definitions and efficiency recommendations for three categories of cropland irrigation:
    - Cropland irrigation (i.e., decreased variation in yields between dry land and irrigated cropland production)
    - Irrigation water management (i.e., soil moisture management and water conservation practices)
    - Fertigation (i.e. utilization of irrigation systems to irrigate as well as apply supplemental organic or inorganic nutrients)
3. Consider establishing a baseline condition that addresses irrigation system operation and management.
4. Consider regional variations in irrigation practices and BMP efficiencies.

[3] http://www.chesapeakebay.net/documents/Nutrient-Sediment_Control_Review_Protocol_v7.14.2014.pdf

This scope of work addresses reduction efficiencies for nitrogen, phosphorus, and sediment.

The first charge is necessary because the interim definition and efficiency values for Cropland Irrigation Management are preliminary. The interim BMP for Cropland Irrigation included a preliminary TN reduction efficiency based on increased consistency of crop yields over time (e.g., reduced yield loss in dry years due to irrigation) matched to nutrient application. The efficiency value was based on the difference in corn grain yields between dryland and irrigated commodity grain corn yields from the 2002 and 2007 Ag Censuses; the only two Ag Census reports which provided this separation of data at the time. The census analysis results identified a smaller range in crop yields for irrigated agriculture than dry land crops. The EP will gather additional information to either refine or replace the interim BMP definition for improved targeting of nutrient applications based on more consistent yields for irrigated systems. The EP also will consider including phosphorus and sediment reduction efficiencies if appropriate based on available data.

The second charge addresses the range of variation in cropland irrigation practices and their effects on potential nutrient and sediment loss pathways. The Expert Panel will consider developing definitions and effectiveness values for three potential categories of cropland irrigation:

1. Cropland irrigation. This category is comparable to the refinement of the interim BMP definition under the first charge. It addresses efficiencies to be gained through targeting of nutrient application rates to more predictable crop yields based on decreased annual yield variations.
2. Irrigation water management. This category addresses potential reductions in nutrient and sediment loss from improved management of the volume of water applied. The EP will consider potential efficiencies from reductions in both runoff and leaching past the root zone with enhanced water management.
3. Fertigation. This category addresses differences in crop yield response variation and surface and subsurface nutrient losses for irrigation systems that are used to deliver supplemental organic or inorganic nutrients. The EP should consider definitions and efficiencies based on cropland irrigation systems as a basis (i.e., analogous to the first category) and water management under fertigation systems (i.e., analogous to the second category). The EP will also consider whether to establish BMP definitions and efficiencies based on various types of irrigation systems (e.g., drip irrigation versus center pivot versus traveling gun irrigation). Finally, the EP will consider how to address acres where irrigation and fertigation are combined. Collaboration with the Nutrient Management EP on fertigation will be critical to ensure that recommendations are complementary as well as to avoid double-counting and ensure effective reporting of practices.

The EP will develop nitrogen, phosphorus, and sediment efficiencies for all categories of the BMP definition, to the extent possible based on available data.

The third charge acknowledges the potential variation in pollutant reduction efficiency based on irrigation type selection, operation and maintenance, and overall management of the irrigation system. Selection of type and management of irrigation systems dictates, to a high degree, the effect of irrigation on crop yields. Proper system design, operation, and maintenance are critical to achieving consistent yields in dry years and optimizing water use to achieve the desired crop yield response. Furthermore, improperly managed irrigation and fertigation systems can be pollutant sources rather than providing a pollution reduction benefit, especially in wet years. The EP will consider establishing a baseline condition for system management that would guide the identification of systems which would qualify for the practice. The EP will consider factors such as appropriate system selection and design, proper system installation and operation, and adequate system maintenance. In considering these and other appropriate factors, the EP will seek to balance improved confidence in the efficiency values for a well-managed system, with potential limitations in identifying BMP applicability for a specifically-defined baseline condition. The EP will consider whether a baseline condition is appropriate for all categories of the BMP and, if so, whether the same baseline should apply to all categories. Finally, the EP will articulate how baseline conditions will be tracked, reported, and verified.

The fourth charge is necessary to address the potential differences in BMP efficiencies for different hydrologic, geomorphic, agricultural crop production, and other conditions that vary throughout the watershed. To the extent that adequate supporting data are available, the EP will address variations in BMP efficiencies for all categories based on physiographic region or other locational considerations. The EPEG notes that some of the previously approved CBWM BMPs have chosen to treat karst geology the same as coastal plains physiography to avoid the need to add karst as a separate category.

In addressing these charges, the EP will refer to the practices documented in EPA's *National Management Measures for the Control of Nonpoint Pollution from Agriculture*, chapter 4F, Irrigation Water Management. The EP is advised of ongoing research by the U.S. Geological Survey (USGS) under the Small Watershed Studies project. USGS is investigating small watersheds in Delaware and Maryland to document the effects of irrigation and other conservation practices on hydrology and shallow groundwater quality. These projects are scheduled to end in July, 2016 (Bucks Branch Project [Delaware]) and September, 2016 (Andover Branch Project [Maryland]). The EP should consider interim data and preliminary results of these projects, to the extent they are available.

Timeline and Deliverables

The Expert Panel project timeline for the development of the panel recommendations is based on the Phase 6.0 model development schedule. This timeline includes the development of a provisional recommendation for this BMP prior to the finalization of a fully documented recommendation report with effectiveness values. Provisional panel recommendations will be used only for initial Phase 6 model development and calibration, and not for future implementation progress reporting by the jurisdictions.

- May 2015 – Panel stakeholder kickoff meeting
- Fall 2015– Provisional BMP paper

  Based on their written EPEG charge, the panel will develop a proposed scope of work including BMP structure and type, draft BMP definition(s), and initial elements of the BMP such as associated components and conservation practices, and USDA-NRCS associated conservation practice standard codes. Initially identified literature citations will be included to provide a range of potential effectiveness values that the panel will consider and supplement with further evaluation. The panel will present their provisional BMP paper to the AgWG, WTWG, and WQGIT for informational purposes, and for initial partnership comments on the proposed direction of the panel's evaluation. The paper will not represent a full recommendation report, and the partnership will not be asked for formal approval at this time.

- May 2016 – **Target date** for panel to release full recommendations and final report for approval by the AgWG, WTWG, and WQGIT.
- August 2016 – If approved by the partnership, panel recommendations are final and will be represented in the final Phase 6 modeling tools.

