Economic Analysis of Innovative Agricultural Practices for Water Resiliency on the Albemarle Peninsula of North Carolina

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Executive Summary

This report builds on the results of the Grassy Ridge Flood Reduction Study (from here on GRFRS) conducted by Kris Bass Engineering by collating relevant benefits and costs of the approaches developed in the study, assessing key economic factors, and identifying barriers to adoption. This report relies on the hydrologic modeling provided in the GRFRS to assess a menu of potential water management and drainage canal modifications: adoption of conservation tillage; use of controlled drainage structures, and construction of two-stage ditches. Using secondary data on the menu items, the study region, and NRCS cost-share programs, the report draws several conclusions:

1. A global benefits-cost analysis suggests all three menu items provide social benefits many times larger than social costs. This result justifies investment from parties which seek to increase social well-being (such as governmental agencies).

2. Example farm-level benefit-cost calculations suggest the potential for voluntary adoption in the study region is limited. The key landowner benefit is the reduction in crop losses due to regular flooding. However, per acre benefits are low and some practices and locations see negative returns on investment.

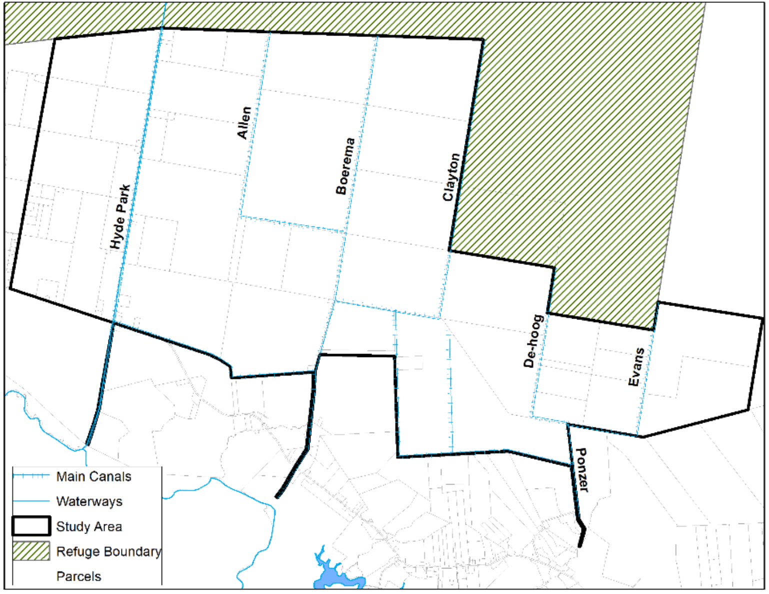
3. Key uncertainties will likely drive reluctance of farmers to invest individually in management practices:
    - The cost-effectiveness of these practices is highly dependent on their as-of-yet undocumented performance in reducing flooding in a novel setting.
    - Cost-effective adoption of these practices is highly dependent on coordinated adoption (e.g. the formation of a drainage district), with individual adoption decisions dependent on investment by other landowners.

4. There is considerable heterogeneity in benefits and costs of adopting these practices across the study region. Where benefits are high relative to costs, landowners will tend to favor adoption, while those seeing higher costs are likely to oppose adoption efforts. The greater the heterogeneity in the ratio of benefits to costs, the less likely a group is to engage in successful coordination.

I. Study Region

The study region encompasses about 10,000 acres of productive farmland below the Pocosin Lakes National Wildlife Refuge (NWR) and the Pongo River, colloquially known as Grassy Ridge. The pocosin ecosystem located to the north features a thick layer of peat and extremely flat topography. This area was drained in the early- and mid-20th century via surface ditches and canals. Despite drainage efforts throughout the region, the area north of the study region proved too difficult to farm due to a lack of slope for drainage and was eventually brought under the management of the NWR. Drainage from this region now runs roughly north-to-south through the Refuge and the study region. These canals drain both the Refuge and the study region.

Figure 1: Map of study region



The study region is shown in figure 1 and lies between the uplands of the Refuge and the Pungo River, providing enough slope for effective drainage and agriculture. However, the region remains extremely flat with mean elevation above sea level between 5 and 10 feet. Key spatial heterogeneity in terms of upstream/downstream, canal gradient, and location relative to the Refuge affects estimates of benefits and costs for the menu of potential approaches.

