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RESEARCH INTRODUCTION

Quantifying the impacts of the Conservation Effects Assessment Project watershed assessments: The first fifteen years

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The United States Department of Agriculture (USDA) spends about US$6 billion each year on agricultural conservation programs to help producers and landowners implement conservation practices (CPs) and systems on their land. In 2003, the USDA Natural Resources Conservation Service (NRCS) entered into partnership with USDA Agricultural Research Service (ARS), USDA National Institute of Food and Agriculture (NIFA), other federal agencies, and many external partners to create the Conservation Effects Assessment Project (CEAP). The goal of CEAP is to quantify the environmental effects of CPs and programs and develop the science base for managing the agricultural landscape for environmental quality (Mausbach and Dedrick 2004; Duriancik et al. 2008). Conservation effects are assessed at national, regional, and watershed scales on cropland, grazing lands, wetlands, and for wildlife. As part of these efforts, CEAP initiated the Watershed Assessment Studies (WAS) component in 2003 to provide in-depth analyses, quantify the effects of CPs at the watershed scale, and enhance our understanding of the effects of conservation in the biophysical setting of a watershed. Fourteen ARS Benchmark watersheds were selected with soil and water quality and water conservation as primary resource concerns on rain-fed agricultural land and to provide information needed to verify the accuracy of models used in the national assessment (figure 1).

Since the inception of CEAP, accomplishments and findings have been published (Duriancik et al. 2008; Osmond 2010; Osmond et al. 2012; Tomer and Locke 2011; Arnold et al. 2014; Tomer et al. 2014). By the end of the first five years, CEAP had defined and initiated a research and assessment plan for estimating the effects and benefits of CPs and programs (Maresch et al. 2008; Duriancik et al. 2008). Duriancik et al. (2008) summarizes specific accomplishments during those first years, including the completion of a synthesis of the scientific literature on the effects of CPs on cropland by ARS and the Soil and Water Conservation Society (Richardson et al. 2008). A major accomplishment during the first five years was the development of the Sustaining the Earth's Watersheds–Agricultural Research Data System (STEWARDS) database (Sadler et al. 2008; Steiner et al. 2008) that documents and provides access to data needed for CP studies and improvement, calibration, and validation of hydrologic models used to assess the effects of CPs. In 2010, a *Journal of Soil and Water Conservation* (JSWC) special section of papers presented an overview of research results ranging from modeling to paired watershed comparisons in many of the 13 NIFA–CEAP watersheds, as well as the syntheses of this work (Osmond 2010). In 2012, Osmond et al. (2012) synthesized the findings of the 13 NIFA–CEAP projects and presented lessons learned and factors that affected implementation of CPs to mitigate against nutrients. Tomer and Locke (2011) reviewed CEAP WAS field research and modeling studies that quantified the impacts of CPs on water quality. The results showed that while CPs improved water quality in general, water quality problems continued at the larger scales due to lack of targeting, channel bank erosion, combined effects related to time lags, historical legacies, climate change, and management practices focusing on single contaminants (Tomer and Locke 2011). Based on these lessons, Tomer and Locke (2011) recommended developing understanding of linkages between water quality, CPs, and indicators of ecological integrity in order to realize the full range of ecosystem services from the agricultural landscapes and associated aquatic environments. Finally, in 2014, a JSWC special section of papers presented an overview of research in 14 ARS Benchmark watersheds during the first decade of CEAP with papers describing multiwatershed syntheses (Tomer et al. 2014), soil health assessment (Karlen et al. 2014), fine sediment sources (Wilson et al. 2014), and climate change impacts on conservation effects (Garbrecht et al. 2014a). After the first decade of CEAP, results indicated increased adoption of minimum soil disturbance technologies and winter cover crops, and a renewed emphasis on riparian corridors.

This article builds on these previous efforts and introduces research papers and a feature article in a special issue that focuses on the findings of the ARS Benchmark and other CEAP watersheds during the first 15 years of CEAP watershed assessments. This article also presents a brief synthesis of CEAP research impacts, mainly in ARS Benchmark and NIFA–CEAP watersheds, and highlights some key CEAP-developed technologies. The paper will summarize measured or modeled effects of CPs, the scales at which the effects have been detected, and how these CEAP findings have served as a feedback mechanism to improve agricultural conservation programs and assessment approaches. Finally, a brief description of future CEAP direction is provided.

SUMMARY OF PAPERS IN THE SPECIAL ISSUE

There are 15 research articles in this special issue, 14 of which report stud-

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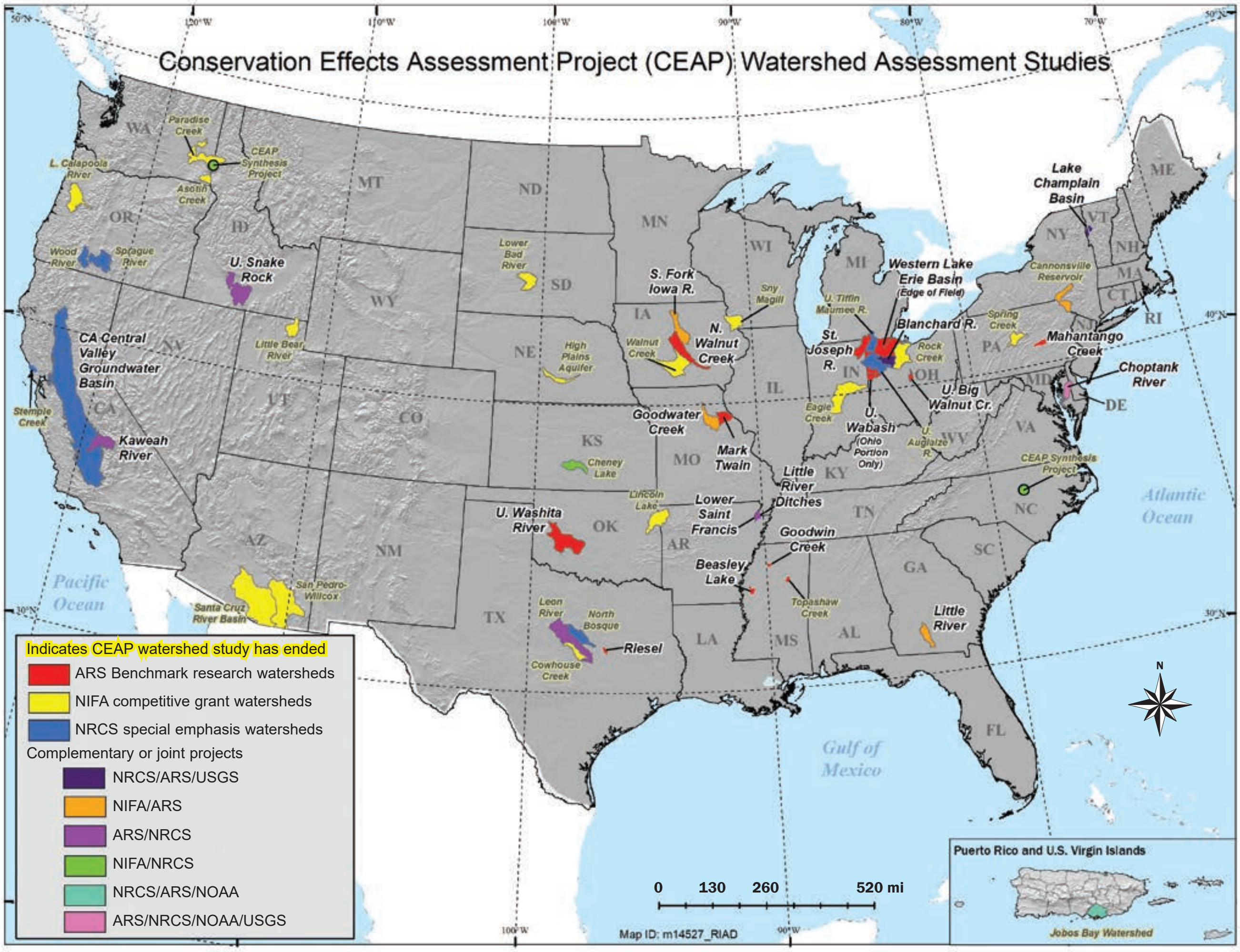
Figure 1

