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Cost of areal reduction of gulf hypoxia through agricultural practice

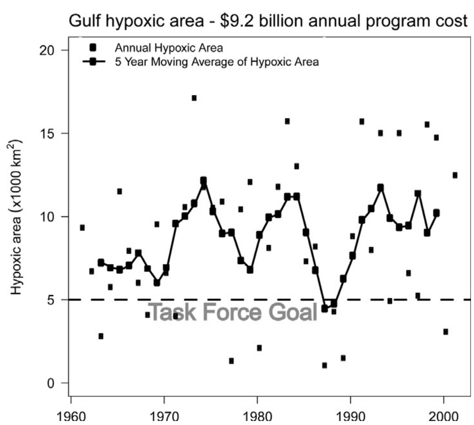
Gerald Whittaker [a,*], Bradley L. Barnhart [a], Raghavan Srinivasan [b], Jeffrey G. Arnold [c]

[a] Agricultural Research Service, USDA, Corvallis, OR, United States
[b] Departments of Ecosystem Sciences and Management and Biological and Agricultural Engineering at Texas A&M University, United States
[c] Agricultural Research Service, USDA, Temple, TX, United States

HIGHLIGHTS

- We calculate the cost to reduce Gulf hypoxia using agricultural conservation policy.
- Total annual policy cost is 9.2 billion USD not including agricultural price shocks.
- The Task Force hypoxia reduction goal is met in only twice in a 40 year simulation.

GRAPHICAL ABSTRACT



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ABSTRACT

A major share of the area of hypoxic growth in the Northern Gulf of Mexico has been attributed to nutrient runoff from agricultural fields, but no estimate is available for the cost of reducing Gulf hypoxic area using agricultural conservation practices. We apply the Soil and Water Assessment Tool using observed daily weather to simulate the reduction in nitrogen loading in the Upper Mississippi River Basin (UMRB) that would result from enrolling all row crop acreage in the Conservation Reserve Program (CRP). Nitrogen loadings at the outlet of the UMRB are used to predict Gulf hypoxic area, and net cash farm rent is used as the price for participation in the CRP. Over the course of the 42 year simulation, direct CRP costs total more than $388 billion, and the Inter-Governmental Task Force goal of hypoxic area less than 5000 square kilometers is met in only two years.

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1. Introduction

Hypoxic growth in the Northern Gulf of Mexico causes large ecological damage and associated economic costs. Nutrients from agricultural practices in the Mississippi/Atchafalaya River Basin (MARB) are considered to be the major factor contributing to this hypoxic growth

* Corresponding author at: Agricultural Research Service, 3450 SW Campus Way, Corvallis, OR 97331, United States.
E-mail address: Jerry.Whittaker@ars.usda.gov (G. Whittaker).

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(Broussard et al., 2012; Raymond et al., 2012). In 1997 the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force (Task Force) was established for support of research and management activities dealing with eutrophication in the northern Gulf of Mexico. Task Force membership currently includes 5 federal agencies, 12 states and the tribes within the Mississippi/Atchafalaya River Basin. The Task Force has set a goal for Gulf hypoxic area of 5000 square kilometers for a 5-year moving average (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2008). There have been studies of the cost of reducing agricultural nutrient loadings to the Mississippi River (Rabotyagov et al., 2010), and studies that calculate the amount of nutrient reduction required to meet the 5000 square kilometer goal (Forrest et al., 2011, 2012; Obenour et al., 2012; Scavia et al., 2013), but no calculation of the cost to approach the Task Force goal. We offer an estimate of the cost of an agricultural policy to reduce agricultural nutrient loadings in the Mississippi and the effect on the size of the Gulf hypoxic area that results.

2. Incentive policy for nutrient reduction

Among many agricultural conservation practices affecting stream nutrient loadings, the Conservation Reserve Program (CRP) provides a convenient policy for evaluation of hypoxia mitigation. The program is in effect a land-use change from agricultural to grassland, and is much simpler to model than alternative conservation practices such as buffer strips, contour farming, terraces, diversions, filter strips and others (Wang et al., 2011). The CRP is also the most effective in a physical sense, since it ends all agricultural operations including soil disturbance and application of agricultural chemicals. The price of application of the CRP conservation practice is also simpler to compute than alternative practices. Price calculation of other practices requires apportionment of labor, machinery and other inputs with the effect on yield. Under the CRP, the government pays a producer to take land out of production and plant a long-term, resource-conserving cover. The CRP establishes payment rates based on the average cash rent for comparable land (Food, Conservation, and Energy Act of 2008, Public Law 110—246, title II, section 2110, paragraph (b), dated June 18, 2008). The data on average cash rent of non-irrigated farm land used in CRP calculations is available at http://quickstats.nass.usda.gov/sector_desc=ECONOMICS&commodity_desc=RENT&agg_level_desc=COUNTY, accessed 9/1/2014.