Table 1: Canal characteristics

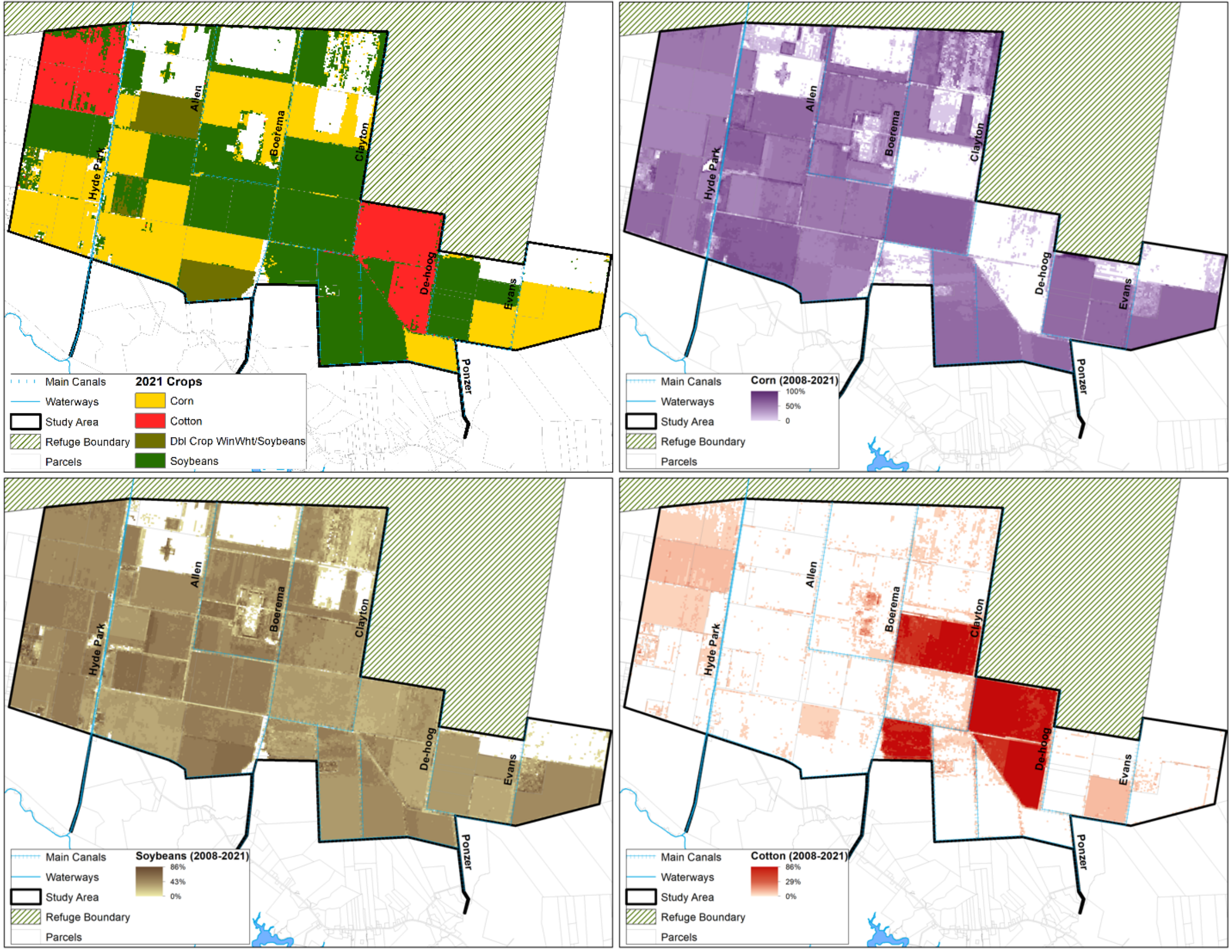
Canal	Upper Reach Slope (%)	Mid Reach Slope (%)	Down Reach Slope (%)	Drainage within Study region (%)
Hyde Park	0.02	0.05	-0.007	0-61
Allen	0.05	0.08	0.03	0-36
Boerema	0.02	0.09	-0.01	0-57
Clayton	0.03	0.03	0.04	0-11
De-Hoog	0.015	0.003	0.004	0-21
Evans	0.01	0.01	0.01	9-18
Ponzer	0.08	0.09	0.09	20-25

Table adapted from GRFRS table 1. Percent drainage within study region calculated using each canal's linear distance from the Hyde County line to study region (length in NWR) as a proportion of total length to each gauging station on the canal. Range is high and low percentage out of the total gauging stations on the canal. Hyde County line is chosen due to accounts in USDA (1994) that near Lake Phelps many canals flow north.

Canal slope is a key determinant of drainage outcomes. Table 1 shows the major canals that were studied in GRFRS, in figure 1 from west to east: Hyde Park, Allen, Boerema, Clayton, De-hoog, Ponzer and Evans. The slope of these canals ranges from -0.01 to 0.09%. Table 1 also provides an estimate of drainage area inside the study region (outside the refuge). The area outside the Refuge is the area in which water management and canal modifications can be made.

Crop production within the study region is primarily corn and soybeans with some cotton. A few fields engage in double-cropping of soybeans and winter wheat. The top left panel of figure 2 shows crop choices in 2021. The remaining three panels show the frequency of cropping for each field in corn, soybeans, and cotton. A key feature of the four maps taken together is the low intensity of any cropping on the fields immediately adjacent to the Refuge between Hyde Park and Clayton canals as well as east of De-Hoog. The upper reaches of Allen and Boerema are slightly flatter than the mid-reaches, making drainage more challenging. There has also been concern among farmers that the water tables at the Refuge are held high to prevent fire and provide wildlife habitat, which could push more water to downslope fields.

Figure 2: Crop production in the study region



Notes: Maps created using data from State of North Carolina, the GRFRS, and USDA Cropscape. The top left panel provides a map of crops grown in 2021 while the remaining panels show the frequency of corn, soybeans, and wheat for 2008-2021.

II. Menu Items

A. Conservation tillage

Conservation tillage (CT) is an umbrella term typically encompassing practices that reduce the intensity or frequency of field tillage. These practices have been shown to improve soil health, reduce runoff, and limit the extent of erosion as well as reduce nutrient losses in some instances. While these benefits have been documented in other regions, the application of these practices in the study region raises significant questions about the use of prior results in this setting.

First, there are questions about the current practices employed by farmers and their similarity to no-till practices (in addition some farms may have already adopted no-till explicitly). The study region has higher water tables than areas typically examined in the literature, meaning it is difficult to get equipment on the field during wet times, which may mimic some low-till practices while making others impossible to implement.

Second, in terms of the total volume of runoff, the implementation of conservation tillage affects only the agricultural areas. Flow from the NWR is not affected by CT, and so the ability of this approach to reduce runoff is limited to what can be achieved on agricultural fields.

The benefits of CT are due to reduced nitrogen and phosphorus runoff and reductions of water in the canal system during floods. An additional benefit of CT is reduced time and fuel from fewer trips across the field. In other locations, a key benefit of conservation tillage is its ability to increase soil organic matter. In the study region, the soil is primarily peat and therefore soil organic matter is already high, and no yield benefits were anticipated through this mechanism.

The costs of CT come from increased application of herbicides and pesticides. In wet soils, reduced tillage can also reduce yields. The costs of CT may be partially offset by financial and technical assistance provided by the USDA through the Environmental Quality Incentives Program (EQIP).

B. Controlled drainage

Controlled drainage (CD)—alternatively called drainage water management—is the use of water control structures, typically with flat board risers, to reduce drainage and raise water tables. CD cannot lower upslope water tables, only raise them. However, the use of CD upslope can effectively delay outflows to downstream areas prone to flooding. The study region has extensive canals, lateral drainage ditches, and in-field drainage ditches, with a ½ mile by 1 mile block capable of holding about 20AF of water, or about 0.76” spread over entire surface.[1] Under free drainage, this water runs off the field ditches and laterals into the main canal, while CD can hold water in upslope canals and ditches for longer periods of time. It should be noted, however, that this is a novel application of CD, and so estimates of benefits resulting from using drainage structures to reduce runoff is necessarily speculative.

The benefits of CD are estimated via reductions in phosphorus and nitrogen runoff and reductions in the amount of water in the canal system during floods. In some settings, CD provides significant yield benefits during the dry season by maintaining higher water tables during drought. Because of the baseline high water tables in the study region, yield benefits from CD are expected to be negligible.

