# Multifunctional Agriculture in the United States

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*We evaluated possible changes to current farming practices in two Minnesota watersheds to provide insight into how farm policy might affect environmental, social, and economic outcomes. Watershed residents helped develop four scenarios to evaluate alternative future trends in agricultural management and to project potential economic and environmental outcomes. We found that environmental and economic benefits can be attained through changes in agricultural land management without increasing public costs. The magnitude of these benefits depends on the magnitude of changes to agricultural practices. Environmental benefits include improved water quality, healthier fish, increased carbon sequestration, and decreased greenhouse gas emissions, while economic benefits include social capital formation, greater farm profitability, and avoided costs. Policy transitions that emphasize functions of agriculture in addition to food production are crucial for creating change. We suggest that redirecting farm payments by using alternative incentives could lead to substantial environmental changes at little or no extra cost to the taxpayer.*

*Keywords: suspended sediment, nutrient runoff, greenhouse gases, carbon sequestration, farm policy*

**Although the primary role of agriculture is to** produce food and fiber, many other functions are important, such as land conservation, maintenance of landscape structure, sustainable management of natural resources, biodiversity preservation, and contribution to the socioeconomic viability of rural areas (OECD 2001). The multiple functions of agriculture have risen to prominence in global trade negotiations (Romstad et al. 2000, Vatn 2002). Japan, South Korea, and several European countries (including Norway and Switzerland) have argued that small to moderate-sized, independent farms can affect the economic, environmental, and social health of rural areas and preserve cultural heritage (DeVries 2000, Romstad et al. 2000). In these countries that value the nonmarket benefits of agriculture, government is encouraged to promote multiple functions of agriculture through "green box payments," so called because they do not distort trade and are not price supports (Romstad et al. 2000).

Farmers, policymakers, environmentalists, and the public increasingly recognize that US farm policies, despite the inclusion of conservation programs, can have harmful effects on both farmers and the environment. It is also increasingly clear that farmers can produce nonmarket "goods," such as environmental and social benefits, as well as food and fiber (Cochrane 2003). How can US farmers be encouraged to produce more of these multiple goods?

US agricultural policies subsidize a selected set of commodities. Agricultural commodities—corn, wheat, soybeans, cotton, and rice—received 89% of the $91.2 billion in commodity payments from 1995 through 2002 to boost the incomes of crop and livestock farmers. Soybeans and corn received 56% of those dollars (EWG 2003). As a result of agricultural policies, technological choices, and market infrastructure, US agriculture perennially produces surpluses (Levins 2000). The consequences of this policy include environmental concerns, fewer agricultural producers, and depressed rural economies (Mitsch et al. 2001, Rabalais et al. 2001, Tilman et al. 2001, Cochrane 2003). Conservation policies have attempted to mitigate environmental problems through land retirement programs, technical assistance, and cost-share programs to influence farming practices. Between 1985 and 2002, approximately 70% of agricultural conser-

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vation spending was for acreage retirement, leaving approximately 30% for working agricultural lands, which represent approximately half the area of privately held land (excluding Alaska) in the United States (Claassen et al. 2001).

We evaluated changes to current farming practices in two Minnesota watersheds to provide insight into how policy could be structured to provide environmental, social, and economic outcomes on working agricultural lands. Working with leaders and residents from two Minnesota watersheds, a team of 17 members, including 2 farmers, developed alternative future agricultural scenarios—ranging from the increased adoption of minimum tillage to the reestablishment of perennial plants and wetlands—and projected potential economic and environmental outcomes. Specifically, we addressed water quality, fish health, greenhouse gas emissions, carbon sequestration, farm profitability, avoided costs, and formation of social capital.

## Study areas

We chose the two study areas, Wells Creek and Chippewa River, to reflect variation in agricultural watersheds in the upper Midwest. Wells Creek is a tributary to the Mississippi River in Goodhue County, southeastern Minnesota (figure 1). Farmers make up 54% of the 16,264-hectare (ha) study area's 1500 residents; an additional 30% of the population lives in rural areas (table 1). The average slope is 6.5%, and the area is 26% wooded, 10% grass or pasture, and 61% cultivated—mostly corn and soybeans, with some small grain and alfalfa hay. Wells Creek historically supported a cold-water fish assemblage, but nine species collected in 1999 were primarily fish that tolerate high temperatures (Patrick Rivers, Minnesota Department of Natural Resources, Lake City, Minnesota, personal communication, 30 October 2000). Brown trout, intolerant of high temperature and sediment, were present in low numbers. The Chippewa River study area is a 17,994-ha subbasin of the Chippewa River basin, primarily in Chippewa County, with a small section in Swift County in western Minnesota (figure 2). In the Chippewa River study area, about 89% of the 6357 residents live in the city of Montevideo (table 1). This study area is flat (slope approximately 2%), with extensive tile drainage, and 81% of the area is planted primarily with corn and soybeans, managed with both conventional and conservation tillage. The Chippewa River is a warm-water river, with a fish assemblage of 19 species (Bruce Gilbertson, Minnesota Department of Natural Resources, Spicer, Minnesota, personal communication, 30 October 2000). Game fish sought by anglers are present in low numbers.

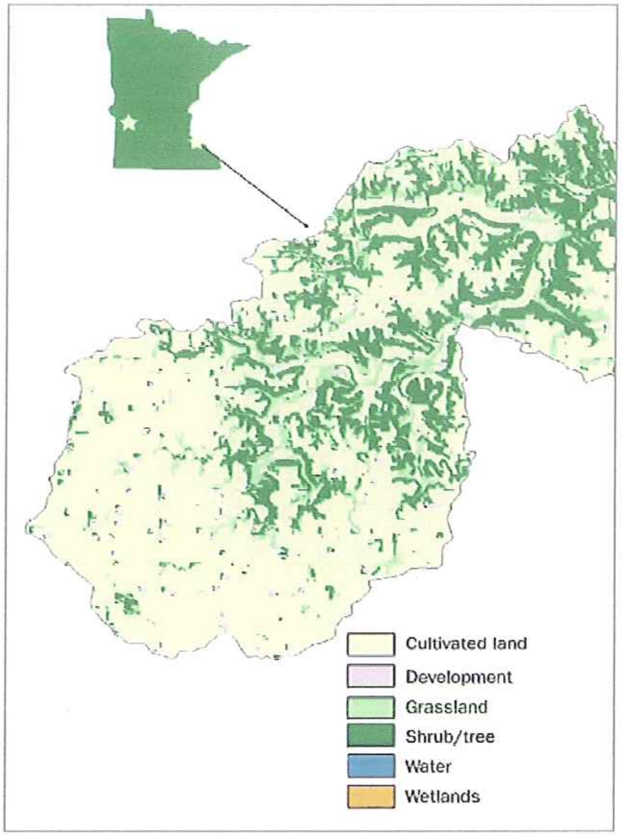

*Figure 1. Wells Creek study area (baseline conditions in 1999), located in Goodhue County in southeast Minnesota.*