Conservation Effects Assessment Project (CEAP) Watershed Assessment Studies sites.



ies carried out at CEAP watershed sites. The watersheds' locations, drainage areas, and major land uses are presented in table 1 while average precipitation, major water quality concerns, and implemented CPs are presented in table 2. Most of the research studies were performed at field scale (Baffaut et al. 2020a; Bjorneberg et al. 2020; Bosch et al. 2020a; Pisani et al. 2020; Reba et al. 2020; Smith et al. 2020; Veith et al. 2020; Williams et al. 2020). Two studies were carried out at multiple scales (Bosch et al. 2020b; Locke et al. 2020) while the rest were performed at watershed scale (Goodrich et al. 2020; Hively et al. 2020; Moorman et al. 2020; Moriasi et al. 2020). The issue also includes a feature article in which Sadler et al. (2020) examine the impact the STEWARDS database system has had on conservation policy, on scientific research, and on education. Ranjan et al. (2020a) report results from an online survey of conservation agency staff working in counties where CEAP sites are located to identify the education and training needs of decision support tool (DST) users and nonusers.

SUMMARY OF MEASURED AND MODELED EFFECTS OF CONSERVATION PRACTICES IN CONSERVATION EFFECTS ASSESSMENT PROJECT WATERSHEDS

Since the inception of CEAP, many studies have been conducted to quantify the effects of CPs on soil and water resources. In this article we present measured and modeled effects of CPs on water quality reported in 119 research studies carried out in ARS Benchmark and NIFA–CEAP watersheds between 2003 and 2020 to highlight part of CEAP impacts (supplemental tables 1 to 3, available at https://www.jswconline.org/content/75/3/57A). In this article, study sites with drainage areas of up to 16 ha (40 ac), those ranging from 17 to 16,187 ha (42 to 39,999 ac), and those with drainage areas greater than 16,187 ha are categorized as plot, field, or edge-of-field (supplementary table 1); subwatershed (supplementary table 2); and watershed (supplementary table 3), respectively. Key research findings at ARS Benchmark and NIFA–CEAP watersheds, including some from these tables, are presented below. The key ARS Benchmark findings are presented at the combined plot, field, and edge-of-field scales and the watershed scale. The subwatershed scale

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Table 1

Summary description of location, areal size, and major land uses for watersheds in this collection.

Watershed	Location	Drainage area (km^2)	Major land uses	Reference
Beasley Lake	Mississippi	6.25	Row crops: soybeans, corn, cotton, sorghum, winter wheat	Locke et al. (2020)
Cienega Creek watershed (subwatershed)	Arizona	1,570 (513)	Grazingland/rangeland	Goodrich et al. (2020)
Tuckahoe Creek watershed (Choptank River Basin)	Maryland	400	Agricultural cropland, forest	Hively et al. (2020)
Goodwater Creek Experimental Watershed	Missouri	72 to 1,191	Agricultural cropland, livestock production	Baffaut et al. (2020)
Little River Experimental Watershed	Georgia	334	Mixed land use watershed that contains row crop agriculture, pasture and forage, upland forest, riparian forest, and wetlands	Bosch et al. (2020a; 2020b)
Lower Mississippi River Basin	Arkansas	—	Agricultural cropland: cotton, rice, soybean	Reba et al. (2020)
Mahantango Creek watershed (WE-38 subcatchment)	Pennsylvania	420 (7.3)	Agricultural cropland and forest, nonintensive beef, dairy, and swine farming plus supportive forage cropping	Veith et al. (2020)
Riesel	Texas	3.4	Cropland and grassland	Smith et al. (2020)
St. Joseph River watershed (Cedar Creek watershed)	Indiana	2,810 (710)	Agricultural cropland	Williams et al. (2020)
South Fork of the Iowa River watershed	Iowa	797	Agricultural cropland: mainly corn and soybeans	Moorman et al. (2020)
Upper Washita River	Oklahoma	610 to 1,802	Cropland mainly winter wheat and grassland/rangeland	Moriasi et al. (2020)
Upper Snake Rock watershed (Twin Falls Canal Company)	Idaho	6,300 (820)	Rangeland and forestland, and irrigated agricultural cropland	Bjorneberg et al. (2020)

studies presented in supplementary table 2 overlap between the two categories discussed. Thirteen of 21 ARS Benchmark CEAP watersheds demonstrated measureable water quality improvements at subwatershed or watershed scales in at least one constituent monitored.

Key Research Findings and Outcomes of Agricultural Research Service Benchmark Watershed Assessment Studies: Effects of Specific Management Practices at Plot, Field, and Edge-of-Field Scales. Practices that were assessed at the plot, field, and edge-of-field scales included drainage management, conservation tillage, cover crops, buffers, irrigation water management, and Conservation Reserve Program (CRP). Results from these studies included reduction of sediment and nutrient in runoff loss, improvement in soil quality, and improved conditions for processes that mitigate contaminant impacts on the environment. In the Mississippi Delta region, several CPs within an agricultural watershed mitigated loss of contaminants in surface runoff. The CRP reduced runoff sediment by >90% and total nitrogen (TN) and total phosphorus (TP) by 50% to 100%. Mixed vegetation buffers reduced runoff sediment by 34% to 70%, but TN and TP reductions varied greatly (Cullum et al. 2010; Locke et al. 2020). Integrating vegetated drainage ditches and sediment retention ponds reduced runoff sediment by 69% and TN and TP by 30% to 50% (Lizotte and Locke 2018). A three-stage vegetated constructed wetland reduced runoff atrazine by 70% to 89%, fluometuron by 58% to 81%, and diazinon by >95% (Locke et al. 2011; Moore et al. 2007).