The costs of CD are the costs of the drainage structure and installation. These structures are recognized as a best management practice by NRCS and the costs for on-farm installation are partially offset by EQIP

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[1] USDA Soil Conservation Service. 1994. Pocosin Lakes National Wildlife Refuge Hydraulic and Hydrologic Study and Water Management Study. URL: https://www.fws.gov/sites/default/files/documents/pocosin-lakes-nwr-hydraulic-and-hydrologic-study-and-water-management-study-1994.pdf

cost-share programs. The efficacy of these structures in managing water runoff is dependent on coordination across the canal. The canal flow reduction benefits of CD fall entirely to downstream fields so without coordinated management, there is no incentive for upstream users to manage water tables to limit downstream flooding.

C. Two-stage ditch

The two-stage ditch is a natural or artificial modification of a drainage canal to allow the canal to form a floodplain-like second stage during high water. Two stage ditches have been utilized in the upper Midwest with documented benefits in terms of reductions in nutrient and sediment runoff. Two-stage ditches have not previously been implemented with the goal of improving drainage or increasing drainage capacity. This novel application has been justified hydrologically in the GRFRS, but there is no literature documenting the benefits or costs of the practice in this application.

The benefits of two-stage ditches accrue as decreases in nutrient runoff and reduction in canal runoff during flood events. An additional potential benefit is that increased drainage capacity could lead to the opportunity to plant crops on the farms bordering the refuge. The value of this benefit is not included in this report. Two-stage ditches are generally regarded as self-clearing and therefore the reduction in ongoing maintenance costs may be a benefit. Given the uncertainty of this application in a novel setting, this benefit is not included, and it is instead assumed that maintenance costs are roughly equivalent to those of the standard canal.

The costs of two-stage ditches include their excavation and the transport and disposal of spoil, and lost production on the land taken out of production to create the second stage area. There is currently no federal cost-share program for two-stage ditches in North Carolina. NRCS conservation practices are designed to address water quality issues like nutrient and sediment runoff as well as soil quality issues, and this is a novel practice in North Carolina in this regard. The Regional Conservation Partnership Program (RCPP) offers one path to cost share, as it is more likely to support innovative solutions to conservation problems. The likely scenario, if funded, is to cover about 80% of the cost.

D. Dredging

Dredging is the removal of sediment at the bottom of canals along their length to provide a more uniform slope and more capacity. The GRFRS evaluated dredging the lower reaches of Boerema and Hyde Park Canals, resulting in potential changes in water flows in these canals as well as Allen and Clayton, which feed Boerema (see GRFRS p. 9). The total distance dredged on Boerema was estimated at 9,000ft and Hyde Park at 4,000ft.

The benefits of dredging are reduced water surface elevations, at the location of the dredging and to a lesser extent upslope. The GRFRS finds dredging benefits to be hydrologically insignificant. The cost of dredging is the per-foot cost of removing material from the canals and then disposing of it and can be significant. In addition, dredging would likely require a permit from the U.S. Army Corps of Engineers, which would be a process that would incur some cost with no guarantee the permit application would be successful. Dredging would generally not be eligible for federal cost share without documented benefits in terms of reductions in nutrient runoff. Because dredging costs are high and changes to hydrologic outcomes are estimated to be minimal, dredging is not included in discussions of costs and benefits.

E. Culvert replacement

Where canals flow under roadways, the GRFRS suggested increasing culvert sizes to at least seven feet in diameter or the use of full-span bridge crossings. The benefit of larger openings is the prevention of roadway crossing overflow, allowing canals to convey the designed discharge, and preventing roadway overtopping and overbank flow. The costs include construction, and it is assumed maintenance remains the same as for current crossings. Roadway crossings will provide benefits primarily to the landowners directly upslope and therefore do not require coordination among adjacent landowners. In the GRFRS, culvert replacement modeling is combined with two-stage ditch construction. For this reason, the benefits for the two approaches cannot be estimated separately. For the remainder of the report, the costs of culvert replacement will be included with those for two-stage ditches, and benefits for two-stage ditches are inclusive of this culvert investment.

III. Costs

A. Conservation tillage

CT is expected to have small costs or even benefits of implementation. An early paper on the Blacklands suggested that "[n]o-till has the potential to maintain, and perhaps slightly enhance yields while reducing labor costs in this flat, wet region.[2]" Enterprise crop budgets from the NC State Department of Agricultural and Resource Economics show no-till corn production reduces net income before fixed costs from $188 to $171, a cost of $17/acre due primarily to increased fertilizer costs.[3] Conversely, soybean per acre net income for high yield regions, such as the study region in Hyde County, increases under no-till from $318/acre to $331/acre.[4] Cotton production sees slight income per acre increases under no-till, from $176/acre to $182/acre.[5]

Because of the expected benefits to implementing no-till for soybean and cotton production, CT (or similar) practices may already have been adopted in the study region. The estimates are obtained using the per-acre benefits and costs multiplied by average acreage in each crop. The NRCS EQIP payment could be up to around $22/acre, but given the low implementation costs in the region and uncertainty of the payment, the subsidy is excluded from the analysis.[6]

CT costs:
Corn: $17/acre x 4,015 acres = $68,260
Soybeans: -$13/acre x 3,498 acres = -$45,468
Cotton: -$6 x 967 acres = -$5,805

Total costs

Total: $16,987/year

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[2] Crozier, C.R. and Brake, S., No-Till in The North Carolina Blacklands: A Case Study for Farmer-to-Farmer Exchange. Proceedings of the 22nd Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Tifton, GA. 6-8 July 1999. Georgia Agriculture Experiment Station Special Publication 95. Athens, GA

[3] Corn conventional till: https://cals.ncsu.edu/are-extension/wp-content/uploads/sites/27/2019/01/Corn-Tidewater-Conventional-Till.pdf
Corn no-till: https://cals.ncsu.edu/are-extension/wp-content/uploads/sites/27/2019/01/Corn-Tidewater-No-Till.pdf

[4] Soybeans conventional till: https://cals.ncsu.edu/are-extension/wp-content/uploads/sites/27/2022/02/Soybean-Conventional-High.pdf
Soybeans no-till: https://cals.ncsu.edu/are-extension/wp-content/uploads/sites/27/2022/02/Soybean-No-Till-High.pdf