Farms in both study areas continue to grow in size; many farmers buy out their neighbors, who switch professions or retire. Leasing land has become more common in recent years, with management companies operating on large, typically noncontiguous areas. In Wells Creek, 1500 farms operated in 1997, down 12% from 1700 farms in 1987; during the same period, corn planting grew by 22% and soybean planting by 74%, reducing the land devoted to dairy farming. Similarly, in Chippewa County the number of farms fell 25% in 10 years, to 618 farms in 1997. The area planted with corn and soybeans increased by 72% and 37%, respectively, replacing small grain.

*Table 1. Demographic and physical characteristics of the Wells Creek and Chippewa River study areas.*

| | Population | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Study area** | **Farm** | **Rural (nonfarm)** | **Incorporated** | **Total** | **Average slope (%)** | **Rainfall (cm/yr)** | **Area (ha)** | **Soil** |
| Wells Creek | 810 | 450 | 240 | 1500 | 6.5 | 75 | 16,264 | Silty-loam to silt-loam |
| Chippewa River | 150 | 525 | 5682 | 6357 | 2.2 | 64 | 17,994 | Silt-clay to silt-loam |

*Source:* Data are from the Wells Creek Watershed Association, the 2000 census for Chippewa County, and county estimates of the Office of Social and Economic Trend Analysis at *www.seta.iastate.edu/census/county.*

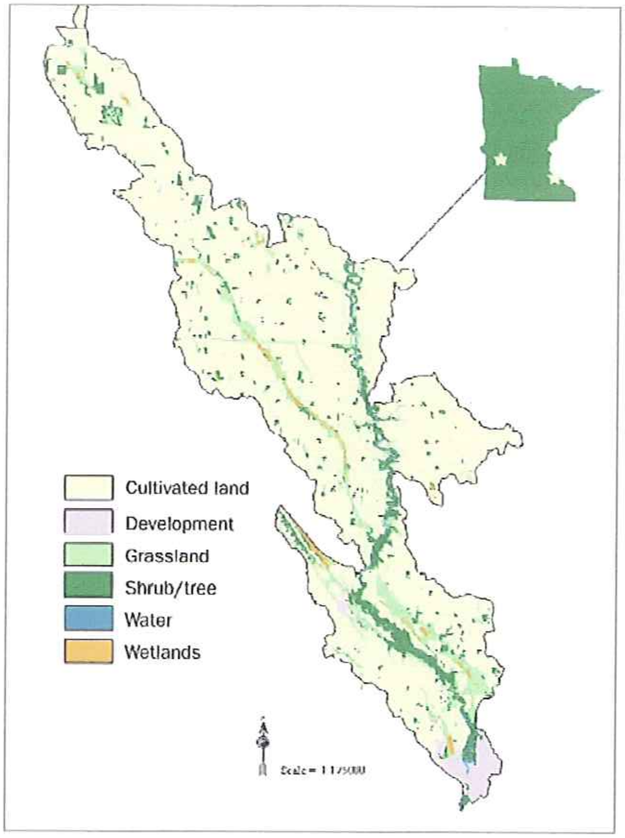

*Figure 2. Chippewa River study area (baseline conditions in 1999), located in Chippewa and Swift Counties in southwest Minnesota.*

## Scenario development

We created four possible scenarios of future land use to provide a basis for our environmental analysis in relation to conditions in 1999. Our goal was to use the scenarios to analyze varying levels of environmental, economic, and social changes that could result from these alternative future land-use patterns. Scenarios were citizen driven, based on historical materials created by basin residents and on results from focus groups and interviews. Focus groups (40 rural residents and producers living in the study areas) outlined their desires and expectations for future agricultural land use in each study area. The focus groups provided direction on broad goals or outcomes in production practices under several scenarios. Specific farming systems were not described in detail, but sufficient information was obtained to allow the team to incorporate a set of production activities that represented the range of possible practices outlined by the participants. Once a set of production activities for each scenario was developed, focus groups were reconvened and additional feedback was solicited, to ensure that this set of farming systems was representative of the range of possible and reasonably practical production activities for the watersheds. Scenarios varied slightly between study areas to account for local conditions.

After these focus group meetings, the team members, including the two farmers, created more detailed descriptions of the scenarios for subsequent analysis (tables 2, 3). These scenarios were used to evaluate quantitative changes in environmental effects and in the associated social costs, short-term production costs, and farm income. In addition, potential social impacts were described on the basis of information gathered through interviews, reviews of institutional mission statements, and other approaches.