In rotation systems with cotton (*Gossypium hirsutum* L.) and peanut (*Arachis hypogaea* L.) near Tifton, Georgia, winter cover crops with strip-till increased soil resilience by reducing surface runoff and sediment loss (Bosch et al. 2015; Endale et al. 2014). Twenty percent of rain on conventional till was lost as surface runoff compared with 12% from strip-till. Greater infiltration in strip-till increased subsurface flow (20% versus 10%). Sediment loss exceeded soil tolerance threshold (2,200 kg ha^{-1} y^{-1} [1,963 lb ac^{-1} yr^{-1}]) in 3 of 10 years in conventional till but never in strip-till. One percent of rainfall events during the study period had >5 cm (2 in) and accounted for 45% of runoff. In row crop systems, cover crops were beneficial in mitigating runoff losses in the Little River Ditches watershed, Arkansas, reducing suspended sediment by 39%, and nitrate-N (NO_3-N) by 86%. Phosphate-P (PO_4-P) was reduced 53%, with higher losses during the fallow season for both cover and no cover crop (Aryal et al. 2018). No-till on claypan soils in Missouri did not reduce runoff volume and greatly increased atrazine losses in runoff (Lerch et al. 2013). Using a rotary harrow incorporated herbicide without destroying residues; however, it reduced edge-of-field atrazine losses from fallow plots by 50% compared to no-till losses. Therefore, incorporation with moderate tillage may be needed in some cases to mitigate surface runoff loss of chemicals (Lerch et al. 2013). In another study,

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Table 2

Climate, and major soil and water quality issues, and applied conservation practices for watersheds in this collection.

Watershed	Average annual precipitation (mm y^{-1})/ temperature (°C)	Major water quality issues	Applied conservation practices	Reference
Beasley Lake	1,410/18.0	Soil erosion, water quality (including hypoxia)	CRP (NRCS Practice 612), bird habitat buffers (CP-33, NRCS Practice 601)	Locke et al. (2020)
Cienega Creek watershed (subwatershed)	448/16.2	Soil erosion, sediment load	Prescribed grazing, pumping plants, and brush management	Goodrich et al. (2020)
Tuckahoe Creek watershed (Choptank River Basin)	1,100/12.8	Sediment and nutrient loading	Winter cover crops	Hively et al. (2020)
Goodwater Creek Experimental Watershed	1,022/12.2	Sediments, nutrients, pesticides, pathogens	Precision agriculture systems that include no-till, cover crops, atrazine split-applications based on weed pressure, variable rates of nitrogen, variable rates of fall-applied phosphorus, filter strip	Baffaut et al. (2020)
Little River Experimental Watershed	1,200/18.7	Water quality: nitrogen, phosphorus, chloride	Natural riparian forest buffers; nutrient management; pest management; grassed waterways; contour farming; seasonal residue management; terraces	Bosch et al. (2020b)
Lower Mississippi River Basin	1,277/14.4	Erosion, nutrients including hypoxia	Winter cover crops and winter shallow water storage	Reba et al. (2020)
Mahantango Creek watershed (WE-38 subcatchment)	1,080/10.0	Nutrient legacy	Contour and strip crop farming	Veith et al. (2020)
Riesel	885/19.6	Sediment and nutrient loadings	Terraces, grassed waterways, nutrient management	Smith et al. (2020)
St. Joseph River Basin (Cedar Creek watershed)		Sediments, nutrients (phosphorus, nitrate, ammonium), and pesticides	Reduced tillage, no-till, drainage water management, conservation crop rotation	Williams et al. (2020)
South Fork of the Iowa River watershed	781/—	Nitrate, phosphorus, sediment, and pathogens	Contour buffers, terraces, grassed waterways, water and sediment control basins and ponds	Moorman et al. (2020)
Upper Washita River Basin	757/15.0	Soil erosion, sedimentation and eutrophication due to phosphorus	Brush control, combined streambank stabilization practices, riparian and filter strip buffer practices	Moriasi et al. (2020)
Upper Snake Rock	250/—	Sediments, nutrients, temperature	Sprinkler irrigation system, irrigation water management, anionic polyacrylamide (PAM) erosion control, nutrient management, sediment basin, and water utilization	Bjorneberg et al. (2020)

Lerch et al. (2015) attributed declines in NO_3-N and PO_4-P transport to decreased winter wheat (*Triticum asestivum* L.) and increased corn (*Zea mays* L.) production in a Missouri watershed where fertilizer application was shifted from fall to spring and incorporation management was practiced. No-till, cover crops, and a three-year rotation or a precision management plan reduced soil loss by 85%, mitigated the negative effects of no-till alone on dissolved constituents, and maintained crop yields from a minimum-till system (Baffaut et al. 2020a). In addition, no-till with cover crops and a three-year rotation increased soil organic carbon (C) in the topsoil by 32% relative to no-till alone. No-till alone increased soil organic C in the topsoil by 22% relative to mulch till (Baffaut et al. 2020a). Baffaut et al. (2015) found that atrazine incorporation by field cultivation on corn and sorghum (*Sorghum bicolor* [L.] Moench) fields resulted in a 17% simulated reduction in average annual atrazine stream loads without a significant increase in sediment stream loads. Annual load reductions ranged from 9% to 25%, and edge-of-field (hydrologic response unit) losses could be reduced by 27% on average.

Conservation practices that target flow processes and routing have proven very effective for nutrient reduction. In Iowa, diversion of subsurface tile discharge from field to flow through a 60 m (197 ft) wide riparian buffer treated 35% to 64% of drainage over five years and removed 50 to

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250 kg N y^{-1} (110 to 551 lb N yr^{-1}) via denitrification (Jaynes and Isenhart 2014). Based on estimates of mass N removal and costs, this technology is competitive with cover crops and woodchip bioreactors. In Ohio, increasing retention time of discharge by controlling drainage in ditches enhanced processing and reduced nutrient loss by reducing discharge (Williams et al. 2015). Specifically, N and P loading were reduced by 8% to 44% and 40% to 68%, respectively. Converting irrigation management systems from furrow to sprinkler improved soil quality in Idaho (Ippolito et al. 2018). Soil quality parameters were compared between upslope inflow during furrow irrigation and downslope under sprinkler irrigation. Sprinkler irrigation eliminated continual erosion, which usually occurs in furrow-irrigated fields, from the inflow end to the bottom end, improving soil quality. Similarly, Williams et al. (2018) demonstrated that injection or tillage incorporation of fertilizer in tile-drained fields reduced dissolved reactive P loss by 66% compared to broadcast application.

Poultry litter rates of 4.5 t ha^{-1} (2 tn ac^{-1}) are considered acceptable in terms of water quality for cultivated land in the Blackland Prairie region of Texas (Harmel et al. 2009, 2011). Litter application on cultivated land increased runoff P by 0.5 to 3 mg L^{-1} but decreased runoff N by 10 to 60 mg L^{-1} (particularly extreme high concentrations). Litter applications of 6.7 t ha^{-1} (3 tn ac^{-1}) and greater caused P runoff of double the targeted 1 mg L^{-1} maximum. On pasture, litter application increased both P and N in runoff (Harmel et al. 2009). In another study, runoff N and P concentrations generally decreased (72% of downstream P was from the first year, most from the first two storms) within the year as time since fertilizer application increased, but few long-term trends in N and P runoff occurred in spite of soil P buildup due to the dynamic interaction between transport and source factors (Harmel et al. 2004). Litter application had no effect on *E. coli* in surface waters. *E. coli* count was highest in grazed pastures due to cattle. Native prairie had higher *E. coli* in runoff compared to cultivated lands due to wildlife (Harmel et al. 2013; Gregory et al. 2019). Poultry litter applied at 4.5 or 6.7 t ha^{-1} (2 or 3 tn ac^{-1}) resulted in the most average annual profit, US$138 ha^{-1} (US$56 ac^{-1}), even greater than commercial fertilizer. However, litter rates above 6.7 t ha^{-1} (3 tn ac^{-1}) resulted in diminished return on investment, US$62 ha^{-1} (US$25 ac^{-1}) or less, or even a net loss (Harmel et al. 2008).