[5] Cotton conventional till: https://cals.ncsu.edu/are-extension/wp-content/uploads/sites/27/2020/12/Cotton-Tidewater-Conventional-Till.pdf
Cotton no-till: https://cals.ncsu.edu/are-extension/wp-content/uploads/sites/27/2020/12/Cotton-Tidewater-No-Till.pdf

[6] https://www.nrcs.usda.gov/sites/default/files/2022-10/North_Dakota_EQIP.pdf (code 329)

B. Controlled drainage

The cost and installation of a CD structure is assumed to be $4,000 with a NRCS EQIP cost-share of 75%.[7] Placement of the structures will be on the lateral ditches, whose locations were estimated via aerial photographs: Hyde Park: 6; Allen: 3; Boerema: 5; Clayton: 2; Ponzer: 3; De Hoog: 2; and Evans: 2. Each control structure is assumed to provide coverage for approximately 200 acres, so we assume each lateral will have two structures, providing 46 structures to cover the approximately 10,000 acres in the study area at a total construction cost of $184,000. The expected life of the control structure is 20 years. A 5% interest rate is assumed, and repair and maintenance costs are estimated at 5% of annual amortized construction costs.[8]

Total costs

Amortized costs (20 years, 5%): $14,765/year
Maintenance costs: $738/year
Total cost: **$15,503/year**

Subsidies

Annualized EQIP 75% cost-match: $11,073/year

C. Two-stage ditch

Canal cross-section diagrams provided in the presentation that accompanied the GRFRS are used to estimate two-stage construction requirements. To do this, the average width and depth of the two-stage design for each canal are used to find the amount of soil removed (columns 4 and 5 of table 2). Estimates are averages based on dimensions provided in the GRFRS for Ponzer, Allen, Boerema, and Hyde Park canals. An overall average from these four canals is provided for fill removal requirements of Evans, De Hoog and Clayton canals. Results of fill amount estimates are shown in column 6 of table 2.[9]

For canals adjacent to farmland in the study region, acres removed from production are calculated as the length (column 2 in table 2) times the width (column 4) with the result shown in column 7. Total area removed sums to 130.75 acres. Costs of farmland conversion to two-stage ditches are given as expected agricultural income weighted by average crop use in the study region: $160/acre (see table 4).

Total construction costs of two-stage ditches are estimated from previous studies. Estimates range from $10 to $50 per linear foot.[10] Although work by Kramer (2011) suggests the lower end of this cost range is more likely.[11] EQIP payments at 75% of cost for Indiana ($8.72/linear foot) and Ohio ($8.33/linear foot)

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[7] Drainage control structure costs: https://efotg.sc.egov.usda.gov/references/public/IA/587-Structure_for_WaterControl_2015_05.pdf
Reimbursement: https://www.nrcs.usda.gov/sites/default/files/2022-10/North_Dakota_EQIP.pdf (Code 587)
[8] https://drainage.wordpress.ncsu.edu/files/2017/04/ag-397-economics-controlled-drainage-evans.pdf (page 8)
[9] Fill Removal Estimates:
Ponzer (slides 7-8): 89ft wide x 2.66ft high= 237ft^2
Allen (slides 5-6): 45ft x 5.71ft= 257ft^2
Allen (5080, slide 11): 44.4ft x 6.67ft = 296ft^2
Allen (14394, slide 13): 39.6ft x 4.78ft = 189ft^2
Boerema (10561, slide 15): 70ft x 2.74ft = 192ft^2
Ponzer (2790, slide 17): 91ft x 2.73ft = 248ft^2
Hyde Park (7520, slide 19): 60ft x 5.86ft = 352ft^2
Average: 62.7ft x 4.45ft = 279ft^2

[10] https://agbmps.osu.edu/bmp/open-channeltwo-stage-ditch-nrcs-582
[11] Kramer, G., 2011. Design, construction, and assessment of a self-sustaining drainage ditch, University of Minnesota-Twin Cities, St. *Paul, MN.*

suggest construction costs of \$11.10-11.60/ft.[12] A conservative estimate of \$25/ft is used. Spoil disposal consists of placing 30 million cubic feet over an area of approximately 10,000 acres, or about 0.8 inches across the area. This cost is assumed to add \$5 per linear foot. Total two-stage canal length is 110,530ft (see table 2). EQIP currently pays for two-stage ditches only in these two states, so subsidies are excluded from our analysis, although there is discussion about payments in other regions.[13]

Table 2: Two-Stage ditch fill removal

	Farmland Length (ft)	Below Farm Length (ft)	Added Width (ft)	Added Depth (ft)	Total Fill Volume (ft^3)	Reduced Acreage (acres)
Allen	14,595	-	43	5.72	3,589,786	14.41
Boerema	16,959	6,663	70	2.74	4,530,700	27.25
Clayton	19,270	-	62.7	4.45	5,376,619	27.74
Dehoog	9,377	-	62.7	4.45	2,616,324	13.50
Evans	10,210	-	62.7	4.45	2,848,743	14.70
Hyde Park	20,979	6,160	60	5.86	9,542,054	28.90
Ponzer	2,065	4,252	90	2.695	1,532,188	4.27
Total	93,455	17,075			30,036,414	130.75

The GRFRS analysis included the replacement of two culverts on Allen Canal (7322 and 11736) and one culvert on Hyde Park (14408). (See GRFRS p. 7-8). Culverts should be replaced by 7ft culverts or bridges. The cost of replacing the culvert is estimated at \$10,000 per culvert.[14] The number of culverts needing replacement is unknown. The GRFRS provides cross-sectional diagrams suggesting the number of road crossings for Allen (3), Hyde Park (7), and Boerema (2). One crossing each on Hyde Park and Boerema is over a state highway and these crossings are already bridges. Satellite photos suggest Clayton has three crossings, De Hoog and Evans have 0, and Ponzer has one which is also already a bridge. This leaves 13 crossings, of which it is estimated 10 need replacement. It is assumed there is no cost share associated with upgrading these crossings, and both two-stage ditches and culverts have a 20-year life.