The final scenarios were based on a continuation of current trends (scenario A); on best management practices, or BMPs (scenario B); on maximizing diversity and profitability (scenario C); and on increased vegetative cover (scenario D). Scenario A (based on current trends) projected a continued decrease in the number of farms and an increase in acreage for corn, soybeans, and sugar beets. Small, diversified farms were present, although comprising an increasingly smaller proportion of the total study area. Scenario B (based on BMPs) involved conservation tillage, 30-meter (m) riparian buffers along both sides of all streams, and recommended fertilizer application rates (i.e., no overapplication). Scenario C (based on high diversity and profitability) focused on increased farm profitability to move beyond BMPs. In addition to the changes under scenario B, scenario C also included wetland restoration and increased crop diversity, with some conversion of cropland to organic products, 5-year crop rotations, perennial crops, and managed intensive rotational grazing (MIRG). The 5-year crop rotation included an increase in small grains and alfalfa and a reduction in area under corn–soybean and corn–sugar beet rotations. Organic production was assumed to occupy less than 5% of the cropping area and was not explicitly modeled in the analyses. Scenario D (based on increased vegetative cover) extended scenario C by adding perennial cover; grasslands replaced cultivated lands on an additional 7% to 14% of the area, riparian buffers that were converted to grass or trees were widened to 90 m, and all row crops were planted with cover crops. The increased grassland reflected conversion to MIRG, restored prairie, and other grasslands; most of the grasslands and prairie were located on steeper lands (> 6% in Wells Creek and > 3% in the Chippewa River study area). The spatial distribution of these changes can be viewed on maps at the Land Stewardship Project's Web site, *www.landstewardshipproject.org/programs_mba.hmtl.*

Hypothetical landscapes were simulated to implement the four projected scenarios (tables 2, 3) by changing land use on geographic information system (GIS) layers for each study area. Scenario A had little effect on land-use practices. Scenario B added buffers but did not change cropping patterns. Scenario C reduced the percentage of cultivated land dedicated to corn and soybeans from 89% to 37% at the Chippewa River study area, and from 74% to 36% at Wells Creek, with concomitant increases in small grains and hay. The area of land in MIRG increased in both study areas. In both study areas, scenario D led to dramatic increases in grasslands not receiving government support, from 8% to 15% at the Chippewa River site and from 10% to 20% at Wells Creek, mostly due to an increase in MIRG. Under scenario D, the Wells Creek area

*Table 2. Land use, in hectares, in the Wells Creek study area under the current baseline (USDA 1999) and four hypothetical scenarios: scenario A (continuation of current practices), scenario B (best management practices), scenario C (high diversity and profitability), and scenario D (increased vegetative cover).*

| Land use | Baseline | Scenario A | Scenario B | Scenario C | Scenario D |
|---|---|---|---|---|---|
| Grassland | 1656 | 1656 | 1656 | 1656 | 3319 |
| Small grains–alfalfa (CT) | 1312 | 1046 | 2022 | 5253 | 3467 |
| Small grains–alfalfa (CN) | 834 | 665 | 0 | 0 | 0 |
| Corn (continuous) (CT) | 1111 | 0 | 1348 | 1318 | 870 |
| Corn (continuous) (CN) | 320 | 0 | 0 | 0 | 0 |
| Corn–soybeans (CT) | 2758 | 3626 | 5585 | 2184 | 1441 |
| Corn–soybeans (CN) | 3172 | 4171 | 0 | 0 | 0 |
| Cover crops | 0 | 0 | 0 | 0 | 424 |
| Riparian buffer | 0 | 0 | 553 | 537 | 1851 |
| Deciduous, wooded | 4223 | 4223 | 4223 | 4223 | 4223 |
| Developed | 372 | 372 | 372 | 372 | 372 |
| Wetlands | 21 | 21 | 21 | 238 | 238 |
| Open water | 32 | 32 | 32 | 32 | 32 |
| Not classified | 28 | 28 | 28 | 28 | 28 |

CN, conventional tillage; CT, conservation tillage.

*Table 3. Land use, in hectares, in the Chippewa River study area under the current baseline (USDA 1999) and scenario A (continuation of current practices), scenario B (best management practices), scenario C (high diversity and profitability), and scenario D (increased vegetative cover).*

| Land use | Baseline | Scenario A | Scenario B | Scenario C | Scenario D |
|---|---|---|---|---|---|
| Grassland | 1464 | 1464 | 1464 | 1464 | 2712 |
| Small grains–alfalfa (CT) | 229 | 185 | 527 | 7413 | 4962 |
| Small grains–alfalfa (CN) | 312 | 83 | 0 | 0 | 0 |
| Corn–soybeans (CT) | 3796 | 6232 | 11,082 | 4607 | 3082 |
| Corn–soybeans (CN) | 7587 | 5309 | 0 | 0 | 0 |
| Corn–sugar beets (CN) | 1494 | 1610 | 1454 | 560 | 375 |
| Cover crops | 0 | 0 | 0 | 0 | 3144 |
| Riparian buffer | 0 | 0 | 356 | 340 | 1240 |
| Deciduous, wooded | 1080 | 1080 | 1080 | 1080 | 1080 |
| Developed | 637 | 637 | 637 | 637 | 637 |
| Wetlands | 154 | 154 | 154 | 653 | 653 |
| Open water | 108 | 108 | 108 | 108 | 108 |
| Not classified | 2 | 2 | 2 | 2 | 2 |

CN, conventional tillage; CT, conservation tillage.

included a larger increase in livestock numbers than projected in the Chippewa River area. In addition, in both study areas, the total area of riparian buffers under scenario D was triple that under scenarios B and C.

## Projected environmental effects

The magnitude of benefits among scenarios depended on the magnitude of changes to agricultural practices. Environmental benefits include improved water quality, healthier fish assemblages, increased carbon sequestration, and decreased greenhouse gas emissions.

**Water quality.** Sediment, nitrogen (N), and phosphorus (P) loadings were estimated for baseline land use (as of 1999) and for each scenario using ADAPT (agricultural drainage and pesticide transport), a field-scale model for water table management. For ADAPT (and for similar biophysical process models), more confidence exists in estimates of sediment, N, and P loss than in estimates of pesticide leaching potential or pesticide loss. Thus, estimates of pesticide leaching or loss were not included in our analysis. ADAPT provides edge-of-field estimates for nutrient and soil losses and can model fields with tile drainage, a dominant feature in the Chippewa River study area and increasingly in the Wells Creek study area. We estimated sediment, N, and P delivery to the mouth of each stream with a modification of ADAPT (Gowda et al. 1999) that aggregates field-edge estimates across each study area (Zimmerman et al. 2003). We developed parameter estimates for leaf area index (LAI) and N and P input so that ADAPT could be used to estimate sediment and nutrient losses associated with MIRG that were consistent with monitoring data from similar fields (Digiacomo et al. 2001). LAI was adjusted on the basis of farm records of the stocking rate and the number of times a paddock was grazed. The N and P application rates for all livestock systems were based on the typical composition and per capita volume of manure. A GIS was used to create data input files for the ADAPT model, reflecting the spatial distribution of current production practices in the study areas. Modifications of ADAPT have been calibrated in several river basins in Minnesota for different soil types, crops, slopes, and other land characteristics (Davis et al. 2000, Dalzell et al. 2001, Westra et al. 2002). Although these studies suggest that the predictions of the modified ADAPT model are both unbiased and precise, we relied only on relative estimates of sediment and nutrient loading among scenarios.