In Mahantango watershed in Pennsylvania, manure applied to no-till soil exacerbated dissolved P losses in runoff, further increasing losses 3- to 28-fold above background levels from critical source areas (Kleinman et al. 2009). In sloping landscapes, saturation excess runoff processes tended to override management factors in the mobilization and transport of P from agricultural fields to headwater streams (Buda et al. 2009a, 2009b). Applying gypsum to soils with high P levels improves infiltration by up to 30% and decreases runoff by up to 30% (Endale et al. 2013). It also decreased P solubility by up to 60% and reduced dissolved P losses in runoff by up to 60% (Torbert and Watts 2013).

Results from Indiana's St. Joseph watershed indicated that replacing tile risers with blind inlets reduced sediment and total P losses by 78% to 79% (Smith and Livingston 2013), atrazine by 57%, 2,4-D by 58%, metolachlor by 53%, and glyphosate by 11% compared to tile risers (Gonzalez et al. 2016). Blind inlets did not influence the frequency of flow, but may increase or decrease the length of ponding in fields compared to a tile riser (Williams et al. 2020). A P removal structure utilizing steel slag as the P sorption material decreased soluble P load in surface and subsurface flow by 37% to 55% (Penn et al. 2020). As observed at other CEAP sites, soluble P and N losses (Smith et al. 2007) as well as atrazine and glyphosate loads (Warnemuende et al. 2007) were greater from no-till plots compared to tilled plots.

Key Research Findings and Outcomes at Agricultural Research Service Benchmark Watershed Assessment Studies: Effects of Integrated Management Practices at the Watershed Scale. Numerous studies have evaluated effects of CPs on sediment, nutrient, and pesticide loadings at watershed scale. Francesconi et al. (2015) demonstrated that cover crops and forage were most successful at reducing sediment and nutrient loss (56% to 88% and 28% to 91%, respectively) in an Ohio watershed and that, compared to single practices, two and three practices resulted in greater sediment and nutrient reductions. Modeled analysis in the Mississippi Delta depicting crop conversion from cotton to corn/soybean (*Glycine max* [L.] Merr.), but with increased irrigation activities, indicated a reduction in average annual sediment loads of 0.90 Mg ha^{-1} (0.40 tn ac^{-1}) for clay and of 0.03 Mg ha^{-1} (0.01 tn ac^{-1}) for silt (Momm et al. 2019b). Another model simulation in Beasley Lake, Mississippi, watershed showed that converting all cropland to no-till soybeans could reduce sediment load by 77%, whereas no-till cotton could reduce it by 64% (Yuan et al. 2008). Lizotte et al. (2010) reported that installation of slotted pipes, slotted board risers, vegetated buffers, reduced tillage, and CRP set-aside reduced invertebrate pesticide bioaccumulation by >50% and was accompanied by a more than two-fold increase in and invertebrate growth in Beasley Lake watershed. In the same watershed, lake total solids were reduced by >88%; P, by 95%; N, by 58%; and following restocking in 1996 to 1997, fishery recovery was slow until after 2000 when water quality improved and peaked between 2006 and 2009 (Knight and Cullum 2014). Integrated watershed-wide implementation of multiple best management practices reduced lake spring total suspended sediment by >60% and increased lake spring water clarity by >100% (Lizotte et al. 2014). In an analysis of three Mississippi watersheds from 2000 to 2003, including Beasley Lake, Zablotowicz et al. (2010) used canonical analysis to assess parameters that indicated the highest suspended solids, dissolved organic C, enzyme activities, algae, and bacteria in the watershed with the least implementation of CPs. In-stream grade stabilization structures in Goodwin Creek Experimental Watershed, Mississippi, reduced mean sediment yield 7% to 50%, and the combined effect of grade stabilization structures and in-field CPs has the potential for a 78% reduction in sediment yield at the watershed outlet (Kuhnle et al. 2008). However, practices targeting surface erosion must be considered in combination with other system sediment sources

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as Tomer et al. (2010) demonstrated that sediment loss from surface runoff, which could be targeted by CPs, was small (22%) compared to channel erosion processes and that similar patterns held for P and E. coli stream loads in Iowa.

Over the years, the USDA NRCS has implemented multiple CPs, such as conservation covers, contour farming, cover crops, grade stabilization structures, grassed waterways, nutrient management, residue and tillage management, terrace and brush management, and fencing, in Oklahoma watersheds. Modeling results show these multiple CPs reduced soil erosion rates of the 16 km^2 (6 mi^2) Bull Creek subwatershed by 77% compared with rates prior to implementation of the CPs (Zhang et al. 2016). Garbrecht and Starks (2009) found that average annual suspended sediment yield at the Oklahoma's Fort Cobb Reservoir Experimental watershed outlet was reduced from 760 to 108 t y^{-1} km^{-2} (2,170 to 308 tn yr^{-1} mi^{-2}) for the pre- and postconservation period, respectively, an 86% reduction. These findings are in agreement with those of a bathymetric survey of 12 flood control reservoirs in the Oklahoma's Little Washita River Experimental Watershed, which showed that reservoir lifespans ranged from 45 to 118 years, with 11 of 12 reservoirs having a lifespan greater than the design period of 50 years (Moriasi et al. 2018). The higher projected lifespans could be attributed to multiple CPs implemented over the years through the NRCS programs. Another modeling study showed that that application of Bermuda (*Cynodon dactylon*) filter strip along cropland borders reduced the amount of eroded overland sediment delivered into the stream channel network by 72% (Moriasi et al. 2011b). Application of riparian forest buffer and combined riparian forest buffer and Bermuda filter strips reduced suspended sediment at the subwatershed outlet by 68% and 73%, respectively. Soil and Water Assessment Tool (SWAT) simulation results in Oklahoma's North Canadian River basin documenting that removal of the current 8% red cedar (*Juniperus virginiana* L.) encroachment would increase water availability to Oklahoma City by 5% of current water demand (Starks and Moriasi 2017). Annualized Agricultural Non-Point Source Pollutant Model (AnnAGNPS) simulations demonstrated that climate change will have an overall effect of increasing sediment and nutrient loads, but that cover crops, double cropping, and no-tillage practices can mitigate these impacts below historical levels (Yasarer et al. 2017).

Several CEAP studies have also studied the impacts of CPs on nutrients. In general, strip-till is an effective method for reducing surface runoff and associated erosion in the Coastal Plain region of Georgia (Endale et al. 2014). However, measurement of both surface and subsurface ammonium (NH_4^+) and NO_3-N loads demonstrated that the combined total five-year N loadings from the strip-till treatment (surface = 5.6 [5.0]; subsurface = 99 [88.3]; total = 104.6 [93.3] kg ha^{-1} [lb ac^{-1}]) were almost twice those of the conventional tillage (surface = 8.3 [7.4]; subsurface = 45 [40.1]; total = 53.3 [47.5] kg ha^{-1} [lb ac^{-1}]) (Bosch et al. 2015). Thus, CP planning for the region may need to include consideration of multiple practices targeted and placed to address specific outcomes. Lerch et al. (2015) attributed declines in NO_3-N and PO_4-P transport to decreased winter wheat and increased corn production in a Missouri watershed where fertilizer application was shifted from fall to spring and incorporation management was practiced. Singer et al. (2011) demonstrated that annual cover crop reduced annual N loads to tile drains by 20% to 28% in the 2-year rotation and 19% to 22% in the 3-year rotation at the watershed subbasin scale over a 25-year period.