Total costs

Land cost (\$160/acre x 130.75 acres, amortized over 20 years at 5%): \$20,920/year
Construction and disposal cost (\$25/ft x 110,530ft, amortized over 20 years at 5%): \$221,730/year
Culvert upgrades (amortized over 20 years at 5%): \$8,024/year
Total: **\$250,675/year**

Subsidies

Option 1: Regional Conservation Partnership Program (RCPP)—80% of construction costs, no ongoing payments
Annualized value of cost share: \$166,298/year
Option 2: EQIP—75% of construction costs, no ongoing payments
Annualized value if cost share: \$177,384/year

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[12] Roley, S.S., Tank, J.L., Tyndall, J.C. and Witter, J.D., 2016. How cost-effective are cover crops, wetlands, and two-stage ditches for nitrogen removal in the Mississippi River Basin?. *Water Resources and Economics*, *15*, pp.43-56.

[13] Bryant, R., Baldwin, A., Cahall, B., Christianson, L., Jaynes, D., Penn, C. and Schwartz, S., 2019. Best management practices for agricultural ditch management in the Phase 6 Chesapeake Bay Watershed Model. URL: https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/ag_ditches_bmp_panel_report_revised_draft_for_cbp_review_11dec2019_marked-up.pdf

[14] Page 91, https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5279284.pdf

IV. Benefits

The options for modifying drainage water and canal management in the Grassy Ridge study region provide three categories of benefits: nutrient reductions, water management and flood reductions, and ecosystem service and wildlife benefits. Wildlife benefits are not quantified in this study although it is important to note the potential value of wildlife habitat to the Red Wolf population in the area.

Nutrient reduction benefits

The reduction of nitrogen and phosphorous runoff from agricultural fields provides a key non-market benefit of the canal modifications and drainage management approaches. The social cost of nitrogen varies widely depending on the location, vulnerability, and preferences of populations affected.[15] In North Carolina, projects that reduce nitrogen and phosphorous in basins with total maximum daily load restrictions (Jordan Lake, Falls Lake, Neuse River, and Tar-Pamlico River) can receive government payments ranging from $10.50 to $120.72 per pound of nitrogen and from $156 to $640 per pound of phosphorous.[16] Estimates from the Pamlico River are used, which delivers water into the Pamlico Sound immediately adjacent to the Pungo River. These estimates are $10.50/lb N and $155.54/lb P. These estimates will be applied to potential nutrient reductions.

Nitrogen loss from North Carolina fields ranges from 5 to 25 pounds per acre per year.[17] Estimates of 7.75 lbs N/year and 0.27 lbs P/year are used for current field-discharges. The total cropped acres in the study region are 8,480 (sum of cotton, corn, and soybeans from table 4). CD reduced N losses to surface waters by over 40 percent and P losses by about 25 percent compared to conventional uncontrolled drainage.[18] Nitrogen losses from controlled drainage are estimated to reduce N discharge from 7.7 to 4.7 lb/acre for a total reduction of 3lb/acre and phosphorus losses from 0.27 to 0.20 lb/acre for total reduction of 0.07lb/acre.[19]

CT is not expected to decrease phosphorus runoff; although organic material does absorb phosphorus, its subsequent decay will release it back into the soil.[20] Higher application of nitrogen fertilizers in no-till settings and the presence of more nitrogen-containing organic components can lead to additional nitrogen leaching, potentially increasing nutrient runoff. For the purposes of this study, nitrogen and phosphorus runoff is assumed to be unchanged under CT.

Two-stage ditches have documented benefits of reducing nutrient runoff, with assumed reductions in phosphorus concentrations at 40%.[21] Two-stage ditches are effective at removing nitrogen on their

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[15] Keeler, B.L., Gourevitch, J.D., Polasky, S., Isbell, F., Tessum, C.W., Hill, J.D. and Marshall, J.D., 2016. The social costs of nitrogen. Science advances, 2(10), p.e1600219.

[16] https://deq.nc.gov/about/divisions/mitigation-services/dms-customers/current-rate-schedules

[17] Gatiboni,L .and Osmond, D. 2019. "Nitrogen Management and Water Quality." NCSU Extension Publication AG-439-02. URL: https://content.ces.ncsu.edu/nitrogen-management-and-water-quality

[18] Poole, C., Burchell, M., and Youssef, M. 2018. Controlled Drainage – An Important Practice to Protect Water Quality That Can Enhance Crop Yields. NCSU Extension Publication AG-851. URL: https://content.ces.ncsu.edu/controlled-drainage

[19] Evans, R.O., Wayne Skaggs, R. and Wendell Gilliam, J., 1995. Controlled versus conventional drainage effects on water quality. Journal of irrigation and drainage engineering, 121(4), pp.271-276.

[20] Duncan, E.W., Osmond, D.L., Shober, A.L., Starr, L., Tomlinson, P., Kovar, J.L., Moorman, T.B., Peterson, H.M., Fiorellino, N.M. and Reid, K., 2019. Phosphorus and soil health management practices. Agricultural & Environmental Letters, 4(1), p.190014.

[21] Hodaj, A., Bowling, L.C., Frankenberger, J.R. and Chaubey, I., 2017. Impact of a two-stage ditch on channel water quality. Agricultural Water Management, 192, pp.126-137.

benches, but do not necessarily increase nitrogen removal in the first-stage channel. For this reason, prior research has suggested that they may not be effective at removing nitrogen unless substantial portions of the water that eventually ends up in the canal flows over the benches, for instance on its way from field ditches and drains to the main canal. Because the setup of the two-stage canal in the study region will not convey water from field and lateral ditches over the second-stage, nitrogen reduction benefits are assumed to be negligible.[22]

Table 3: Water quality benefits

Panel A		**Phosphorus**		**Nitrogen**	
	Crops (ac)	**Runoff (lb/ac)**	**Price ($/lb)**	**Runoff (lb/ac)**	**Price ($/lb)**
Baseline	8,480	0.27	155.54	7.75	10.5

Panel B

	Reduction (lb/ac)	**Benefit ($)**	**Runoff (lb/ac)**	**Benefit ($)**
CD	0.07	92,329	3	89,040
CT	-	-	-	-
Two-Stage Ditch	0.11	145,088	-	-

Water management benefits

The key benefits from increased capacity and reduced flows through the study region will come from a reduction in periodic flooding of cropped fields as a result of overtopping canal banks and flooding fields. The hydrologic analysis is not sufficiently granular to predict with accuracy the expected crop losses due to flooding of specific parcels, or the reduction of these losses because of improved water management. The hydrological analysis also does not inform the potential for the reduction of saturation of currently uncropped fields on the border of the refuge. This study focuses on aggregate estimates of benefits from reduced flood severity.