Phase 6.0 BMP Verification Recommendations

The panel will utilize the Partnership approved *Agricultural BMP Verification Guidance*[4], as the basis for developing BMP verification guidance recommendations that are specific to the BMP(s) being evaluated. The panel's verification guidance will provide relevant supplemental details and specific examples to provide the Partnership with recommended potential options for how jurisdictions and partners can verify Cropland Irrigation Management practices in accordance with the Partnership's approved guidance.

References

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[4] http://www.chesapeakebay.net/documents/Appendix%20B%20-Ag%20BMP%20Verification%20Guidance%20Final.pdf

Attachment 1: Outline for Final Expert Panel Reports

- Identity and expertise of Panel members
- Practice name/title
- Detailed definition of the practice
- Recommended nitrogen, phosphorus, and sediment loading or effectiveness estimates
    - Discussion may include alternative modeling approaches if appropriate
- Justification for the selected effectiveness estimates, including
    - List of references used (peer-reviewed, unpublished, etc.)
    - Detailed discussion of how each reference was considered, or if another source was investigated, but not considered.
- Description of how best professional judgment was used, if applicable
- Land uses to which the BMP is applied
- Load sources that the BMP will address and potential interactions with other practices
- Description of pre-BMP and post-BMP circumstances, including the baseline conditions for individual practices
- Conditions under which the BMP works:
    - Should include conditions where the BMP will not work, or will be less effective. An example is large storms that overwhelm the design.
    - Any variations in BMP effectiveness across the watershed due to climate, hydrogeomorphic region, or other measureable factors.
- Temporal performance of the BMP including lag times between establishment and full functioning (if applicable)
- Unit of measure (e.g., feet, acres)
- Locations within the Chesapeake Bay watershed where this practice is applicable
- Useful life; effectiveness of practice over time
- Cumulative or annual practice
- Description of how the BMP will be tracked, reported, and verified:
    - Include a clear indication that this BMP will be used and reported by jurisdictions
- Suggestion for a review timeline; when will additional information be available that may warrant a re-evaluation of the estimate
- Outstanding issues that need to be resolved in the future and a list of ongoing studies, if any
- Documentation of any dissenting opinion(s) if consensus cannot be reached
- Operation and Maintenance requirements and how neglect alters performance

Additional Guidelines

- Identify ancillary benefits and unintended consequences
- Include negative results
    - Where studies with negative pollution reduction data are found (i.e. the BMP acted as a source of pollutants), they should be considered the same as all other data.

- Include results where the practice relocated pollutants to a different location. An example is where a practice eliminates a pollutant from surface transport but moves the pollutant into groundwater.

In addition, the Expert Panel will follow the "data applicability" guidelines outlined Table 1 of the Water Quality Goal Implementation Team Protocol for the Development, Review, and Approval of Loading and Effectiveness Estimates for Nutrient and Sediment Controls in the Chesapeake Bay Watershed Model[1].

Appendix C: Cropland Irrigation Management Expert Panel Meeting Minutes

8/23/16
Conference Call

- Panelists introduced themselves, and briefly described their backgrounds and expertise related to agricultural irrigation.
- Tim Sexton and Mark Dubin reviewed the scope of the panel and the timeline for completing recommendations.
- Mark Dubin, Tim Sexton, and Lindsey Gordon will work to begin scheduling a face-to-face and open stakeholder meeting for September, and will distribute a poll to panel members to identify a date and time.
- Mark Dubin noted the important differences in irrigation used for watering and irrigation used for fertilization (fertigation), and the panel will have to consider these moving forward.

Participants:
James Adkins, UD
Jennifer Ferrando, Tetra Tech
Tim Sexton, VA DCR
Tyler Monteith, DNREC
Judy Denver, USGS
Cory Whaley, UD
Mark Dubin, UMD
Greg McCarty, USDA ARS
Matt Johnston, UMD

09/19/16
Face-to-Face Meeting

Actions & Decisions:
ACTION: James Adkins will work to locate the University of Delaware data for cropland irrigation.
ACTION: Panel members should begin reviewing literature sources for irrigation information, and should send references to Mark Dubin (mdubin06@umd.edu).
ACTION: Jerry Lewis will look at RUSLE2 sediment data for irrigation.
ACTION: Greg McCarty will work to provide Maryland data on irrigation.
ACTION: Panel members should send keywords to be used in the literature search and review to Jennifer Ferrando, Tetra Tech (Jennifer.ferrando@tetratech.com).

- Panel members introduced themselves, and Tim Sexton provided introductory remarks on the purpose and work of the panel moving forward. The panel will need to determine the effectiveness of cropland irrigation management in terms of nutrient and sediment reductions to the Chesapeake Bay by reviewing all available literature.

- Judy Denver: How does the model account for irrigation?
    - Mark Dubin: We use ag census data right now. We'll start using annualized NASS data in conjunction with the ag census 5-year data. That said, NASS data is state level, but we typically work with county-level data. Irrigated cropland is currently represented as an interim BMP, and cannot be used for progress measurements but rather for planning purposes only.
    - Judy Denver noted that differences in rainfall and physiography may impact the effectiveness of irrigation.
- Matt Johnston: Since we are already adjusting crop yields and uptake to account for irrigation, the group should also consider what the water quality difference is between a single acre with irrigation (and the same yield) and an acre without irrigation (and the same yield).
- Mark Dubin noted that the types of literature sources and their appropriateness will impact what the panel should consider. Peer-reviewed sources are ideal, and grey literature or unpublished data will receive less weight.
- Judy Denver asked about what types of management strategies will be recommended by the panel, and how they will parse out this aspect of the panel's charge.
- James Adkins: So we're not necessarily making recommendations on whether a pound/bushel harvested would be equivalent to a pound/bushel irrigated.
- Matt Johnston: If you have 100 bushels/acre, it would get 100 lbs applied, x 0.79 for uptake. Now the yield doubles because of irrigation, so there's 200 bushels/acre, and everything else is doubled. If you follow the math, this includes the output. But the question is, is that output (in terms of leakage) correct?
    - Mark Dubin: We need to map out the options for how these recommendations would be represented in the modeling.
    - Matt Johnston: At this stage in model development, the only real option is the efficiency to affect how much is running off the land.
- Tim Sexton: Knowing that in MD, there are a lot of tomatoes on drip, I'm not sure how we would be able to account for that because the model doesn't have those types of land uses.
- Judy Denver: Is there much irrigation outside of the coastal plain?
    - Mark Dubin: There's some in Frederick County, and up in PA. A lot is used for fertigation and specialty crops.
    - Denver: So most of our concern for this BMP is local to the Eastern Shore.
- Tim Sexton: If we come up with this efficiency for dry versus irrigated land, and that's all we get, then at some point in time, we may be able to split the pie and focus on other elements more.
- Greg McCarty: What about fertigation?
    - Mark Dubin replied that this was a tough aspect to cover because it intersects with nutrient management, but noted that the panel will have to define it.
- Matt Johnston: (https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Ag_Atlas_Maps/Crops_and_Plants/Field_Crops_Harvested/12-M160-RGBDot1-largetext.pdf) This link is

nationwide for irrigated corn, but still confirms our assumption that this is an Eastern Shore/Coastal Plain practice.