Changing farming practices according to the scenarios reduced the delivery of sediment, N, and P to the mouth of the river in both study areas (table 4). There was little projected change in sediment or nutrient loading if current trends (scenario A) continued in either study area. The greatest reductions in sediment and nutrient loading occurred under scenario D; for Wells Creek, sediment loading was reduced by more than 80%. The goal of reducing N by 30% in the Mississippi River to reduce hypoxia in the Gulf of Mexico (set in 2001 by the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force; *www.epa.gov/msbasin/actionplan.htm*) would be possible in the Wells Creek study area under scenarios B, C, and D. In the Chippewa River study area, implementing BMPs (scenario B) would not meet the goal (table 4); a more diverse farming system with more vegetation would be needed (scenario C or D). With respect to P, all scenarios for both study areas, except the continuation of current trends (scenario A), would meet the state of Minnesota's goal of a 40% reduction in loading.

*Table 4. Percentage change in various ecological and economic indicators from baseline conditions to those under four scenarios, Wells Creek and Chippewa River study areas.*

| Indicator | Baseline | Scenario A | Scenario B | Scenario C | Scenario D |
|---|---|---|---|---|---|
| **Wells Creek** | | | | | |
| Sediment (Mg/yr) | 36 | 4 | –31 | –56 | –84 |
| Nitrogen (kg/yr) | 1364 | –7 | –37 | –63 | –74 |
| Phosphorus (kg/yr) | 3430 | –4 | –54 | –70 | –71 |
| Greenhouse gas (MTCE) | 5003 | –2 | –13 | –19 | 54 |
| SOC (metric tons/yr) | 3902 | –3 | 31 | 41 | 86 |
| Lethal fish effects (days/yr) | 6.7 | 10 | –57 | –72 | –98 |
| Production costs ($/yr)[a] | 13,521,781 | –1 | –3 | –8 | 45 |
| Nitrogen fertilizer use (kg/yr) | 851,260 | –7 | –47 | –73 | –85 |
| Net farm income ($/yr)[a] | 2,089,045 | –1 | –1 | 12 | 105 |
| Commodity payments ($/yr) | 1,369,864 | –1 | –6 | –44 | –63 |
| CRP payments ($/yr) | 114,896 | 0 | 113 | 110 | 378 |
| Commodity + CRP ($/yr) | 1,745,261 | –1 | 3 | –27 | –24 |
| **Chippewa River** | | | | | |
| Sediment (Mg/yr) | 1.78 | –9 | –25 | –35 | –49 |
| Nitrogen (kg/yr) | 6348 | 1 | –17 | –51 | –62 |
| Phosphorus (kg/yr) | 2322 | –5 | –42 | –70 | –75 |
| Greenhouse gas (MTCE) | 2065 | 0 | –6 | –39 | –37 |
| SOC (metric tons/yr) | 4792 | 17 | 37 | 59 | 112 |
| Lethal fish effects (days/yr) | 11.2 | 2 | 0 | 0 | –10 |
| Production costs ($/yr)[a] | 9,201,615 | 1 | –3 | –19 | –38 |
| Nitrogen fertilizer use (kg/yr) | 875,205 | 1 | –8 | –62 | –90 |
| Net farm income ($/yr)[a] | 979,255 | 2 | 3 | 58 | 32 |
| Commodity payments ($/yr) | 1,385,998 | 2 | –3 | –56 | –70 |
| CRP payments ($/yr) | 306,114 | 0 | 27 | 26 | 245 |
| Commodity + CRP ($/yr) | 1,692,112 | 2 | 3 | –41 | –13 |

CRP, Conservation Reserve Program; MTCE, metric tons carbon equivalent; SOC, soil organic carbon.

*Note:* Projections involve the continuation of current farming practices (scenario A), best management practices (scenario B), practices aimed at inceasing diversity and profitability (scenario C), and practices that increase vegetative cover (scenario D).

a. Production costs and net farm income represent the change from baseline for farm products for 2000 (Southeast Farm Business Management and West Central Farm Business Management programs for 1999; *www.mgt.org/fbm/reports/1999/se/se.htm*).

**Fish populations.** Zimmerman and colleagues (2003) calculated the daily suspended sediment concentrations in each stream using sediment loading predicted by the ADAPT model, streamflow, and stream bank erosion. By calculating the total number of days each year that concentrations of suspended sediment reached lethal or sublethal thresholds for the respective fish assemblages, they estimated the magnitude of sublethal or lethal effects due to suspended sediment on the resident fish in both study areas. The number of sublethal and lethal events was calculated using Newcombe and Jensen's (1996) meta-analysis, which quantitatively related fish response to concentrations of suspended sediment and duration of exposure. Sublethal effects are defined as moderate habitat degradation, impaired homing, physiological stress (such as coughing or increased respiration), and reduction in feeding rates or feeding success. Lethal effects are reduced growth rate, delayed hatching, reduced fish density, increased predation, severe habitat degradation, and mortality (Newcombe and Jensen 1996). Lethal and sublethal effects on fish generally increased as the suspended sediment concentrations and duration of exposure increased, although the nature of this relationship varied with the fish assemblages. Thresholds corresponding to juvenile and adult salmonids were used to represent the Wells Creek assemblage, whereas the Chippewa River was represented by adult freshwater nonsalmonids, comprising mainly warm-water species.