Table 4: Crop production and economic value estimates in study region

	Study region		**Yield (bu/ac)**	**Price ($/bu)**	**Loss per acre ($)**			**Income**
	Acres	**Percent**	**cotton:lb/acre**	**cotton:$/lb**	**100%**	**50%**	**25%**	**net $/acre**
Corn	4,015	39.0%	150.22	5.00	750	375	188	188
Soybeans	3,498	33.9%	48.38	10.97	531	265	133	208
Cotton	967	9.4%	977.2	0.82	801	401	200	176
Ditches	361	3.5%			0	0	0	0
Not Cropped	1468	14.2%			0	0	0	0
				Study region Weighted Averages	**547**	**274**	**137**	**160**

Sources: Yield and price data are five year means. Yield data from USDA Quick Stats for Hyde County average. Soybean and corn price data for nearest elevator (Creswell, NC) from the North Carolina State University corn, soybean, and wheat price and basis database. Cotton price data from USDA cotton price report. Ditch area estimate from USDA (1994).[23] Crop areas from USDA Cropscape data layer.

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[22] Ibid.

[23] USDA Soil Conservation Service. 1994. Pocosin Lakes National Wildlife Refuge Hydraulic and Hydrologic Study and Water Management Study. URL: https://www.fws.gov/sites/default/files/documents/pocosin-lakes-nwr-hydraulic-and-hydrologic-study-and-water-management-study-1994.pd

The study region is predominantly cropped in corn and soybeans (columns 2 and 3 in table 4) with cotton, non-cropped acreage, and ditch area making up the remainder. Revenue per acre is estimated using five-year average yields in Hyde County and prices from the nearby Creswell, NC elevator (for corn and soybeans) and USDA price (cotton). To estimate the per acre benefit of reduced flooding, all costs of production are assumed to be incurred prior to flooding, so the change in benefits is simply lost revenue.

The level of crop damage from small-scale flooding may be total or partial; estimates are provided for the benefits of reduced flooding that would have caused 25%, 50%, and 100% crop losses (columns 6-8). For land not in production that can be brought into production as a result of improved water management, the income above variable costs from crop budgets from the NC State Agricultural and Resources Economics Department (column 9), could be used.[24] This illustrative per-acre benefit is not included in our final analysis.

To find overall study averages, the loss per acre of each crop is weighted by the percentage of farmland in that crop. Ditches and non-cropped land are assumed to see no losses from flooding, and thus no benefits from reduced flooding.

Kris Bass Engineering provided estimates of inundated area under a variety of scenarios as described in the GRFRS. The estimates are based on flows for the canal drainage equation for the study region (assumed for the economic analysis to correspond to a two-year flood event, i.e. this is the assumed return frequency). Under this flow level, 53% of the modeled area becomes inundated (although the distribution and amount of inundation is not estimated here), corresponding to 4,326 acres. The total estimated annual loss from flooding is estimated at $1,184,146 for 100% crop destruction on the flooded acreage and $296,036 for 25% losses on the flooded acreage. These model results are show in panel A of table 5.

The reductions in flooded area as a result of the adoption of CD, CT, CT and CD combined, and two-stage ditches is shown in panel B. Model results suggest that CD or CT independently reduces flooded acreage in the study region by 8 percentage points. The two approaches together yield an 18pp decrease, while two-stage ditches lead to a 38pp decrease. Applying these reductions in flooding yields annual benefit estimates ranging from $453,184 for two-stage ditches where 100% of flooded crop area was lost to $25,048 for CD or CT where only 25% of flooded crop area would be lost to production.

Table 5: Flood management benefits

Panel A			**Total Annual Cost ($)**		
	Acres Flooded	**Flood Area (%)**	**100% Loss**	**50% Loss**	**25% Loss**
Baseline	4,326	0.53	1,184,146	592,073	296,036

Panel B		**Total Annual Benefit ($)**		
	Change (pp)	**100% Loss**	**50% Loss**	**25% Loss**
CD	-0.08	100,191	50,096	25,048
CT	-0.08	100,191	50,096	25,048
CD + CT	-0.18	213,887	106,943	53,472
2-Stage Ditches	-0.38	453,184	226,592	113,296

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[24] Corn: Tidewater region, convention till, 2019 (https://cals.ncsu.edu/are-extension/wp-content/uploads/sites/27/2019/01/Corn-Tidewater-Conventional-Till.pdf)
Soybeans: Conventional Till 2021 (https://cals.ncsu.edu/are-extension/wp-content/uploads/sites/27/2020/12/Soybean-Covnetional-Till.pdf)
Cotton: Tidewater, conventional till, 2021 (https://cals.ncsu.edu/are-extension/wp-content/uploads/sites/27/2020/12/Cotton-Tidewater-Conventional-Till.pdf)

A. Conservation tillage

Total benefits

Phosphorus reduction: $0
Nitrogen reduction: $0
Reduced flooding: $100,191/year
Total: $100,191/year

B. Controlled drainage

Total benefits

Phosphorus reduction: $92,329/year
Nitrogen reduction: $89,040/year
Reduced flooding: $100,191/year
Total: $281,560/year

C. Two-stage ditch

Total benefits

Phosphorus reduction: $145,088/year
Nitrogen reduction: $0/year
Reduced flooding: $453,184 per year
Total: $598,272/year

V. Coordination

Thus far, the analysis has looked at the benefits and costs of the menu items aggregated across the entire study region. While these benefit and cost estimates are useful in considering policies affecting the entire region, aggregation is likely to obfuscate key heterogeneity in the costs and benefits of implementation. Because the investments in the study region will be made by individual landowners, understanding this heterogeneity in who bears costs and receives benefits and in what proportion is the key to understanding landowner adoption decisions.

In the case of managing drainage, the study region does not have an organized framework for coordinated drainage management. In North Carolina and other states with significant areas of naturally waterlogged soil, drainage districts coordinate the use of the shared drainage resources. The optimal scale of drainage management decisions exceeds that of agricultural production and drainage districts allow landowners to coordinate as a group over drainage decisions while retaining rights to sell, produce, and use their land as they see fit. Without such a mechanism, coordinated action is more challenging.