- Matt Johnston: This one is much better as it shows percent by county, and you can select your irrigated crop of choice: https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Ag_Census_Web_Maps/
- Matt Johnston also reminded the panel that most BMP panels begin their work with the open assumption that the BMP does not receive credit, and encouraged the panel not to box themselves in by deciding that a credit is mandatory.

- James Adkins noted a wish to see nutrient content for water (i.e. fertigation) or deficit irrigation put in the parking lot, and for the panel to focus on primary issues for irrigation management so that the bulk of acres are represented.

ACTION: James Adkins will work to locate the University of Delaware data for cropland irrigation.

- Panel developed a list capturing the items they will consider in their work, and items that will be sidelined for consideration by a future panel.
- Mark Dubin noted that Tetra Tech will be able to provide assistance with the published literature review, but that panel members will be asked to search grey/unpublished literature. Should the panel require additional assistance, funding is available through Virginia Tech to complete literature review and meta-analysis.

ACTION: Panel members should begin reviewing literature sources for irrigation information, and should send references to Mark Dubin (mdubin06@umd.edu).

- Tim Sexton asked the panel if water soluble P should be a consideration.
  - Judy Denver replied that very little water-soluble P was likely leaching into the ground water.
- Panel agreed to invite outside experts, including Jack Meisinger, to panel meetings in order to gain additional information.
- James Adkins expressed concern about availability of published literature on this topic. Mark Dubin noted that the panel will collect everything available to them, and consider using best professional judgement in order to develop a final efficiency value. The Panel can also recommend research needs in their full report.
- Panel agreed to consider N and P to the extent possible based on available literature.

ACTION: Jerry Lewis will look at RUSL2 sediment data for irrigation.

ACTION: Greg McCarty will work to provide Maryland data on irrigation.

Participants:

Lindsey Gordon	CRC
Tim Sexton	VA DCR
Mark Dubin	UMD
James Adkins	UD
Judy Denver	USGS
Matt Johnston	UMD
Corey Whaley	UD
Jerry Lewis	USDA NRCS

Tyler Monteith	DE DNREC
Greg McCarty	USDA ARS

09/19/16
Open Stakeholder Session

- Panel members and session participants introduced themselves.
- Tim Sexton provided a brief introduction of the panel's work, and reviewed the draft list of considerations as developed by the panel.
- Jason Keppler: Is the panel going to solely consider center pivot irrigation, or are there other systems that will be considered as well?
    - Sexton: I wouldn't say center pivot is the only type of system, though most of the systems we'll be considering on the eastern shore on row crops are using a center pivot system.
    - Keppler: There's certainly other types of systems out there – subsurface tape irrigation, etc. But I recognize the justification of the panel for how much time they have to work on this effort. I think it's good to focus on the bulk of irrigation acres across the watershed.
- Lindsay Thompson: What are some potential limitations of the model that might impact your work?
    - Sexton: The model relies heavily on ag census data and NASS data (which is only available at a state level). It's mostly just a data availability issue here, not that the model doesn't have the capacity to incorporate this BMP – we will be representing it as a nutrient efficiency BMP.
- Lindsay Thompson: We know some of the issues we've run into is a lack of available data. Has there been any preliminary data-gathering effort, and how do you think we'll do as far as that availability?
    - Sexton: We don't know that answer quite yet. If you know someone with research related to this subject, please let us know.

Open Session Participants:

Jason Keppler	MDA
Lindsay Thompson	DE-MD Agribusiness Assoc.
Joel Blanco	U.S. EPA
Robin Pellicano	MDP
Lindsey Gordon	CRC
Tim Sexton	VA DCR
Mark Dubin	UMD
James Adkins	UD
Judy Denver	USGS
Matt Johnston	UMD
Corey Whaley	UD
Jerry Lewis	USDA NRCS
Tyler Monteith	DE DNREC

Greg McCarty	USDA ARS

10/04/16
Conference Call

Actions & Decisions:
ACTION: Panelists should send keywords to be used in the literature review to Jennifer Ferrando (Jennifer.ferrando@tetratech.com). Full literature sources should be sent to Jennifer and Mark Dubin (mdubin@chesapeakebay.net).
ACTION: Panelists should work to identify someone willing to do contract work for the panel, including a review of available literature and summarization of data.

- Minutes from the September 19th meeting were approved.
- Tim reviewed the actions from the panel's previous meeting on September 19th. Panelists should consider literature sources that would help inform the panel's work, and send any references or keywords for searches to Jennifer Ferrando (Jennifer.ferrando@tetratech.com).
- Tim Sexton conferred with Jack Meisinger, USDA, regarding available data and literature. Jack suggested simulated rainfall studies with leachate data, and that irrigation management would be used to reduce the amount of water moving through the root zone, thereby reducing the amount of nitrate leaching from this soil zone.
  - Jennifer Ferrando asked if these types of studies would need to report nitrate content of the water.
  - Tim replied that lysimeter studies of water movement, looking at nutrient content, would be useful to the panel. Greg Evanylo and Mark Alley may have in-field research using lysimeters.
- Jennifer Ferrando reviewed her drafted list of keywords for the literature search.
  - Mark noted that the panel can consider grey literature and unpublished research data.
  - Judy Denver has been looking at studies of groundwater beneath irrigated land, and recommended the panel consider this in their work.
  - Panelists provided additional keywords to include in the search, such as dryland and deficit irrigation. Practices considered deficit irrigation in other regions may be comparable to dry-land irrigation in the CBW region; therefore it would be useful to consider.
- Mark Dubin asked panelists when they anticipate having data available from their projects.
  - Judy replied that she could have data available in the next month.
  - James replied that his data is subject to any upcoming storm events.
- Mark Dubin suggested the panel hold a face-to-face meeting at the end of October in order to review Judy's information.
- James Adkins asked who would be conducting the literature search.

- Tim replied that funding for Tetra Tech to do the searches is no longer available, and requested the panelists try to locate a graduate student that could be hired as a contractor.