The Chippewa River study area had more mean annual days with sublethal and lethal events than Wells Creek under baseline conditions. Changes in sediment loading decreased lethal events up to 98% in Wells Creek, but had only a minor effect in the Chippewa River (table 4). In the Chippewa River area, the number of days with sublethal and lethal events did not change significantly across scenarios. Because of the flat topography of the Chippewa River study area, sediment concentrations were often lower but of longer duration than in Wells Creek. In addition, the fish species in the Chippewa River are probably more sensitive to extended exposure to suspended sediment than the fish in Wells Creek (Newcombe and Jensen 1996).

Although difficult to predict, reductions in lethal and sublethal events related to suspended sediment for fish in Wells Creek could allow a change in the fish assemblage to one with an increased number of cool-water or cold-water species. If expanded riparian areas provided shade for 50% of the stream surface, trout populations in Wells Creek would be expected to increase (Blann et al. 2002). Wells Creek is in a region that historically supported brook trout; thus, scenario D could be important for stream restoration.

**Greenhouse gases.** Greenhouse gases produced by agriculture are major contributors to the greenhouse effect (Lal et al. 1999). Agriculture in Minnesota contributes carbon dioxide ($CO_2$; 18.5 million metric tons carbon equivalent [MTCE] per year), methane ($CH_4$; 2.8 million MTCE), and nitrous oxide ($N_2O$; 1.2 million MTCE) to US greenhouse gases (USEPA 2003). In the United States, about 43 million MTCE of $CO_2$ is released from agricultural energy use and soil carbon losses each year. Direct energy use accounts for 15 million MTCE, and indirect energy use results in an additional 13 million MTCE. Indirect energy use includes production of farm inputs, with 73% related to fertilizer production. Losses of soil carbon through tillage and conversion of land between uses (e.g., wetland to cropland) result in 15 million MTCE of $CO_2$ emissions (Faeth and Greenlaugh 2000). Pasture-raised animals require less fuel for operations and less feed than do confined animals. A study by the New York dairy industry indicated that wide-scale use of pasture-based systems could lead to 27% to 33% less soil erosion and 23% to 26% less fuel use in crop production (Rayburn 1993). Such systems would also tie up 14 million to 21 million metric tons of $CO_2$ and 5.2 million to 7.8 million metric tons of $N_2O$ in the organic matter of pasture soils. As discussed below, pasture sequesters and holds carbon in the soil, in contrast with tillage-based systems, in which carbon is released each year.

Emissions of $N_2O$ add about 88 million MTCE each year in the United States, including 49 million MTCE from direct emissions, such as fertilizer application and N fixation by crops (Faeth and Greenlaugh 2000). Pasture-raised livestock systems require fewer field crops for their feed than confined systems; thus, reductions in $N_2O$ could result from shifting animal production to pasture. On a watershed scale, converting land to pasture, increasing rotations, and widening riparian buffers can reduce N losses from fields. In the Chippewa River study area, land-use changes were calculated to reduce losses of $N_2O$ by 83%, from 17,562 kilograms (kg) per year to 2958 kg per year, using the guidelines of the Intergovernmental Panel on Climate Change (IPCC 2001).

Methane is a by-product of ruminant digestion and decomposition of manure. Dry manure, as deposited on pastures, produces insignificant amounts of $CH_4$ (USEPA 2004). In contrast, dairy cows and feedlot steers in confinement produce 427 and 10 kg, respectively, of carbon equivalents per animal per year (USEPA 2004). In 1997, the dairy, beef, and swine sectors of the US livestock market produced 15.2 million MTCE from manure (USEPA 1999). About 60% of the $CH_4$ produced by animals is generated during digestion. Although animals on pasture produce less $CH_4$ per unit of feed consumed, they may need to eat greater volumes of feed to maintain health and production (Hegarty 2001); however, this relationship is poorly understood.

Greenhouse gas emissions associated with our scenarios were calculated from estimated changes in N fertilizer use (table 4) based on farmer surveys. These estimates include projected changes in land use, changes in the number and type of livestock (to determine the contribution of ruminants and manure to projected emissions), and potential reductions in N fertilizer use when farmers take credit for N in legumes and animal manure fertilizer. Emissions of $N_2O$ from altered fertilizer use were calculated using guidelines from the IPCC (2001). For livestock, all animal numbers and management, except for ruminants, were held constant among scenarios. Ruminants were differentiated among dairy and beef heifers, cows, and steers and were classified into those housed in confinement, conventionally grazed, and grazed using MIRG. Emissions of $CH_4$ and $N_2O$, with respective global warming potentials of 21 times and 310 times that of $CO_2$ for each class, were calculated and converted to carbon equivalents according to IPCC guidelines (IPCC 2001). For MIRG, we assumed that animals grazed in paddocks for up to 24 hours, eight times per season, to allow for the recovery and continued growth of pasture plants both above and in the soil. Under scenario D, the area of pastured grasslands grazed using MIRG doubled in each study area. Therefore, the number of ruminant animals in scenario D increased by 6785 dairy animals (125%) and 1710 beef animals (125%) in Wells Creek, and by 640 dairy animals (252%) and 515 beef animals (90%) in the Chippewa area.

A reduction in greenhouse gases of as much as 39% is predicted in the Chippewa River study area if scenario C is adopted (table 4). In the Wells Creek study area, the predicted reductions are smaller, because dairy animals generate more $CH_4$ than beef cattle. If dairy animals were increased by an additional 125% in the Wells Creek study area, greenhouse gas emissions would increase by 54% (table 4). However, this increase could be offset by the carbon sequestration potential of pastures replacing cropped fields.