In the study region, a key challenge lies in the need for canal-wide adoption of each measure to secure full benefits. For instance, if conservation tillage is implemented throughout the study region, its relative impact on the farms in the upper reaches of the canals near the Refuge border is much smaller than at the lower reach of each canal. Farms in upper reaches therefore see limited benefits but bear the same costs as middle and lower reach farms. Similarly, CD cannot reduce upslope water, but provides benefits to downstream users in reducing flooding. Upper reach farms will have little incentive to engage in CD, where they bear costs, but downstream farms receive benefits. The fields in the study region that are not typically cropped border the Refuge, and thus see little to no reduction in water tables due to CD, which provides downstream benefits. In contrast to CD and CT, the benefits of two-stage ditches generally increase for farms upslope, as shown in the GRFRS modeling exercise. This relationship, however, varies depending on local canal geometry and slope.

Table 6 provides the per acre benefits for one key benefit reduced flooding frequency across the adoption of CD, CD and CT together, and two-stage ditches. These results come from a hydrologic modeling exercise where flood frequency is measured in the different reaches. Results vary by location due to the topography of the area, canal bank and water surface elevations, and interactions of slope and water discharge along the canal length. Results shown are annual benefits in dollars relative to status quo flood regime assuming a 100% loss rate for flooded crops.

The table displays the heterogeneity across and within canal systems. For instance, the adoption of two-stage ditches on upper Boerema yields $9/acre in benefits but $163/acre on upper Allen, and $111/acre on middle Boerema. The overall cost of implementation for two-stage ditches ($250,675/year) divided by the total cropped area (8,480 acres) gives an approximate cost of $29.56 per acre. Comparing this average with any of the menu item benefits for Boerema suggests landowners in stretches will not voluntarily undertake two-stage adoption. Without canal-length adoption of two-stage ditches, the overall estimated benefits will decline, potentially lowering them to below the construction cost threshold for all landowners.

Table 6: Within- and across-canal heterogeneity in flood reduction benefits (per acre)

		Allen	**Boerema**	**Clayton**	**De-Hoog**	**Evans**	**Ponzer**	**Hyde Park**	**Avg.**
CD	Upper	$59	$4	$31	$6	$9	$23	$34	$24
	Mid	$49	$38	$8	$7	$61	$2	$6	$24
	Lower	$42	$32		$26		$0	$12	$16
CT + CD	Upper	$101	$6	$66	$31	$48	$49	$52	$50
	Mid	$76	$75	$36	$25	$202	$9	$10	$62
	Lower	$111	$67		$77		$0	$29	$41
2-Stage	Upper	$163	$9	$258	$267	$267	$207	$88	$180
	Mid	$113	$111	$265	$270	$258	$269	$23	$187
	Lower	$230	$0		$265		$274	$215	$141

The formation of a drainage district or a special service district may allow landowners to overcome these coordination issues. Both entities allow for land assessments to pay for infrastructure improvements, such as the CD structures and two-stage ditch construction. A drainage district is formed through a court petition and local election, and if approved all property owners in the district elect drainage commissioners. A special service district is created through the County Board of Commissioners and has many of the same powers as a drainage district, but executed through the commissioners rather than a separate local board.

Drainage districts are more expensive to form and there does not exist a readily available estimate of the cost of formation, which will likely depend on idiosyncratic aspects of the area and landowners in the formation region. For this reason, formation cost is ignored, but still represents a key obstacle to the adoption of the menu items. Hyde County has one existing drainage district, Hyde Co. Drainage District 7, which assesses fees up to $18 per acre. Assuming the formation of a special service or drainage district is required to effectively coordinate any of the proposed measures, the assessment for such a district is estimated at $18 per cropped acre, or a total of $152,640/year.

Total cost

Total coordination costs: $152,640/year

VI. Benefit cost analyses

Benefit cost analysis (CBA) is a method for comparing alternatives on their relative financial benefits and costs. A global CBA includes all relevant benefits and costs borne by all parties, including non-market benefits and costs as well as costs borne by governmental agencies. This type of analysis is useful in understanding the overall desirability of a project to society and may be used by an agency decision-maker in choosing what programs to fund. In a global CBA, subsidies and assessments are ignored because they are a cost to one entity and a benefit to another.

A farm-level CBA focuses on the benefits and costs to a landowner who is making an investment decision for a particular menu item. Farm-level analysis limits costs to those borne by the landowner; for the landowner, subsidies serve to reduce costs and assessments increase them. Farmer benefits and costs also vary spatially and are difficult to estimate without farm-level data on income and costs. For this reason, the report provides an example farm-level CBA and lookup tables to provide a tool for farm-specific benefits and costs.

Global CBA

Two global CBAs are performed: a full global CBA and a CBA including only flood-control benefits. Results are shown below. Total benefits minus total costs represents the total benefit surplus created by the menu item. The ratio of benefits to cost provides a comparable measure of the return for each project, i.e. how many times the costs are generated in benefits.

The global CBAs suggest all three menu items provide benefits greater than costs, relative to the status quo. These results provide analytical justification for government agencies to pursue subsidy programs to provide incentives to landowners to engage in these practices, which provide substantial benefits to the public.

Conservation tillage	**Controlled drainage**	**Two-stage ditch**
Total Benefits	Total Benefits	Total Benefits
Phosphorus: $0	Phosphorus: $92,329/year	Phosphorus: $145,088/year
Nitrogen: $0	Nitrogen: $89,040/year	Nitrogen: $0/year
Flooding: $100,191/year	Flooding: $100,191/year	Flooding: $453,184 per year
Total: $100,191/year	Total: $281,560/year	Total: $598,272/year
Total Costs	Total Costs	Total Costs
	Amortized costs: $14,765	Land: $20,920
	Maintenance costs: $738	Construction: $221,730
		Culverts: $8,024
Total: $16,987/year	Total Costs: $15,503 /year	Total: $250,675./year
Benefit-Cost Ratio: 6:1	***Benefit-Cost Ratio: 18:1***	***Benefit-Cost Ratio: 2.4:1***
Flood Control Ratio: 6:1	***Flood Control Ratio: 6:1***	***Flood Control Ratio: 1.8:1***

Because the proposed menu items are novel for the region and for creating flood control benefits, these results are highly uncertain. A full analysis of uncertainty associated with each estimate is beyond the scope of the current work. It is important to note, however, that many of these uncertainties might be positively correlated, for instance if drainage management is less effective than expected in reducing flooding, it may also be worse at reducing nutrient runoff than expected. A more thorough analysis of costs and benefits may be possible during the design phase of any proposed work.