Williams et al. (2015) demonstrated that drainage water management in Ohio watersheds decreased annual tile discharge 8% to 34%, NO_3-N loads (−8% to 44%), and dissolved P loads (40 to 68%); and later showed (Williams et al. 2018) that dissolved P concentration in tile water was reduced 66% and 75%, respectively, when fertilizer was injected or tilled into Ohio soils. In addition, Moorman et al. (2015) used load duration curves from three different Iowa watersheds to demonstrate that installing wood chip bioreactors on ≤0.27% of watershed (cumulative volumes sufficient to achieve a hydraulic residence time of 0.5 days) could result in a total annual NO_3-N load reduction of 20% to 30%. Lizotte et al. (2017) monitored the influence of multiple integrated CPs on oxbow lake nutrient concentrations in an intensive row crop agricultural 625 ha (1,544 ac) watershed between 1996 and 2009 and observed that reductions in the TP concentrations were associated with vegetative buffers and rainfall. In contrast, Feyereisen et al. (2008) were unable to document a clear linkage between a significant downward trend for annual mean total P and seasonal increases in NO_3-N within a Georgia watershed where in-field CPs had been implemented on 11% of watershed area from 1980 to 2003.

SWAT simulation results indicated that riparian buffers may reduce annual total organic N loads in the Chesapeake Bay watershed 17% to 45% depending on the extent of riparian buffer implementation (Lee et al. 2020). The Root Zone Water Quality Model simulations for the tile-drained portion of the corn–soybean and continuous corn cropping systems in the five-state Corn Belt area under the assumed management systems and uniform soil properties, showed that cover crops have the potential to reduce NO_3^- loadings to the Mississippi River by approximately 20% (Kladivko et al. 2014). In addition, winter rye (*Secale cereale* L.) cover cropping on drained fields at 41 sites across the Midwest from 1961 to 2005 could have reduced the average annual N loss by 11.7 to 31.8 kg ha^{-1} (Malone et al. 2014).

Key Research Findings and Outcomes at National Institute of Food and Agriculture–Conservation Effects Assessment Project Watersheds. Of the 13 NIFA–CEAP projects, 12 were surface water projects with defined watersheds, while one focused on groundwater (Osmond 2010; Osmond et al. 2012). Six of the 12 watershed projects were able to demonstrate measureable water quality improvements at small watershed scales. All had significant implementation of effective CPs for constituents of concern and had appropriate water quality monitoring designs and duration to help detect effects (Osmond et al. 2012). Three employed long-term monitoring (>20 years; Paradise Creek, Idaho; Phase III Management Area in the Central Platte Natural Resources District, Nebraska; and Rock Creek,

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Ohio), and three used paired watershed designs (Walnut and Squaw Creeks, Iowa; Cannonsville Reservoir, New York; and Spring Creek, Pennsylvania). One project (Rock Creek, Ohio) later saw a reversal of water quality benefits as soluble reactive P increased, probably due to greater and more intense rainfall, additional drain tiles, and surface-applied fertilizer without incorporation due to no-till production (Meals et al. 2012a). Some NIFA–CEAP projects that used long-term monitoring and significant conservation were unable to demonstrate water quality change because nutrient concentrations were too low. Other reasons for lack of progress in reducing pollutants were due to insufficient water quality monitoring designs, mismatch between pollutant of concern and CP implementation, lack of CP targeting, and lag time issues.

OTHER IMPACTS OF THE CONSERVATION EFFECTS ASSESSMENT PROJECT

Better Watershed and Ecological Assessments. The research that was established to quantify effects of conservation include basic research that has advanced understanding of flow paths and hydrologic processes at multiple scales. Research in Pennsylvania advanced our understanding of critical source areas within watersheds where conservation and management practices may have larger impacts than in other portions of the watersheds (Buda et al. 2009b) building off earlier work by Gburek et al. (2002). An early multiwatershed research effort found that half or more of suspended sediments in streams resulted from channel or concentrated flow processes rather than upland erosion (Wilson et al. 2008), a finding that was confirmed by more detailed studies in Oklahoma (Zhang et al. 2015, 2016). Hively et al. (2011) related nutrient and chemical fate to landscape features in subwatersheds of the Choptank watershed. Similarly, Franklin et al. (2013) identified different geomorphic features related to nutrient distributions within Oklahoma watersheds under wet and dry hydrologic regimes. Including farm ponds in a watershed simulation in Goodwin Creek Experimental Watershed, Mississippi, improved the overall accuracy of predicted streamflow due to decreased average streamflow and peak flow rates caused by ponds capturing runoff within the landscape (Yasarer et al. 2018). Beck et al. (2019) quantified changes in floodplain connectivity with stream channel evolution as it relates to nutrient and sediment budgets. Williamson et al. (2019) delineated tile-drained networks in order to better understand flow paths that are critical to water quantity and quality in the Upper Midwest. These and other watershed and ecological assessments did not necessarily quantify conservation effects, but provided critical insight of flow paths and processes that is essential to guide timing and place of measurement sites in watersheds. Because climate is a key driver in determining flow paths, different hydrologic processes are important under wetter and drier periods for a given watershed as quantified by Garbrecht et al. (2014a, 2014b, 2016).

Better Tools for Planning, Mapping, and Monitoring Conservation. As CEAP researchers tackled complex problems in complex landscapes, new methods and tools were required to improve the quality, affordability, and efficiency of collecting and presenting data and information. McCarty et al. (2014) identified a metolachlor metabolite (MESA) that was applied to reveal agricultural NO_3-N fate and transport in the Choptank River watershed. Zhang et al. (2015) and Gellis et al. (2018) applied isotopic analysis to identify sources of sediments within complex landscapes. Such knowledge allows more effective targeting of conservation to reduce the amount of erosion and associated contaminant movement within the watershed. Such methods can also provide insight into C redistribution within a landscape (Ritchie and McCarty 2003). For data sparse watersheds, Moriasi et al. (2011b) demonstrated that bathymetric surveys of impoundments along with sediment coring could provide knowledge about average annual sediment delivery from a watershed from the time of impoundment to the time of sampling, thus providing useful model calibration and validation data.

Several scientists have developed remote sensing technologies to characterize soil properties such as fertility-related properties (McCarty and Reeves 2006); soil health indicators (Fortuna et al. 2019); and salinity, clay content, and bulk density (Sudduth et al. 2013). Additionally, studies in several of the watersheds have been used to evaluate soil health indicators across a wide range of conservation management systems (Karlen et al. 2014; Lohani et al. 2019; Zobeck et al. 2015). Cost-effective monitoring of soil properties' responses to management is critical because of the key role soils play in partitioning of precipitation into runoff, infiltration, and percolation. In tile-drained areas, older tile drainage networks are often not well mapped. Allred et al. (2018) developed methods to identify patterns of tile drains using ground penetrating radar, or alternatively using visible-color, multispectral, and thermal infrared imagery deployed on unmanned aerial vehicles (Allred et al. 2020). In addition, some CEAP studies led to the development of remote sensing indices to identify in-field tillage practices and quantify winter cover residue for compliance with conservation payments (Hively et al. 2018; Sullivan et al. 2008). For example, Settimi et al. (2010) compared actual placement of CPs in the landscape to relative risk vulnerability and found that 65% of fields identified as at risk for surface water contamination had appropriate CPs implemented with correct placements. Goodrich et al. (2020) used remotely sensed cover characteristics combined with National Resources Inventory ground cover data and process models as a cost-effective method to conduct large area assessments with greater temporal and spatial resolution. These combined technologies were used to address the CEAP Grazing Lands goal of assessing the effects of rangeland CPs on soil and water.