**Carbon sequestration.** Management of agricultural soils, specifically tillage and crop residue management, affects soil carbon content. Carbon content is also affected by temperature, soil moisture, soil type, frost depth, animal activity, and biomass production. Robertson and colleagues (2000) estimated that reduced tillage cropping systems in the United States could sequester 30.0 grams carbon per $m^2$ per year (0.3 metric ton per ha per year). Even without conservation tillage, an increase of up to 0.1 metric ton per ha per year in soil organic carbon (SOC) may occur from conventional management of cropland (US Department of State 2000). Perennial crops have the potential to capture and hold large quantities of carbon as SOC, accumulating up to 0.9 metric ton carbon per ha per year in Minnesota (Paustian et al. 1997). There are many measurements of rates of SOC accumulation across agricultural practices (Huggins et al. 1998, Post and Kwon 2000, Kucharik et al. 2003, West and Marland 2003), but it is unclear how long SOC will continue to accumulate with changes in management practices. We calculated the potential increase in SOC (in metric tons per ha per year) for land uses projected under our four scenarios, using a value of 0.1 for alterative cropping (US Department of State 2000), 0.3 for conservation tillage (Robertson et al. 2000), 0.9 for pastures (Follett et al. 2001), and 2.0 for wetlands (Lal et al. 1999). In the Wells Creek study area, SOC would increase by 86%, from 3902 to 7245 metric tons per year, under scenario D. This increase would offset by 22% the greenhouse gas emissions caused by $CH_4$ from increasing the number of cattle. In the Chippewa River study area, SOC was estimated to increase from 4792 to 10,147 metric tons per year (an increase of 112%) for scenario D (table 4), increasing total net carbon storage (SOC minus total greenhouse gas production) by 328%.

### Short-term economic effects

Economic benefits evaluated in our study included social capital formation and greater farm profitability. Greater farm profitability was associated with scenarios with increased vegetative cover. We suggest that redirecting farm payments to provide alternative incentives could lead to substantial environmental changes at little or no extra cost to taxpayers.

**Farm production costs.** Adoption of any of the scenarios would change the set of inputs used in the mix of production activities and the costs of production. For example, under baseline conditions, 851,260 kg of N fertilizer per year is applied at the Wells Creek study area, and 875,205 kg per year is applied at Chippewa River (table 4). Because many producers are risk averse, nutrients are often applied at rates that exceed agronomic recommendations, resulting in higher than needed production costs and sometimes affecting water quality (e.g., reducing dissolved oxygen; Berka et al. 2001). If producers follow University of Minnesota Extension Service recommendations and take credit for the N content of legumes in rotations or in manure applied as fertilizer, application rates and production costs are reduced (table 4).

Production costs were calculated using producer surveys and data from the West Central Farm Business Management Association (Chippewa study area) and the Southeast Farm Business Management Association (Wells Creek study area; Westra et al. 2002). Variable production costs (fertilizer, agrochemicals, and machinery) for each production system were calculated from input levels obtained from the producer surveys. Overhead, fixed, and other economic costs of production were estimated from comparable operations from the respective farm business management associations. Because most producers surveyed had the necessary equipment for the transition to small grains or hay in a crop rotation (scenarios C and D), no additional transition costs were assumed. Similarly, for conservation tillage systems, all producers surveyed had the necessary equipment to switch from conventional tillage to conservation tillage without purchasing additional equipment. As a result, variable production costs were reduced for a conservation tillage system, relative to the conventional tillage system, as fuel and equipment repair costs were reduced (Westra et al. 2002).

Aggregate production costs, calculated as an area-weighted summation of production costs for each system, changed under most scenarios (table 4). For the current-trend scenario (scenario A), there was a negligible change in production costs. Cost savings under BMPs (scenario B) would result from a decline in N fertilizer use of 47% in Wells Creek and 8% in the Chippewa River, reduced tillage costs, and land converted into buffers. Production costs declined further under scenario C, because costs associated with small grains and alfalfa are lower than those for corn and soybeans (see reports at *www.mgt.org/fbm/reports/1999/se/se.htm* and *www.mgt.org/fbm/reports/1999/wc/wc.htm*). The perennial cover (scenario D) had higher costs at Wells Creek, but lower costs at Chippewa River, compared with the baseline; this is not surprising, considering the increase in dairy production and associated expenses under MIRG at Wells Creek. Although machinery use is included in production costs, expenses associated with a transition to new production systems (transaction costs) can be significant (see below).

**Net farm income.** Net farm income (the ratio between the return to management and the cost in time and labor) was a function of output produced by farmers under the various systems modeled, a 5-year weighted average real output price (2000) for crop and livestock products in Minnesota, and production costs for each system (table 4). Because net farm income excludes management labor costs, it can be considered as net returns to management. We assumed that output prices remained unchanged in all scenarios, because the quantity supplied or produced in our study areas was small relative to the market for most commodities and livestock products. An average output (yield, hundredweight [45.5 kg] of milk, etc.) was used for each production system. The output for each system represented the surveyed producer's estimated average production, adjusted to reflect differences in soil quality within each watershed (Westra et al. 2002). As a result, variability in output and income over time was not incorporated into our analysis. Government commodity program payments were not included in farm income estimates, because we were interested in how income would be affected by changing farming practices alone. However, we do provide an estimate of how commodity payments could change based on the shift in practices (table 4). Commodity payments were estimated by adjusting mean commodity payments per farm enrolled in the area farm business management association by the percentage of the total farm program payments in Chippewa and Goodhue Counties for each crop (EWG 2003). Wells Creek also had dairy payments in 2000, and we applied 9% of the Goodhue County dairy subsidies across each scenario, a percentage based on the size of the study area in relation to the county.

Net farm income for Wells Creek was projected to fall slightly under scenarios A and B (table 4). For scenario A, reduced revenues resulted because slightly more land was planted with corn and soybeans. Without payments for these crops from government commodity programs, net farm income declines. For scenario B, the decline in farm income is due to reductions in yield for conservation tillage and land converted to buffers. By contrast, net farm income increases under scenarios C and D in both study areas (table 4). The result for scenario A indicates how commodity payments encourage production that lowers farm income, increases government costs, and increases environmental damage, relative to what could potentially be achieved under scenarios B, C, and D. Commodity payments are projected to decrease significantly under scenarios C and D (table 4). Assuming that riparian buffers in scenarios B, C, and D could be enrolled in the Conservation Reserve Program (CRP), these payments could partially offset lower commodity program payments (table 4). CRP payments are based on CRP rental rates in each county. There could also be significant one-time payments, totaling up to $1,300,000 if new wetlands (scenarios C and D) were enrolled in a program (e.g., the Wetland Reserve Program). However, in economic terms, the marginal cost to taxpayers for environmental changes projected under scenarios B, C, and D is likely to be zero, consistent with a study by Digiacomo and colleagues (2001).