- Greg noted that Jason Keppler could provide them with well permit data for MD, but that it would be at a parcel-scale and could present problems for matching with field-level data.
- Judy Denver noted that it would be good to know the age of the irrigation systems.
- Mark noted that the panel will need to consider how to represent change over time. James had concerns that the change over time isn't linear, and to make predictions based on that may be spurious.
  - Judy offered to provide information on potentially irrigated land. James replied that this was not the primary mission of the panel, and worried it would delay their work. He suggested the panel instead use ag census data.
- Tim asked if the panel should look at denitrification. Judy replied that her work tries to look at N isotopes, but that it's tough to consider but could be worth using as a search term.
- Mark and Tim proposed the panel hold a half-day face-to-face on September 27th from 9:00 – 12:00 at the Wye Research Center.

<u>Participants:</u>

Lindsey Gordon	CRC
Mark Dubin	UMD
Tim Sexton	VA DCR
Jennifer Ferrando	Tetra Tech
Tyler Monteith	DNREC
James Adkins	UD
Greg McCarty	USDA ARS
Judy Denver	USGS
Cory Whaley	UD

10/27/16
Face-to-Face Meeting

<u>Actions & Decisions:</u>
Action: Tim Sexton will continue to review available literature, and will contact his colleagues for datasets. Tim will also work with Brian Benham (VT) to hire a contractor to work on the literature review.
Action: Panelists should continue to send suggestions for keywords to be used in the literature review to Jennifer Ferrando (Jennifer.ferrando@tetratech.com).
Action: Jennifer Ferrando will compile additional literature sources and distribute a spreadsheet for panelists to review. Each panelist should read and summarize 2-3 literature citations from the list in preparation for a conference call in December.

Action: Lindsey and Mark will schedule a panel conference call for early December to review the literature search.

- Judy Denver, USGS, presented on recent data on the effect of cropland irrigation management on water quality in selected study sites of the Delmarva Peninsula.
    - James Adkins: I would say this information is fairly representative of what's done, especially on the extremes of too much and too little.
- Dubin: We have to consider how we might create these BMPs within the modeling and tracking. We might have an average situation, and then a condition where the person is using additional data to improve their management. Soil moisture or lysimeter data, for example.
- Adkins: There's 11 different irrigation rates that have been tested, with a range of moisture levels and moisture management methods. I think these N uptake efficiencies for irrigated and dryland could be our base condition.
- Denver: If we do model these sites, we could put best conditions in and see how weather conditions would change things.
- Adkins: 2014 was an exceptional corn growing year, so I would suspect than in any other typical year the corn numbers would be a bit depressed on the dryland field. So there may be a need to look at average county yield versus this yield to reference whether this is a reasonable number and reference what type of year we're dealing with.
- Ken Staver: What would the yield goal be on the dryland field?
    - Adkins: That number seems atypical, knowing the grower. I'm not sure what happened there; it might have been a transition period.
    - Staver: Is this total N or PAN?
    - Denver: PAN.
- McCarty: Did you find any N enrichment in these wells?
    - Denver: Surprisingly we didn't, but I have some additional data we could look at.
- Judy Denver: Another complicating factor in these studies is whether poultry litter was applied, since this can really affect P and K.
- Tim Sexton asked if the age of the water could be responsible for higher nitrate concentrations in deeper wells.
- Judy Denver: Nitrogen use efficiency is generally greater with irrigation than dryland farming.
- Dubin: So the balancing between nitrate loss versus N use efficiency – your use efficiency increases but you have a higher loss out of the bottom.
    - McCarty: I think it should be normalized to yields.
    - Adkins: We have higher loss implied by concentration, but we also need to consider flow rate.
    - Dubin: It just seems to me that even if you account for volume, the range is still increasing between dry and irrigated.
    - Denver: I think it might be good to do the modeling, so we can see the impact of these practices.
- McCarty: Do you have ET incorporated?
    - Denver: We have models, but it's very difficult. Still, I think that would be a good way to go in the beginning.

- McCarty: You could use a flux tower.
- Adkins: We have referenced ET in those locations that match closely with soil moisture. So we could get good estimations from that.

- Sexton: It would be interesting to see how the model works out for the mass balance.
  - Dubin: What's your timing for the modeling work?
  - Denver: We first have to get funding, but I think within a year after funding we could have an article ready.
- James Adkins suggested that he work with Judy in order to integrate their research.
- Greg McCarty presented GIS-based data on irrigation sites in the Delmarva, Choptank region.
- Dubin: Can we do a comparison between DE and MD in terms of total acres under irrigation? It provides good justification for the Bay Program on why this BMP is important.
- Mark asked if the eastern shore of VA has a comparable irrigation location dataset, so that he can report back to the Bay Program modeling team on the total number of acres captured under this BMP.
- Jennifer Ferrando gave an update on the literature sources that have been collected thus far, and reviewed the types of literature that are being prioritized.
  - James Adkins suggested that flood irrigation studies are very low priority.
  - Mark Dubin: The partnership gets concerned when we reference studies outside of the U.S., so I would put low priority on international studies.
- Action: Tim Sexton will continue to review available literature, and will contact his colleagues for datasets. Tim will also work with Brian Benham (VT) to hire a contractor to work on the literature review.
- Action: Panelists should continue to send suggestions for keywords to be used in the literature review to Jennifer Ferrando (Jennifer.ferrando@tetratech.com).
- Tim Sexton: This panel won't have the draft report completed to meet the timeline for incorporation into the Phase 6 model. Knowing it will not meet those deadlines, then we have a lot of time to work on this. So in order for us to get this into the model for the next calibration, it will have to be completed by late 2018.
- Mark Dubin suggested the panel target the release dates for Judy and James' datasets in terms of completing their recommendations.
  - James noted that there may be significant changes to his research methodology and results, and the data the panel should rely on will likely be Judy's.
- Action: Jennifer Ferrando will compile additional literature sources and distribute a spreadsheet for panelists to review. Each panelist should read and summarize 2-3 literature citations from the list in preparation for a conference call in December.
- Action: Lindsey and Mark will schedule a panel conference call for early December to review the literature search.

Participants:

Tim Sexton	VA DCR
Mark Dubin	UMD
Lindsey Gordon	CRC

Judy Denver	USGS
Jerry Lewis	USDA NRCS
Greg McCarty	USDA
James Adkins	UD
Corey Whaley	UD
Jennifer Ferrando	Tetra Tech
Tyler Monteith	DNREC

02/06/17
Face-to-Face Meeting

<u>Actions & Decisions:</u>
ACTION: The panelists agreed to divide up literature sources evenly between them for review. Lindsey Gordon will assign the citations and provide .pdfs to panel members. Panel members should review the sources for information pertaining to irrigation practices and nutrient/sediment efficiencies, and take notes in the literature summary table. Reviews should be completed and information sent to Lindsey in time for a follow-up face-to-face meeting scheduled for 3/20 from 9:00 – 12:00 PM at the UMD Extension Facility in Queen Anne's County, MD.