Owing to technological advancements, practical needs of conservation planning, and institutional support for initiatives like CEAP, DSTs have become an integral component of the conservation planning process. In collaboration with other agencies, CEAP has facilitated the evaluation and development of DSTs to facilitate the conservation planning process by providing agency staff with science-based

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technical assistance. A major contribution from the CEAP watershed project is the Agricultural Conservation Planning Framework (ACPF) watershed assessment tool (Tomer et al. 2013, 2015a, 2015b; Porter et al. 2018), which combines innovative assessment techniques and algorithms with spatial datasets to identify effective locations suitable for installation of CPs. The framework allows for selection from a menu of targeted CPs best suited to individual situations, thus supporting the conservation planning process with analysis and providing a social aspect that enhances engagement between producers, landowners, and management agencies. The ACPF is now being applied in selected priority regions and further developed for new settings by ARS and universities in partnership with NRCS. For example, it has been used to support watershed planning for water retention and wetland restoration (Tomer and Nelson 2020), or for precision placement of many other types of CPs (Ranjan et al. 2019, 2020b).

Another important DST is the Soil Vulnerability Index (SVI), which was developed by NRCS to classify inherent vulnerability of cultivated cropland soils based on sediment and nutrient losses via surface runoff and leaching (Thompson et al. 2020). Recently, data, and existing model simulations from the CEAP watershed network were used to evaluate SVI across a range of climatic and physiographic conditions and led to a special JSWC issue (Baffaut et al. 2020b). Work to continue evaluation and development of SVI across the CEAP watershed network continues with an ongoing project. Another index is Claypan Conductivity Index (CCI), developed specifically for soils with restrictive soil layers (Mudgal et al. 2012), which has be used to support precision conservation research in Missouri. As part of this CEAP special issue, Ranjan et al. (2020a) conducted an online survey of staff working in CEAP WAS sites.

Development of Model Calibration and Validation Standards. To support the model component of the CEAP WAS, scientists from multiple ARS locations established model evaluation guidelines for systematic quantification of accuracy in CEAP WAS simulations (Moriasi et. al. 2007). Standardized guidelines are increasing accountability and public acceptance of model output to support scientific research and guide policy, regulatory, and management assessments. Although these guidelines were developed specifically for CEAP WAS, they have found widespread acceptance internationally. These guidelines were among the foundational manuscripts from which the American Society of Agricultural and Biological (ASABE) developed the ASABE Standard for calibration and validation of hydrologic and water quality models (ASABE 2017). These guidelines also contributed to the development a customized framework to parameterize and validate the Agricultural Policy/Environmental eXtender (APEX) model for implementation of the Nutrient Tracking Tool by USDA (Moriasi et al. 2016).

Better Predictive Capacity. The commonly used hydrologic and water quality models continually undergo development to improve processes, integrate with other technologies to enhance capabilities, or develop support software tools to increase the credibility of modeling outcomes of effects of CPs. A few examples are provided to highlight additional impacts that have improved science. Momm et al. (2019a) integrated Revised Universal Soil Loss Equation 2 (RUSLE2) erosion and AnnAGNPS sediment transport models to support the development and evaluation of conservation management plans at the watershed scale. In addition, Momm et al. (2019c) incorporated enhanced riparian buffer components within AnnAGNPS that provides capabilities to evaluate buffer management practices on sediment and nutrient loads associated with their placement on the landscape. Momm et al. (2016) developed AnnAGNPS geographic information system (GIS)-based wetland component AgWet and integrated it with AnnAGNPS to provide capabilities to estimate the potential sediment/nutrient reduction by wetlands. This technology provides conservationists the capability for improved management of watershed systems and support for nutrient credit trading programs. Bingner et al. (2016) incorporated state-of-the-art ephemeral gully science into AnnAGNPS to provide the ability to determine the effect of CPs and changing soil conditions on the development of ephemeral gully erosion. Guertin et al. (2015) developed the Automated Geospatial Watershed Assessment (AGWA) tool to automate the parameterization and execution of KINEROS2 and SWAT. Past KINEROS developments are described by Goodrich et al. (2012).

Qi et al. (2020) incorporated multiple runoff-infiltration partition methods into SWAT to better reflect NO_3^- processing. Evenson et al. (2018) modified SWAT to better simulate depressional wetlands, which improved structural and process representation of wetlands. This modified model makes it possible to quantify wetland functions at broad spatial scales. Moriasi et al. (2011a, 2012) incorporated shallow water table depth and tile drainage routines into SWAT to improve simulation accuracy of subsurface tile flows and the associated NO_3-N leachate. Guzman et al. (2015) linked SWAT with the modular three-dimensional finite-difference groundwater flow (MODFLOW) models to account for surface and subsurface processes. The linked model is a useful tool for regions where groundwater is extracted for agricultural production. Bieger et al. (2017) and Arnold et al. (2018) revised the SWAT into a modular form to create SWAT+, to facilitate model maintenance, future code modifications, and to foster collaboration with other researchers to integrate new science into SWAT modules. SWAT+ provides greater flexibility in spatial representation of processes within a watershed. Data from CEAP WAS and STEWARDS was used to support development, calibration, and validation of SWAT+. Moriasi et al. (2019) developed a graphical interface for updating landuse in SWAT to simplify incorporation of multiple land use maps during the simulation period of modeling studies in order to provide realistic model parameterization and scenario simulations. This is especially important in watersheds where significant land use change may occur over a simulation period. Arnold et al. (2012) and Wang et al. (2012) provide details of past developments related to the APEX and SWAT models.

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Contribution to Development of Conservation Standards. Under CEAP WAS, we now have more data on practice performance at field scale, not just plot scale. These practice assessments have contributed better quantification of the range of benefits a practice standard delivers in a field context over longer periods, as opposed to plot scale results under rainfall simulations for limited time periods. Data such as these are helping NRCS refine CP standards, as well as refine estimates of benefits achieved from implementation. For example, a new CP standard for "Amending Soil Properties with Gypsum" to address dissolved P loss concerns was evaluated for environmental performance at the edge-of-field scale (King et al. 2016). These data are being used by NRCS to inform estimates for P reductions from gypsum application. A recent synthesis of gypsum use has also been published that will provide guidance for the CP standard (Zoca and Penn 2017).

Williams et al. (2020) in this issue examines the effectiveness of the blind inlet as a modification of a CP standard used for sediment and nutrient reduction, particularly P reduction in P sensitive watersheds. The blind inlet was conceived as a potential CP as a result of ongoing watershed assessment in the St. Joseph River CEAP watershed study. It was determined that tile risers throughout the pothole landscape could serve as potential hydrologic pathways of transport under inundated conditions. A concept for a blind inlet practice, as a modification of the NRCS CP standard for underground outlet, was designed, implemented in monitored fields in the CEAP watershed, and evaluated over more than 10 years (Smith and Livingston 2013; Gonzalez et al. 2016). Results documented the water quality performance of the standard, as well as the effective lifespan of the design, and were used to support development of a new interim CP standard by Indiana NRCS. Later, the practice standard was adopted as a full CP standard by NRCS in several relevant states, and evaluation is ongoing under CEAP watersheds in several states.