### Externality costs

In addition to environmental and economic benefits, we evaluated potential cost savings due to reduced sedimentation and flooding. Reduced sedimentation led to significant cost savings in the Wells Creek study area, but the savings were much less pronounced in the Chippewa River study area. Flooding could be reduced by the addition of riparian buffers and restoration of wetlands.

**Reduced sedimentation.** Ribaudo (1989) estimated some costs of negative environmental externalities associated with sedimentation in freshwater systems. Sedimentation creates several economic costs, including dredging stream channels. Using an inflation-adjusted cost of $5.92 per metric ton (real 2000 dollars) for damages caused by each ton of waterborne sediment (Ribaudo 1989), we estimated the economic damages or costs avoided through reductions in sediment loading under baseline conditions and in each of our scenarios. For the baseline, economic damages associated with sedimentation were $213,131 per year for Wells Creek. In the Chippewa River, where less sedimentation occurred, baseline economic damages were estimated to be $10,525 per year. The cost per unit of damage was assumed to be constant throughout; thus, cost reductions across scenarios directly paralleled the reduction in sediment load.

**Reduced flooding.** Flooding often results in agricultural, residential, infrastructural, and long-term economic losses. Flood magnitudes have increased in the Mississippi River Valley over the past several decades, at least partly because of extensive land-use change, in conjunction with greater channel confinement (Miller and Nudds 1996). Within our scenarios are several options that could reduce runoff and flooding. Scenario D would increase soil infiltration capacity and reduce runoff by approximately 35% in both study areas (Zimmerman et al. 2003). Riparian buffers should reduce overland runoff into streams (Smith 1992, Daniels and Gilliam 1996), and wetland restoration can reduce flood flow volumes (Demissie and Khan 1993, but see Shultz and Leitch 2003). Modeling has shown that reducing runoff by 10% within a watershed may reduce the flood peaks with a 2- to 5-year return period by 25% to 50%, and might reduce a 100-year flood by as much as 10% (USACE 1995).

In Wells Creek, an increase in wetland area from 21 to 238 ha could reduce peak flow and flood flow volumes approximately 10.4%, and in the Chippewa area, an increase in wetland area from 154 to 653 ha could reduce flows by 5.8%. Converting land into grass would also reduce flow rates, because of increased infiltration and water storage capacity.

### Contingent valuation

Are citizens willing to pay for environmental benefits in our study areas? Many changes in environmental quality have no market mechanism by which people can reveal their willingness to pay for benefits. We used contingent valuation (Bishop and Heberlein 1990) to estimate the economic value associated with environmental benefits. We conducted an additional series of focus groups (different from those that addressed watershed scenarios) that covered valuation of environmental changes to identify questions for a mail survey and personal interviews. On the basis of these focus groups, our contingent valuation centered on a 50% reduction in soil erosion and agricultural nutrient runoff, a 25% reduction in slight to moderate flooding from agricultural lands, a 10% to 20% reduction in greenhouse gases from agriculture, and a 50% increase in bird and wildlife habitat on Minnesota farmland. These levels are consistent with scenarios C and D.

We used a statewide mail survey to assess willingness to pay for environmental changes. A random sample of 1000 households yielded 834 potential respondents, after we removed 166 that could not be reached by mail (undeliverable addresses, deceased, change of address outside Minnesota, etc.). We received 394 responses, a 47% response rate. Respondents indicated that they were willing to pay $201 annually per household to reduce environmental impacts. Personal interviews of 125 people (64 in the Wells Creek and 61 in the Chippewa River areas) indicated a higher willingness to pay ($394 annually per household). The higher willingness to pay in our watersheds could be "yea-saying" due to the personal nature of the interviews compared with the mail survey. However, residents of our study watersheds may actually place higher value on environmental benefits, because they identify benefits as more localized and tangible than statewide respondents.

### Social transition issues

We found that environmental and economic benefits can be attained through changes in agricultural land management, but change will not occur without change in the social structure of rural communities. We evaluated the current structure of social and human capital, and found that the development of new social capital is particularly important to the success of scenarios C and D.

**Social capital.** Social capital contributes to the formation of financial and human capital, and involves mutual trust, reciprocity, groups, collective identity, a shared future vision, and working together (Pretty 2003). Social capital that forms between or among like people or groups is called *bonding social capital.* Social capital that forms between or among groups with different interests is called *bridging social capital* (Flora and Flora 1987).

The greatest contrast between scenarios A and B, the commodity approaches, and scenarios C and D, the diversified systems, is at the community level. New social capital is particularly important to the success of scenarios C and D. To succeed, these diversified systems need a base of bonding social capital on which to build. Bridging social capital is also necessary for the transition to diversified systems. This bridging would need to link producers with consumers, resulting in a reasonable share of consumer expenditures flowing directly to producers, local small-scale processors, and service providers.

Most institutions in both study areas tend to support current systems of production and marketing, according to a review of documents and our interviews of 30 people from government agencies, universities, nonprofit organizations, and businesses in Wells Creek and 35 people in the Chippewa River study area. Some organizations focused on diversified agriculture exist in both study areas. However, representatives from those interviewed say that the organizations are not sufficiently linked to major educational, social, and business institutions to serve community needs for information and services. Most farmers working to establish diversified systems turn to institutions outside the local watershed to get information and, sometimes, supplies for their farms. Investments to develop bridging social capital will be needed to support the diversified scenarios (C and D).

**Human capital.** From about 1930, the rural population of the United States began to decline (Cochrane 2003). Subsidies to farmers for commodity production have not slowed the decline. Continued technical development of agriculture may not affect out-migration. For example, for every \$5 million of new investment in contract swine production, between 40 and 45 new jobs are created, but about 120 to 135 independent producers are put out of business (Ikerd 1998). Health care is problematic under all scenarios. Farmers in the focus groups commented that lack of affordable health coverage is the main reason farm families have at least one member working off the farm, and this is also a barrier keeping young people away from farming.