<u>Review of Work Thus Far</u> – Tim Sexton, VA DCR, and Mark Dubin, UMD
The panel has discussed the status of on-going research in the context of cropland irrigation. Drip irrigation was eliminated from the list of considerations. Jennifer Ferrando has been working to compile a literature review summary table. Mark and Tim noted that the panel has the option of providing recommendations for an 'interim BMP', which can be used solely for planning purposes for Phase III WIP development, and not for credit in the Watershed Model until the next open period in 2019 to add BMPs to the modeling tools.
<u>Discussion of Literature Review</u> – Tim Sexton, VA DCR
Tim presented the results of the literature review, and discussed sources for the panel members to investigate.
ACTION: The panelists agreed to divide up literature sources evenly between them for review. Lindsey Gordon will assign the citations and provide .pdfs to panel members. Panel members should review the sources for information pertaining to irrigation practices and nutrient/sediment efficiencies, and take notes in the literature summary table. Reviews should be completed and information sent to Lindsey in time for a follow-up face-to-face meeting scheduled for 3/20 from 9:00 – 12:00 PM at the UMD Extension Facility in Queen Anne's County, MD.

- Tim Sexton noted that he would like to invite Jack Meisinger, USDA, to discuss his research with the panel.
- Tim and Mark reminded the panel that N, P, sediment, and soil types will be important to consider when developing recommendations for the practice, and that the panel can identify considerations for future iterations of this panel.

- Panelists should read their assigned literature sources and pull out any information pertaining to irrigation practices and their effect on nutrient and sediment reductions. Notes should be captured in the literature review spreadsheet.

State of the Research – All

The panel discussed alternative local data sources that are available, and determined which of these sources help inform their recommendations.

- James Adkins noted that his research is still in progress – results are not ready for public release, and his team needs to complete multiple repetitions of their study design in order to verify results. He did not anticipate having meaningful results until at least 2020.
- James Adkins also did not anticipate seeing large differences in nutrient efficiency values based on coastal plain geography, and asked what type of efficiency value this panel would be considering – nutrient, energy, etc. Mark Dubin replied that the panel would primarily be considering nutrient efficiencies since the model does not consider energy efficiency. James noted that a lot of the work with USDA NRCS primarily considers energy efficiency, and so would likely not provide a good database to inform the panel's recommendations.
- James Adkins also noted that national work is generally geared to application efficiency and water use efficiency, and doesn't necessarily align with water-quality benefit efficiencies.
- James Adkins explained that based on current research a lot of irrigators release less water than they are calibrated for, which could have significant impacts on water quality. He recommended that this be addressed in the panel report, and noted that there is limited information on standard conditions for irrigation that would require making a lot of assumptions.
- Judy Denver noted that her work seems to indicate that irrigated fields may have higher rates of N leaching in the summertime. She noted that she could not support lowering credit for water quality for irrigation at this point, and instead recommended that there not be an efficiency value for nitrogen until more information can be obtained. James Adkins added that the study locations from Judy's work may or may not reflect conditions everywhere.
- Mark Dubin added that the agriculture sector has the most BMPs, a lot of which intersect and interact with each other. The irrigation BMP has the potential to associate some of its practices with the Nutrient Management BMP (i.e.- variable rate application, etc).
- Tim Sexton remarked that the panel has the option to recommend that based on best available science, irrigation practices do not provide benefit in terms of nutrient and sediment reductions. He also noted that this does not negate the fact that irrigation practices provide a wide range of benefits outside of nutrient and sediment reduction.

Participants:

Tim Sexton	VA DCR
Mark Dubin	UMD
Lindsey Gordon	CRC
Cory Whaley	UD

Jerry Lewis	USDA-NRCS
Judy Denver	USGS
James Adkins	UD
Jennifer Ferrando	Tetra Tech
Tyler Monteith	DNREC
Greg McCarty	USDA-ARS

06/06/17
Face-to-Face Meeting

<u>Welcome and Introductions</u>
Mark Dubin introduced Jeremy Hanson, Virginia Tech, who will provide technical assistance to the panel's work moving forward.

- Tim Sexton will be providing updates on the work of the panel thus far at the AgWG quarterly meeting in June.

<u>Review of Work Thus Far</u> – Tim Sexton, VA DCR, and Mark Dubin, UMD

- Previous discussions have concerned the lack of information on leachate of N and P from irrigation. Possible next steps include considering alternative forms of information, such as modeled data. Wade Thomason will be presenting today on this possible avenue.
- Mark Dubin proposed targeting the AgWG's September quarterly meeting to release a draft final report.

<u>Approach to Estimating Nutrient Efficiency Improvements with Irrigation</u> - Wade Thomason, VT
Wade Thomason, Virginia Tech, presented information on methods to estimate nutrient efficiency improvements using irrigation for the panel's consideration.

- Tim Sexton: We had a discussion on other cropping systems as compared to corn – do you think there's a comparison that we could make regarding other crops that are irrigated? In terms of NUE on irrigated versus non-irrigated land?
    - Wade Thomason: You could follow the same thought process if you could get the data for other crops. I don't know of that off the top of my head. My guess would be that those ratios are very similar.
- Mark Dubin: We have the opportunity with the Phase 6 model to apply specific BMPs to specific crop types.
- Tim Sexton: The only research I found on N and WUE was from the College of Texas. I don't know how, based upon one paper, we could assign the difference between them – corn and sorghum are pretty close.
- Mark Dubin: I can't think of any sorghum that's irrigated.
- James Adkins: I think we need to figure out how many acres are worth our times, which is why forage sorghum is almost to the point where dairy and irrigation are almost exclusive of each other. I think we need a threshold to figure out which crops are worth our time.
- Mark Dubin: If forage sorghum is being grown in a dairy operation and is getting fertigation, then it's a totally different wheelhouse.