Farm-level CBA

A farm-level CBA is estimated for two example locations:

1. A 100-acre farm growing cotton on the upper Hyde Park Canal that loses 25% of crop on land flooded.
2. A 100-acre farm growing soybeans on the middle reach of Clayton Canal that loses 50% of crop on land flooded.

To estimate the per acre benefits of flood reduction an estimate of the annual average area flooded, e.g. what average percentage of any given acre is flooded, is needed. This number will vary across the study region, so a lookup table is provided for annual flood damage reductions based on the area flooded in a high-runoff year (approximately a two-year flood event). Note that crop insurance yield products are typically available to cover losses up to 85% of actual production history, meaning only the first 15% of yield losses are paid by the farmer.

Table 7: Reduced flood damage benefits

	Corn $/ac			Soybeans $/ac			Cotton $/ac		
Average flood damage	**100%**	**50%**	**25%**	**100%**	**50%**	**25%**	**100%**	**50%**	**25%**
1%	7.50	3.75	1.88	5.31	2.65	1.33	8.01	4.01	2.00
2%	15.01	7.50	3.75	10.61	5.31	2.65	16.02	8.01	4.01
3%	22.51	11.26	5.63	15.92	7.96	3.98	24.04	12.02	6.01
4%	30.01	15.01	7.50	21.22	10.61	5.31	32.05	16.02	8.01
5%	37.52	18.76	9.38	26.53	13.26	6.63	40.06	20.03	10.01
6%	45.02	22.51	11.26	31.83	15.92	7.96	48.07	24.04	12.02
7%	52.52	26.26	13.13	37.14	18.57	9.28	56.08	28.04	14.02
8%	60.03	30.01	15.01	42.44	21.22	10.61	64.09	32.05	16.02
9%	67.53	33.77	16.88	47.75	23.87	11.94	72.11	36.05	18.03
10%	75.03	37.52	18.76	53.05	26.53	13.26	80.12	40.06	20.03
11%	82.54	41.27	20.63	58.36	29.18	14.59	88.13	44.07	22.03
12%	90.04	45.02	22.51	63.66	31.83	15.92	96.14	48.07	24.04
13%	97.55	48.77	24.39	68.97	34.48	17.24	104.15	52.08	26.04
14%	105.05	52.52	26.26	74.27	37.14	18.57	112.17	56.08	28.04
15%	112.55	56.28	28.14	79.58	39.79	19.89	120.18	60.09	30.04
16%	120.06	60.03	30.01	84.88	42.44	21.22	128.19	64.09	32.05
17%	127.56	63.78	31.89	90.19	45.09	22.55	136.20	68.10	34.05
18%	135.06	67.53	33.77	95.50	47.75	23.87	144.21	72.11	36.05
19%	142.57	71.28	35.64	100.80	50.40	25.20	152.22	76.11	38.06
20%	150.07	75.03	37.52	106.11	53.05	26.53	160.24	80.12	40.06

For our example farms, each will implement CT, install one CD structure, or install 1,000ft of two-stage canal. From the farmer's perspective, nutrient reduction benefits are ignored, as there are no existing payment schemes in this watershed. Each farm is assumed to have crop insurance coverage at 85%, meaning flood damages are capped at 15% of total acreage value. The costs of each measure are offset by any EQIP or other subsidy payment. No subsidy is assumed for CT. All measures incur the land assessment charge.

Based on simulation results from Kris Bass Engineering, Farm 1 on upper Hyde Park sees flood reduction benefits of around 12%, 12%, and 32% for CT, CD, and Two-Stage scenarios respectively. Looking up 12% and 32% in table 7 for cotton with 25% losses (32% reduction in losses at 25% is equivalent to looking up a 16% loss at 50%), then multiplying by 100 acres, gives the flood reduction benefits shown in Farm 1's CBA. For farm 2, simulation results suggest middle Clayton sees flood reduction gains at 3%, 3%, and 97% for CT, CD, and Two-Stage scenarios. The 97% reduction at 50% crop loss is equivalent to a 47% reduction at 100% crop loss, which is in excess of the crop-insurance limit (i.e. some of these gains were never realized losses). This benefit is reduced to 30% for 50% crop loss (lookup 15% for 100% crop loss in table). Looking up these values in the soybean columns and multiplying by 100 acres provides the benefit estimates for farm 2.

Table 8: Farm-level benefit-cost analysis (annualized)

	Farm 1			Farm 2		
	CT	**CD**	**Two-Stage**	**CT**	**CD**	**Two-Stage**
Flood Reduction Benefits	2,402	2,402	6,409	796	796	7,958
Construction Costs	0	-321	-2,268	0	-321	-2,268
Subsidy	0	241	1,505	0	241	1,505
Annual Costs	600	-16	0	1,300	-16	0
Assessment	-1,800	-1,800	-1,800	-1,800	-1,800	-1,800
Benefits-Costs	1,202	409	3,846	296	-1,197	5,395
Net Per Acre Benefits	12	4	38	3	-	54

Costs are based on construction and maintenance costs for a single CD structure and construction, land, and assessment costs for 1,000 ft of two-stage ditch. For CT, additional benefits from no-till accrue to farm 2 from increased soybean income at $13 per acre and for farm 1 for increased cotton production as $6 per acre.

Benefits minus costs and net benefits per acre suggest small to moderate gains for the adoption of these practices by the example farms. Benefits vary based on crop type, menu choice, and location in the study region. CD investment on farm 2 is results in annual costs in excess of benefits. While the benefits exceed the costs in five of six scenarios described here, the per acre benefit in many cases is not large and is uncertain. The net benefits to farmers are also inclusive of subsidies, which may be costly to obtain or might not be considered in analysis by some landowners. In addition, flood reduction is a novel application of all three approaches, and two-stage ditches have not been used in the region previously. For these reasons, caution is warranted in predicting the adoption of these practices.

The two key assumptions in this analysis, and the likely barriers to adoption, are (i) the uncertainty in the magnitude of the flood reduction benefits, and (ii) the assumption of coordination. Evidence of the effectiveness of the menu items in reducing flooding via increased crop production can address item (i). Examples of nearby collective drainage management, and its efficacy and costs can address item (ii).