The Upper Mississippi River Basin (UMRB) was selected for simulation of the effect of participation in the CRP on the size of the Gulf hypoxic area. Land use in the UMRB is approximately 40% agricultural, and the basin contains about 15% of the drainage area of the MARB. USGS estimates using the SPARROW (Spatially Referenced Regression On Watershed attributes) model (Smith et al., 1997) calculate that about 52% of the nitrate discharged to the Gulf is from the UMRB (Goolsby et al., 1997).

3. Use of CRP to meet task force goal

Given the magnitude of estimates of nutrient reduction required to meet the Task Force goal, about 60% by the most recent estimate (Obenour et al., 2013; Scavia et al., 2013), we hypothesized that a very large change to the current agricultural production configuration in the UMRB would be required to achieve a useful reduction in Gulf hypoxic area. The USDA Conservation Effects Assessment Project (CEAP) estimates that treatment of all under-treated acres in the UMRB would decrease nitrogen loadings by 33% from current agricultural practice (Conservation Effects Assessment Project (CEAP) Cropland Modeling Team, 2012), clearly insufficient to meet the Task Force goal. Therefore we simulated the change of all row crop land in the UMRB (54,185,298 acres in UMRB-SWAT) to grass under the Conservation Reserve Program. We note that the policy we simulate removes a large part of the US Corn Belt from production. We do not propose the enactment of such a change. The effects of such a large change would propagate through commodity prices and employment, and could even lead to internal migration. To model a politically feasible policy, for example, the acreage could be distributed among all watersheds in the Mississippi Basin. For the purposes of modeling and simulation of a perturbation of the nutrient delivery system to the Gulf of Mexico, the removal from production of all acreage in a single basin is simpler, and achieves the same result as an analysis of a distributed CRP acreage.

4. Methods

We used the Soil and Water Assessment Tool (SWAT) for simulation of the effect of an agricultural conservation policy on nutrient loadings in the Mississippi (Arnold and Fohrer, 2005). SWAT is a landscape level model for simulation of distributed hydrology, plant growth, nutrient use and fate, and agricultural practices, among many other processes. SWAT is widely used, and refereed journal citations of SWAT currently number 1451. SWAT divides the landscape into sub-watersheds connected by a stream network. Within each sub-watershed, all unique combinations of land cover, soil and soil type are modeled individually. While designed for use on large, ungauged basins, all of the processes that SWAT simulates can be calibrated to available data. Our selection of SWAT was based on the proven capabilities for simulation of hydrology, which compares favorably with specialized hydrological models (Smith et al., 2012), and for simulation of agricultural practices.

A special version of SWAT has been set up for the study of biofuel feedstock production in the UMRB. A detailed description of the inputs to SWAT-UMRB, including land use, management practices, soils, fertilizer application, and meteorological data, is available in Srinivasan et al. (2010). SWAT_UMRB was set up with 131 sub-watersheds, the 8 digit HUCs delineated by the USGS. SWAT-UMRB runs on a daily time step, and uses maximum and minimum temperatures and daily precipitation for basic weather inputs, where a separate weather data set was calculated from historical observations for each sub-basin for 1960–2001 using the gridded data approach of Di Luzio et al. (2008). National Hydrography Dataset was the source for stream configuration and the accompanying 90 m digital elevation model (DEM) provided slopes for watershed configuration and topographic parameter estimation using the SWAT ArcView interface. The soil data used was from the STATSGO base from the NRCS, USDA (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053629). Land use was obtained from the Cropland Data Layer (CDL) (http://nassgeodata.gmu.edu/CropScape/) and 2001 National Land Cover Data Base (NLCD2001, http://www.mrlc.gov/index.php).

SWAT-UMRB has been validated and applied in several studies (Secchi et al., 2011). The simulation of nitrogen loadings is the basis of this study, and a comparison of the simulated sum of nitrates and nitrites compared with observed values at Grafton, IL is shown in Fig. 1. The mean error is 7%. The distribution of errors is approximately normal, with a mean of 15.4 thousand metric tons and a standard deviation of 104.0. The two largest errors are an under-prediction of −232 thousand metric tons in 1987, where the simulation lags a year behind a large multi-year decrease in nitrogen loading, and an over-prediction of 226 thousand metric tons in 1993.

There has been no published linkage from SWAT-UMRB simulation outputs to the size of Gulf hypoxic area. Current biological models of Gulf hypoxic area use spring nitrogen loadings measured close to the mouth of the Mississippi River as a primary determinant (Scavia et al., 2013). There have also been several studies that use linear regression on weather based inputs and spring nitrogen loading at the mouth of the Mississippi River to predict Gulf hypoxic area (Turner et al., 2012; Mattern et al., 2013). There is a high correlation between monthly nitrogen flux at the outlet of the UMRB at Grafton, IL, and monthly nitrogen flux at the outlet of the MARB, and a strong correlation among nitrogen flux at both locations and the estimated area of Gulf hypoxia (Goolsby, 2000). We hypothesized that a statistical model regressing the observed