- Tim Sexton: So we need to figure out if we have an efficiency for corn – and I do have several papers that may back up what Wade has presented, with a range between irrigated and non-irrigated corn.
- James Adkins: Furrow irrigation is such a different system from what we consider, that I wouldn't really suggest we focus too much on that.
- Tim Sexton: I found a number of studies that are between the 15-16% for N uptake efficiency, and all of them had to do with corn or cotton. If I had to summarize any information I may have found, I wouldn't say there's much on P.
- Wade Thomason: Between 10-15,000 acres of irrigated tobacco are reported by USDA. Cotton is about 5-8,000 a year, which is less than 10%.
- Tim Sexton: Wade – what do you think about reduction losses for N in corn for irrigated versus non-irrigated, as a percentage? This would be other than the 15-16%?
    - Mark Dubin: Is there an opportunity where we can exacerbate surface losses due to wet versus dry years?
    - Wade Thomason: I would guess yes – once it gets to nitrate, it will move with water. If we get to the point where irrigation plus a significant amount of precipitation results in a significant movement in the water profile, then yes. But if we get 7 inches of rain, it's going to leach anyway.
    - Mark Dubin: So you're thinking of equating losses to plant production.
- James Adkins: You have to consider that places where there is irrigation are places where there isn't a lot of soil moisture holding capacity – I would think that would reduce the importance of weather events then.
- Mark Dubin: So if we represented this practice as a lower loss factor, then that would probably make more sense in the model.
- Wade Thomason: If I were on this panel, I would suggest you push forward with corn, and reach out to some contacts at Clemson and North Carolina to get some data for other crops at a later time.
- ACTION: Tim Sexton will inquire about the percentage of total acres that are irrigated for other cropping systems to determine whether the panel should look into that research. Specific crops include cotton and tobacco.
- James Adkins suggested that small grains would be the next largest irrigated crop. Wade replied that he didn't think there was much data, but noted that the value of irrigating small grains would be less because of drought.
- Wade Thomason has trails of irrigated/non-irrigated small grains information that would be representative of VA. Corey Whaley has information for wheat.
- ACTION: Wade Thomason will put together tables of data relating to irrigated/non-irrigated small grains data.
- Mark Dubin replied that based upon this data, the rate of N placement was more important than the timing.
- Mark Dubin: Part of this could be represented with a NM BMP – it could be supplemental to that credit with a rate that's at or below the recommended one.
- James Adkins: So we're just concerned with the overall efficiency of irrigating versus non-irrigating; it has nothing to do with timing.

- Wade Thomason noted that he was comfortable with the panel using the information from his reports in their final recommendations.

Discussion of Literature Review – All

- James Adkins asked if similar data to Wade's existed for other states. The data likely doesn't exist for DE.
- Greg McCarty: What about credit for N mining in groundwater? Should that be taken into consideration?
- Matt Johnston recommended against basing a credit solely on yield.
- James Adkins made the point that the entire system was a mass balance, and since there may not be any reduction in nutrients applied, then the entire practice may be a wash in terms of nutrient reductions.
- Group discussed and agreed that a majority of irrigation in the watershed is not for supplemental purposes.
- Matt Johnston: My concern is that increase NUE is outweighed by leaching.
- Tim Sexton: Wade and I have found that for irrigated versus non-irrigated for N removal is between 15-16% that would not be available for leaching.
- Greg McCarty: Leaching on the Eastern Shore is very seasonal. So how much will irrigation actually increase leaching per se?
- ACTION: James Adkins and his colleagues will summarize their irrigation research and provide that information to the panel when it is available.
- Tim Sexton noted that the panel's current direction is to explore u sing 15% Nitrogen uptake efficiency as a recommendation, with no additional information for P.

Wrap-up, assign homework, next steps – Tim Sexton

- Mark Dubin suggested developing a briefing document, to include definitions of the practice, what types of practices, land uses, and nutrients will be considered in the panel recommendations. This document will also include that the panel is focusing on the coastal plain, and that cropping systems require a threshold of irrigated acres in order to be considered by the panel (ex: 10% of total acres).
- ACTION: Mark Dubin, Tim Sexton, and Jeremy Hanson will develop a briefing document, and will circulate it to the panel before the AgWG June quarterly meeting for review.

Participants:

Mark Dubin	UMD
Jeremy Hanson	VT
Tim Sexton	VA DCR
James Adkins	UD
Corey Whaley	UD
Lindsey Gordon	CRC
Greg McCarty	USDA ARS
Wade Thomason	VT
Tyler Monteith	DNREC
Matt Johnston	UMD

03/13/18

Face-to-Face Meeting

DECISION: Panel agreed that there is not sufficient science-based research available to indicate a reduction in nitrogen losses due to irrigation of corn, therefore a nitrogen efficiency value cannot be established at this time. The panel also acknowledges that there are future research needs, citing additional studies and modeling efforts.

- Meeting minutes from the June 6th meeting were approved.
- Tim Sexton reviewed the panel's progress made to date.
- Judy Denver presented on research looking at the effects of irrigation on nitrate transport to groundwater.
    - The Bucks Branch report is approved and in publication, but not available in print yet.
    - James Adkins: Are these 2 sites representative of what we see in a majority of fields?
        - Judy Denver: I don't know about a majority, but I think they are representative.
    - James Adkins: But as you move farther away from a stream, do these conclusions change? In both cases here, we're fairly close to streams.
        - Tim Sexton: Soil characteristics probably don't change much. But delivery time would.
    - Mark Nardi: Areas along the edges of drainage ways have a much more direct connection to the stream.
    - Judy Denver: I don't think you can avoid leaching nutrients even in dry fields, but I think that irrigation can enhance leaching during the season.
    - James Adkins: It's also important to consider the differences between a well-managed irrigated field, and just an irrigated field. From an economics standpoint, it's not always beneficial to micro-manage irrigation, but it is from a nutrient management standpoint.
- Amy Shober presented research looking at how soil moisture conditions affect production yields.
    - Objectives of this work included quantifying the effects of selected fertilizer strategies on WUE and NUE on corn under center pivot irrigation.
    - Conclusion: fertilizer method did not affect irrigated corn yields (fertigation versus side dress).
    - Conclusion: Generally, in-season N applications had no effect on NUE.
    - Conclusion: High irrigation increased N in leachate.
    - Conclusion: Over the long-term, irrigation raises yield and NUE.
    - Not enough samples to draw conclusions on nitrogen amounts in groundwater.