Many other CPs have been evaluated for effectiveness under CEAP projects. Moorman et al. (2015) evaluated the potential for watershed-scale NO_3^- load reductions with the use of denitrifying bioreactors in three CEAP watersheds. Hively et al. (2009) documented a method for evaluating the effectiveness of cover crops for NO_3^- reduction using remote sensing techniques combined with ground truth data. This work has continued to expand in application, and in Hively et al. (2020), the approach is used in combination with other data to analyze historical changes and performance of cover crops at the watershed scale. Aryal et al. (2018) also examined effects of cover crops in another region. King et al. (2018) has researched the effects of various aspects of the 4Rs for nutrient management as part of the CEAP watersheds edge-of-field network in Ohio. Insights from these long-term assessments have helped inform the revision of the NRCS CP 590 as well as to inform strategies for enhancing management of nutrients, especially P, in harmful algal bloom affected watersheds in both the Great Lakes and Lake Champlain basins. Penn and Bowen (2017) have evaluated and further developed P removal structures for trapping dissolved P losses, especially in tile-drained settings. Assessment of effectiveness of saturated riparian buffers on water resources continues in some CEAP watersheds to expand the dataset on saturated riparian buffers in other locations (Jaynes and Isenhart 2019) and to evaluate its potential if applied more broadly (Tomer et al. 2013).

More Accessible Data and Impacts on Research. As summarized by Sadler et al. (2020), development of the STEWARDS database significantly increased the accessibility and impact of the data collected from these historical research watersheds. The success of STEWARDS contributed to new approaches to data management within ARS. While impact is difficult to assess, STEWARDS has clearly raised the visibility of ARS data—more than 20 million data records have been downloaded directly from STEWARDS and about two to three times that amount of data has been accessed through an interagency portal for water quality data (Sadler et al. 2020). In an effort to enhance discoverability and use of CEAP data, as well as interagency coordination for water resource issues, STEWARDS was linked to the Water Quality Exchange/Water Quality Portal so that users of the portal could also have direct access to USDA water quality data via STEWARDS. In addition to publishing data in STEWARDS, several of the watershed teams developed collections of papers published in peer-reviewed journals that documented details of the history, methodology, and synthesized key research findings. These collections of papers were introduced by Hatfield et al. (1999), Marks (2001,) Locke (2004), Bosch et al. (2007), Moran et al. (2008), Bryant et al. (2011), Harmel et al. (2014), Steiner et al. (2014b), and Sadler et al. (2015). Another important database is the Conservation Practice Effectiveness (CoPE) Database developed by Smith et al. (2019). The CoPE database presents a compilation of data on the effectiveness of innovative practices developed to treat contaminants in surface runoff and tile drainage water from agricultural landscapes. This database, which includes traditional CPs such as no-till as well novel CPs such as denitrification bioreactors, is intended to help conservation planners, and it is a source of soft data to support development, calibration, and validation of models used in CEAP studies. CEAP funded the development of Measured Annual Nutrient loads from Agricultural Environments (MANAGE), a readily accessible, easily queried database of site characteristics and field-scale nutrient export data (Harmel et al. 2008), that was updated to include water quality data from forest and drainage land studies (Harmel et al. 2016). Data from these databases and those published in special issues have been used to calibrate, validate, and improve processes of hydrologic and water quality models such as AnnAGNPS (Bingner et al. 2015), APEX (Williams and Izaurralde 2006), KINEROS/AGWA (Goodrich et al. 2012), and SWAT (Arnold et al. 1998, 2012).

Leveraging and Synergy. Because of the long-term research commitment in the CEAP Benchmark watersheds, there is strong scientific capacity and infrastructure that has leveraged resources to develop new knowledge, provide training to the next generation of researchers, and develop new technologies for more robust and productive agricultural systems. Large

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NIFA-funded Coordinated Agricultural Projects, which focus research, extension, and education efforts to solve significant agricultural problems, were established in collaboration with the Columbus, Ohio, CEAP team (the Corn CAP [Morton 2014]) and the El Reno, Oklahoma, CEAP team (the Grazing CAP [Steiner et al. 2014a). The Oklahoma CEAP watershed was also selected by an Oklahoma Established Program to Simulate Competitive Research (EPsCOR) project for linked social-ecological sustainability research. CEAP scientists from ARS and NRCS participated in the establishment of a Water Quality Partnership in Ohio to develop mitigation strategies in partnership with the Environmental Quality Incentives Program (EQIP) that reduced mean monthly reservoir atrazine concentrations to below drinking water standards in the Upper Big Walnut Creek near Columbus, Ohio, with a cost savings of US$2.73 per EQIP dollar spent (King et al. 2012). There were also three regional and a national Conservation Innovation Grant for P Index comparisons, which involved many land grant faculty as well as CEAP scientists (Osmond et al. 2017; Sharpley et al. 2017; Kleinman et al. 2017).

Another major partnership involves the USDA ARS Long-Term Agroecosystems Research (LTAR) network (Walbridge and Shafer 2011; Kleinman et al. 2018). Most LTAR sites are collocated with CEAP, and scientists conducting research under these two networks are cooperating and sharing information to meet their research goals and objectives. Furthermore, LTAR projects leverage CEAP's core sites for intensive data collection to address local, regional, and national scale agricultural issues. Additionally, scientists from CEAP and LTAR locations played critical roles in establishment of the USDA Regional Climate Hub network.

CONSERVATION EFFECTS ASSESSMENT PROJECT IMPACTS AS FEEDBACK TO IMPROVE AGRICULTURAL CONSERVATION PROGRAMS

Data and insights generated from CEAP WAS projects have been useful in informing the design, delivery, and outcome assessment of NRCS conservation programs (Duriancik et al. 2018). In this way, CEAP has been integral to adaptively managing NRCS conservation program delivery. For example, data and lessons learned from CEAP WAS synthesis efforts were integral to supporting NRCS targeted and small watershed-based approaches (Hydrologic Unit Code 12 scale) for the water quality–focused Landscape Scale Conservation Initiatives as they were developed by NRCS (Osmond et al. 2012; Tomer and Locke 2011). This includes the Mississippi River Basin Initiative and two subsequent revisions to the program guidance for that effort; the Priority Watersheds based approach for the Great Lakes Restoration Initiative, which was introduced in the same year as the NIFA–CEAP Synthesis publication; the Showcase Watersheds approach for the Chesapeake Bay Initiative; and the watershed-assessment based approach to the latest rules for the National Water Quality Initiative. Lessons learned from CEAP WAS were also applied to the call for proposals and review criteria for the Regional Conservation Partnership Program in its first round of funding. Many of these initiatives have called for proposals for projects that must identify specific water quality resources of concern, identify constituents of concern, use methods to identify critical source areas, and identify methods and partners to assist with monitoring or tracking approaches to document conservation implementation against an established watershed scale assessment or plan as a means to quantify outcomes of conservation efforts (Osmond et al. 2012). Additionally, some analysis has been done to evaluate program approaches toward achieving water quality goals (Duriancik et al. 2018; Harmel et al. 2018).