- *Study was not able to make definitive claims about the benefits of irrigation on WUE and NUE (due to adequate-excessive rainfall in study period).
- The panel was asked to select one of 3 decision options:
    - Option 1: There is sufficient science-based research available that indicates a reduction in N losses due to irrigation of corn and an N efficiency value can be established.
    - Option 2: There is enough science-based research available to provide a conservative N efficiency value for irrigated corn at this time, under the condition that the N effectiveness value will be re-evaluated for use in a future watershed model.
    - Option 3: There is not sufficient science-based research available at this time to indicate N loss reductions for corn.
- James Adkins: I don’t think we can reasonably select option 1 or 2. Options 3 looks reasonable
    - Judy Denver: I Agree.
- James Adkins noted that additional information that has not yet been made public exists, and that studies should continue to look at this topic.
- Judy Denver: I think it’s important to note that even if you’re doing a good job managing irrigation, the potential is there to increase leachate. And we want to look at whether better management could alleviate that problem. And we certainly have a better idea of how to monitor more strategically and efficiently to get the data we need.
- Mark Nardi: We really need to do a 5-8 year study on this, and with more people involved to get a better sense of the average condition.
- James Adkins: My reluctance is the intensity level to perform irrigation management correctly rarely gets done on a research farm.
- James Adkins: In regards to concerns from outside parties, as long as we leave the door open for more research, it’s ok to acknowledge that we don’t have enough to draw a conclusion at this time.
- Jeremy Hanson: I anticipate comments coming in that if irrigation is good for yields, then why don’t we have a value for load changes. What would our response be?
    - Judy Denver: Both of the studies we did indicate that might not be the case.
    - Amy Shober: And you can’t decouple the idea of nutrient management and irrigation management. If you’re over irrigating but applying N at an appropriate rate, you’re potentially pushing the N below the root zone and it’s not beneficial to your crop, and vice versa. It’s complicated.
    - Tim Sexton: The interim efficiency was based upon the irrigated having more N removal versus non-irrigated.
    - Jeremy Hanson: But if it’s irrigated, you are planning for that higher yield goal so you’re increasing applications overall.
- James Adkins: I’m not ready to say that the interim practice isn’t valid.

- Judy Denver: Some of the research could be modeling so we could develop scenarios ranging from wet to dry, hot to cold, etc.
- James Adkins: We don't have good numbers on yield response to irrigation rate. There is some deficit irrigation work done in semi-arid regions, but not much in humid regions. So the question mark is how that affects plant uptake and yield.

DECISION: Panel agreed that there is not sufficient science-based research available to indicate a reduction in nitrogen losses due to irrigation of corn, therefore a nitrogen efficiency value cannot be established at this time. The panel also acknowledges that there are future research needs, citing additional studies and modeling efforts.

- Judy Denver: There's also many people that are irrigating a wetland or wetter areas, and that's where you can get huge nutrient transports. So there's another type of management that isn't done, but should be evaluated on these fields. This would be something to consider in the future.
    - James Adkins: So that would be variable rate irrigation (VRI).
- Tim Sexton: There's 2 different things that should be looked at: modeling data that does exist, which would help us look at how we evaluate irrigation under different environmental conditions. We also need to look at additional irrigation in the field. I understand the crop scientist piece, but based on what we've found, the data doesn't prove any of the conclusions that increased protein means less nutrients available for leaching.
- Mark Nardi: I think we need to advocate modeling concurrent with monitoring.
- Mark Dubin: I think it's also important to note that this practice interacts with other practices on the field, not just in a vacuum. Measures like biomass are influenced by factors other than just irrigation.
- Loretta Collins asked the group how they felt about the current interim efficiency value of 4% for nitrogen. Group agreed that the decision whether or not to replace the interim efficiency value was to be made by the Partnership, but that the panel could not define any efficiency value for the practice at this time.

<u>Participants:</u>

Tim Sexton	VA DCR
Loretta Collins	UMD
Lindsey Gordon	CRC
James Adkins	UD
Corey Whaley	UD
Amy Shober	UD
Jeremy Hanson	VT
Greg McCarty	USDA
Tyler Monteith	DE DNREC

Judy Denver	Retired
Mark Nardi	USGS
Mark Dubin	UMD

12/18/18, *Conference call*

Actions & Decisions:

DECISION: The Expert Panel approved the revised draft: "Recommendation of the Best Management Practice Expert Panel for Cropland Irrigation," with inclusion of discussed adjustment/revisions received by close-of-business Dec 21st, 2018.

ACTION: Greg McCarty will provide refined language related to feedback discussed today and agreed upon by the group via *Track Changes* to the Dec 16 draft version (attached).

ACTION: James Adkins will provide a narrative description of typical irrigation management on the Delmarva Peninsula via *Track Changes* to the Dec 16 draft version (attached).

ACTION: Any necessary revisions will be made and distributed to the panel members by close-of-business on Dec 28th, 2018 for review, with anticipated release of the finalized draft "Recommendation of the Best Management Practice Expert Panel for Cropland Irrigation" to the Chesapeake Bay Partnership no later than the second week of January 2019.

DECISION The Expert Panel agreed to a public open meeting to discuss and answer questions regarding the finalized draft "Recommendation of the Best Management Practice Expert Panel for Cropland Irrigation" on Thursday, January 24th, 2019 at the Carvel Center in Georgetown, DE. [More details to come]

Status Update/Review

Tim Sexton, VA DCR, reviewed decisions and issues discussed at the most recent Expert Panel meeting on March 13th, 2018 and established a framework for today's discussion.

- Loretta Collins reviewed the timeline noting that the last draft must be finalized for January 10th distribution to the partnership. There will be a 30-day review and comment period following its release. Then, we will incorporate and respond to comments received.
- Tim Sexton asked how much progress the panel members made on reviewing the latest draft.
    - James Adkins: Looked over the draft and agreed with some of Greg's comments. I do agree that this is not as simple as an independent BMP.
    - Judy Denver reviewed the draft.
    - Amy Shober did not fully review the draft yet.
    - Greg McCarty looked over the draft and commented.
    - Corey Whaley did not fully review the draft yet.

- Mark Dubin: This BMP has crossover with others, and modeling tools allow us to layer BMPs on top of each other until the point of diminishing return is reached. That's why we use percentages reduced as a unit. Sometimes secondary BMPs are represented through other factors in the modeling other than just the practice itself. I verified that the representation of irrigated vs. non-irrigated is operating on annual NASS data. We're representing a single value for % acres irrigated or non-irrigated for counties per year. Many other practices such as nutrient management are better captured now than ever.
    - Tim Sexton: For conservation tillage, the efficiency values were not based solely on uptake, it was based upon reduction within the root zone. For cover crops, the efficiency is based on how much leaching reduction there is in comparison to other crops.
- Greg McCarty: Is N represented on a yield basis? And how is marginal land taken out of production represented?
    - Tim Sexton: I believe Phase 6 is looking at county yield basis. Taking marginal land out of production is accounted for in land use change, similar to land converted from turf grass to forest. In the model there is a substantial load reduction when you have a change like that. That reduction from land use change is not associated with an efficiency value. If you have comments you'd like us to consider, please use track changes in the document so we can incorporate them and try to address those comments with the limited information we have.
    - Mark Dubin: Land-use conversion has a reduction moving from higher to lower productive land that is a part of the Phase 6 model.
- Judy Denver: I don't quite agree with James and Greg. I didn't feel like we were deemphasizing nutrient management. I think what we said is realistic based on current knowledge, there are many caveats for areas where more research is needed. We have significant research that shows irrigation adds nutrients, and does not reduce them. James is right in that some farmers don't use irrigation correctly. I don't have a problem saying we can't give irrigation credit right now.
    - Tim Sexton: I agree with that. We looked at 200+ papers from locations far from the watershed where they manage water much differently. We also looked at research from Judy and James and came to a reasonable conclusion. I'm not sure that the average farmer goes as in-depth as agricultural engineers with plotting irrigation curves. Every state in the bay allows 20% more N application on irrigated lands than non-irrigated lands. I've scratched my head on that guideline. If Greg feels that he should incorporate additional research differently, I'm all for that.
- Judy Denver: If we want to tie this research together, we need to look more into what is getting through the root zone depending on the environmental settings. We need more data to find a reasonable outcome. We couldn't tie agronomy to water quality as well as we had hoped.
    - Greg McCarty: This could perhaps be addressed with good data in watershed models with verification.

- Tim Sexton: One of the biggest problems is farmers refusing to put water meters on wells to see how much water their using. We have to use number estimates that nobody likes when it comes to permitting. We don't have 1% of farmers that can tell us exactly how much water their using. If that's representative of the average farmer, we don't know.
    - James Adkins: I disagree with that in DE and MD. Most farmers have an idea within 10% of how much water to apply to fields. Many are managing water with upper level scheduling. It may just be on a pad of paper, but they are logging it. Maybe there's a strong variation between regions in the watershed.
- Mark Nardi and Alex Soroka: This is a two part problem. Irrigation efficiency and management is one side, and fertilizer application rates to irrigated lands is a predicted % yield. When we have wet years like this one, N moves at lightning speeds through the water table. It's the uncontrollable factors that really will blow the system up.
    - Tim Sexton: We have to look at average numbers for rainfall to avoid high differences between wet and dry years.
    - Amy Shober: We did not have a drought year represented in our research. If we had even one drought year, I think we would have seen a different result.
    - Judy Denver: I agree that you would have since different results.
    - Tim Sexton: Nature is going to be hard to deal with, no matter what we come up with.
- Tim Sexton: Do you feel compelled to write comments on this by Friday?
    - Greg McCarty: I can do that, yes.
- Jeremy Hanson: Would James or another be able to add a paragraph describing a sense of how farmers on Delmarva are managing their irrigation? Even a narrative without data, to make the point you discussed earlier.
    - James Adkins: I know that UD has better technology, there are crop consultants using a DIM system, there are a select bunch using soil moisture, and a good amount of people using pen and paper.
    - Tim Sexton: A paragraph on management systems would be great as well.
    - James Adkins: I can describe popular methods in a narrative way, although I can't supply percent usage to methods.
- Tim Sexton: Does anyone have an issue with the outcome of the report with no efficiency value?
    - Jeremy Hanson: I keep hearing that we're not defining an efficiency, but we're not saying there's no benefit. There may be benefits outside of the irrigation BMP that we can't quantify and we need to emphasize those potential benefits from other perspectives, in terms of water quality.
- Jeremy Hanson: Are there any other issues to raise from the group now? After this last commenting and incorporating, I want to make sure everyone is comfortable.
- Tim Sexton: So we will get comments by Friday, we'll incorporate, and send back out to everyone. Then it will be finalized and released in the beginning of January.
    - Jeremy Hanson: It's more of a fatal flaw review before it's released, this will be last time to sign off before it goes out to the partnership.

- Jeremy Hanson: I will read down the list of panelists for official approval by consensus.
    - Mark Nardi: As long as full panel approves after these comments, I agree.
    - Judy Denver: I agree
    - James Adkins: I agree
    - Greg McCarty: Yes
    - Corey Whaley: Yes
    - Tim Sexton: Yes
    - Amy Shober: I'm good with it

Action: Greg McCarty will provide refined language related to feedback discussed today and agreed upon by the group via *Track Changes* to the Dec 16 draft version (attached).

Action: James Adkins will provide a narrative description of typical irrigation management on the Delmarva Peninsula via *Track Changes* to the Dec 16 draft version (attached).

Decision: The Expert Panel approved the revised draft: "Recommendation of the Best Management Practice Expert Panel for Cropland Irrigation," with inclusion of discussed adjustment/revisions received by close-of-business Dec 21st, 2018.

Action: Any necessary revisions will be made and distributed to the panel members by close-of-business on Dec 28th, 2018 for review, with anticipated release of the finalized draft "Recommendation of the Best Management Practice Expert Panel for Cropland Irrigation" to the Chesapeake Bay Partnership no later than the second week of January 2019.

Next Steps

States are in the final phase of drafting their Phase III Watershed Implementations Plans. The recommendations of the current Expert Panel on Cropland Irrigation will have implications for this process. It is strongly encouraged that the current panel release its recommendations to the Chesapeake Bay Program partnership in week #1 or week #2 of January 2019. A public stakeholder meeting (with webcast) is tentatively scheduled for Thursday, January 24th for the panel to present and discuss its recommendations in detail with interested parties. Specific times and logistics TBD for that meeting and webcast.

- Jeremy Hanson: We will be hosting a webinar to go over the results and outcomes of this expert panel in detail.
    - Loretta Collins: We are in the scheduling process with a potential date of January 24, 2019 and the primary presenters may be Judy and Amy with James.
    - Judy Denver: I won't be available, but Mark Nardi may be able to stand in.
    - Mark Nardi: Yes, I've got that on my radar.
    - Tim Sexton: I'd prefer the morning if possible.
    - James Adkins noted that room 3 at the Carvel Center is reserved for January 24.

Decision: The Expert Panel agreed to a public open meeting to discuss and answer questions regarding the finalized draft "Recommendation of the Best Management Practice Expert Panel for Cropland Irrigation" on Thursday, January 24th, 2019 at the Carvel Center in Georgetown, DE.

Participants:

Tim Sexton	VA DCR
Loretta Collins	UMD
Allie Wagner	CRC
James Adkins	UD
Corey Whaley	UD
Amy Shober	UD
Jeremy Hanson	VT
Greg McCarty	USDA
Judy Denver	Retired
Mark Nardi	USGS
Mark Dubin	UMD
Alex Soroka	USGS

Appendix D: Summary of CBP partnership feedback received and responses

[This appendix will be compiled after the report is released to partnership. Will be shared/distributed as a separate document during the partnership review process and added here following partnership approval of report.]