CEAP WAS are also integral to documenting and estimating outcomes of conservation to support agency reporting requirements and adaptive management efforts. For example, field data from CEAP WAS are used to support model development and validation needs, which are used in turn to produce outcome estimates. Data on practice effects from monitoring innovative practices that are researched under CEAP WAS, but not yet able to be modeled, are also used to produce estimates of practice benefits in the interim when needed. Watershed assessments conducted could also be used to track practice implementation against those plans, and report on effective implementation progress in critical source areas. This kind of analysis has been used to adaptively manage conservation efforts and inform or adjust conservation strategies in the regional water quality initiatives named above over time.

Also supportive of adaptive management of conservation strategies was the impactful work on assessing P losses, especially dissolved forms, in the Western Lake Erie Basin. Smith et al. (2015) documented that approximately half (48%) of P lost at the edge-of-field was in the form of dissolved P. Additionally, King et al. (2015) documented for the first time the same finding at a watershed scale. As well, they also showed that a significant loss pathway of the dissolved P was via tile drainage and macropores bypassing soil matrix flow in these soils. These findings have been broadly utilized by water quality and conservation agencies throughout that region and helped inform more effective conservation strategies in the US Domestic Action Plan for Lake Erie. These findings are also being extended to inform NRCS and partner conservation strategies in the Lake Champlain Basin, challenged with similar conservation and water quality issues.

FUTURE CONSERVATION EFFECTS ASSESSMENT PROJECT DIRECTIONS

While numerous effects and benefits of CPs have been documented through CEAP WAS and related efforts since 2003, much more work to assess outcomes remains to be done. The 2018 Farm Bill included greater discussion of outcomes than prior ones, and as progress on water resource concerns in some regions begins to be evident, most major water resource regions still have staggering goals for water quality remaining to be addressed. While agricultural CPs are only one part of needed reductions collectively, they are often documented as a significant area with potential benefits (Duriancik et al. 2018). That means great opportunity remains for conservation actions and for more effective conservation efforts. However,

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challenges to measureable progress, such as legacy pools of nutrients and sediment as well as the influence of lag time on our ability to detect effects, must simultaneously be addressed.

Addressing Factors that Limit Watershed or Aquifer Conservation Impacts. Efforts to measure lag time in watersheds have been initiated under the USDA Watershed Lag Time Project as part of CEAP and LTAR. This effort will benefit from coordinated support and contributions from other partners, and coordination efforts to expand on current sampling are underway. Likewise, legacy sources of nutrients and sediment hamper measureable progress that is being achieved otherwise. While new assessments for legacy P or possible new CPs related to those pools have begun, more work needs to be initiated in other priority regions to assess legacy nutrients as well as additional work on applying existing or innovating new CP standards to address legacy pools. New CEAP WAS projects on this are very stakeholder based, but more must be done to expand this for greater breadth and benefit. Influence of drought, climate, and extreme weather events on CP performance is also a remaining question and priority for conservation assessment. Determining what can be done to enhance our ability to detect effects of CPs applied at various scales is essential. Therefore, there is need to increase the variety of treatments and replications in watershed assessments. Some of these include (1) implementing paired watersheds, subcatchments, or fields; (2) identifying subcatchments where more practices would be beneficial; (3) including several practices among subcatchments, both treatments and controls; (4) determining optimum catchment size to assess practices; and (5) determining length of time required to assess practices.

Efforts to continue evaluation and development of watershed assessment tools and techniques have yielded great benefits as a result of CEAP. However, work to expand the evaluation and application of these tools to additional priority watersheds is key to advancing the effectiveness of CPs and programs for greater water resource benefits (Maresch et al. 2008; Groffman et al. 2010; McLellan et al. 2018). An important step in supporting broader use of watershed assessment approaches and tools for more effective conservation is understanding the education and training needs for conservation professionals, as well as DST design enhancements needed from developers (Ranjan et al. 2020a). Education and training are not CEAP objectives; however, they will need to be considered to enable watershed assessment capacity and apply CEAP lessons learned. Enhanced technical partnership support is one approach to build capacity for watershed assessment. This partnership is critical to applying the lessons learned from prior CEAP WAS syntheses in more operational situations. Partnerships among NRCS, ARS, and universities are working on some aspects of tool evaluation, development, and technical support for tool application. These efforts will need to continue to build broader capacity, and plans are being developed for that. Stakeholder perceptions and use of such assessment results are also critical to adoption of practices (Ranjan et al. 2019).

Additional Synthesis to Guide Future Efforts. One major priority for CEAP WAS is to conduct a next step synthesis, to capitalize on all the effort and information gathering conducted to produce this overview. This next recommended effort would be a thorough synthesis to provide further analysis and, thus, insight into the following questions related to the effectiveness of CPs:

(a) What effects of CPs have been measured?
(b) At what scale(s) have effects been observed?
(c) What can be done to enhance ability to detect effects going forward, especially nutrients?
(d) What are the major take home messages of these CEAP watershed sites after 15 years of research?

Revitalizing Conservation Effects Assessment Project Watersheds Network and Capacity while Enhancing Coordination. In order to continue the work of documenting outcomes of conservation on water and soil resources, there is a need to revitalize the existing sites within the CEAP WAS network. For example, from all our synthesis and lessons learned, we know that more robust monitoring designs at smaller scales nested within the small watershed are useful in detecting effects at increasing scales. Some sites are in need of additional monitoring locations, enhancements to the constituents monitored, greater frequency of sampling, or paired designs to better document conservation effects (Meals et al. 2012b). Projects to evaluate sequential effects of stacking CPs within a catchment or field have been proposed and initiated but could be expanded (Tomer 2018). Additionally, improved coordination with NRCS and conservation districts on practice implementation in critical source areas within CEAP watersheds can enhance ability to detect effects of precision conservation approaches and water outcomes in general, on which data are much needed to respond to reporting mandates and encourage further adoption of conservation behaviors.

There is also a need to consider additional priorities for new sites to be added to the network. New sites have been added in recent years in priority regions, such as the Western Lake Erie Basin and Lake Champlain Basin, as paired watershed studies to improve statistics. Additionally, new capacity has been added to address water availability and management concerns (including aquifers) or new water CPs, e.g., in California where several new projects have been established. There are other important water resource regions where we do not currently have CEAP watershed assessments, but needs and stakeholder interest have been expressed. An inventory of expertise across sites can also be useful for determining gaps or weaknesses for staffing priorities within partner organizations, particularly ARS, to address capacity loss and succession planning.

Building out the network will enable more opportunities for developing subnetworks, multilocation projects on similar topics of interest. These cross-location projects have yielded important conservation insights and expanded the breadth of results across geographies in the past (Tomer et al. 2014; Wilson et al. 2014; Garbrecht et al. 2014a; Karlen et al. 2014). This improves CP standard effectiveness evaluation under different settings as well as improving model development and validation opportunities. Coordination with other similar

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research and assessment networks, beyond those already ongoing identified above, could also yield opportunities to include additional sites depending on assessment questions to be addressed. CEAP has always taken advantage of expanding partnerships and opportunities through leveraging other missions and resources, and with significant conservation challenges remaining ahead, and often fewer resources and capacity, the time for collaboration toward better outcomes is now.

SUPPLEMENTARY MATERIAL

Supplementary tables for this article are available in the online journal at https://www.jswconline.org/.

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The findings and conclusions in this publication are those of the authors and should not be construed to represent any official USDA determination or policy.

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