## Consequences of diversifying agriculture

Our analysis indicates that diversifying agriculture on actively farmed land could provide environmental, social, and economic benefits. Citizens would be willing to pay for these benefits. Our analyses confirm the evaluation of Tilman and colleagues (2001) and Wackernagel and colleagues (2002): If present land-use trends continue, environmental, social, and economic problems will worsen. We conclude that the nonmarket environmental and economic benefits of diversifying agriculture merit greater inclusion in current US farm policy.

Adoption of scenarios B, C, and D would lead to changes in agricultural inputs (e.g., fuel, pesticides, fertilizer) and to reductions in production expenses associated with a decline in N fertilizer use. These scenarios would also result in increased conservation tillage and the production of small grains rather than corn and soybeans. The rise in net farm income under scenarios C and D suggests that the environmental benefits probably could be achieved at lower government expenditures—an increase in net social benefit. Nonmarket environmental benefits that could be realized under scenarios B, C, and D include improved water quality and fish health, increased carbon sequestration, decreased greenhouse gas emissions, and reduced soil erosion. We found that significant environmental changes could be attained through a combination of land-use changes, ranging from individual practices (e.g., adoption of BMPs) to more comprehensive systemic changes (e.g., establishment of perennial plant systems and wetlands; see also Mitsch et al. 2001).

Different types of geography, climate, soil, and even social infrastructure may require a variety of strategies to attain environmental benefits in different watersheds. For example, the adoption of BMPs alone may not be enough to meet goals for reducing the hypoxic zone in the Gulf of Mexico. In relatively flat landscapes, such as the Chippewa River study area, meeting such goals would require diverse farming systems that include perennial plant systems. In steeper landscapes, such as Wells Creek, BMPs using recommended fertilizer rates might suffice, but additional reductions could be achieved with a diversified landscape. We suggest that US farm policy could be designed to create incentives for farmers to use farming systems that provide environmental benefits while fitting local situations. Such a policy would probably be more economically efficient than the current conservation programs. Minnesota residents indicated that they would be willing to provide incentives (\$362 million annually) for significant changes in environmental benefits. Study area residents indicated a desire to develop public policy, research, education, and marketing strategies to promote greater diversification of food and fiber production in ways that yield environmental and social benefits.

Major transition costs are associated with building social and human capital. Farmers using diverse perennial agricultural systems indicated that they have begun to build social capital and have found innovative ways to find and share information beyond traditional government and extension systems. Innovations are necessary because many current governmental programs, and programs coordinated by the land-grant university system, focus on a few crops and reinforce production of traditional commodities, such as corn and soybeans. Farmers in both study areas suggested that innovation on the farm is more likely to occur if local institutions are willing to change along with farmers.

Focus group participants stated that present commodity programs discourage diversified agriculture and conservation efforts. Concentration within agriculture creates fewer and more specialized farmers who bypass local input suppliers. The decline in local rural businesses prompts city and county officials to seek economic development with outside firms.

These firms often provide low-wage manufacturing or service jobs. Moreover, in the response to the farm crisis of the 1980s, effective job skills were not developed locally and resources were not mobilized for aiding local merchants and entrepreneurs, even though the cost per job created was lower than for an absentee-owned farm (Flora et al. 1997). A larger number of moderate-sized farms would make for a healthier main street (Flora and Flora 1987).

## Policy implications

Present US conservation programs operate within a system of income- and commodity-support programs focused on maximizing production. Between 1985 and 2002, about 70% of the US Department of Agriculture (USDA) budget for conservation was for land retirement programs. We suggest a reorientation of US farm policy. Rather than support commodity production, US farm policy should support agricultural diversification to enhance nonmarket ecosystem services. Future farm programs should reward farmers for environmental benefits. Policies that help create options, provide safety nets for all farmers, and offer incentives for pilot and demonstration projects could help restore vibrancy and diversity to the working landscape. These policies should integrate across environmental goals, because a more holistic program may be more efficient (McCarl and Scheider 2001, Vatn 2002).

Pasture and hay production should be supported throughout the US Midwest to allow an increase in ruminant production on grass, as under scenarios C and D. A coordinated policy could also promote grass-finished beef by altering USDA meat-grading standards and by publicizing its lack of antibiotics and its reduced risk of contamination by bovine spongiform encephalopathy and microbes such as *Escherichia coli* O157 (Diez-Gonzalez et al. 1998). Our study indicates that a policy to support crop rotations and MIRG on working farmland, through the Conservation Security Program (CSP) or other green payment programs, could provide income to encourage land-use changes from row crops. For example, the CSP could be used instead of the CRP to enroll the expanded buffers found in scenario D and allow harvesting of perennial crops for biomass energy, hay, or grazing. The CSP could also promote an ongoing use of these lands that might not otherwise be maintained when CRP contracts expire.

Agricultural policy should promote strategic preservation and restoration of wetlands. As indicated in our scenarios, the total area of farmland lost to wetland restoration as a result of changes in farming practices probably could be much less than the area covered in present land retirement programs, and these changes will be less expensive in the long term. Wetlands targeted for restoration and preservation should be in historical wetland sites, and they should be located to maximize hydrological connection with upland areas.

Our focus in this article has been primarily on food production, environmental quality, and continuing agriculture in a changing landscape. However, if US farm policy changes to embrace multifunctional agriculture, additional thought and energy should be expended to broaden the focus even further, to include energy production, recreation, education, and other activities that bring income and economic development to rural areas (e.g., using perennial grasses for biomass energy). At least one producer in the Chippewa study area has converted row crops to grassland, stocked pheasants, and opened the area to fee hunting. Scenario D incorporates perennial vegetation, especially in riparian areas that could attract grassland birds (Best et al. 1995) and birdwatchers.

Critics of our proposals to reorient agricultural policy might assert that these changes will result in reduced production, thereby exacerbating worldwide food shortages now and in the future. It is true that we would expect these policy changes to reduce the total production of corn and soybean commodities. However, meat production probably would show no net change, and production of corn, soybeans, and other crops that are directly consumed by humans might even increase. From a broader perspective, the present US agricultural policy has produced flooding in the north-central United States, hypoxia in the Gulf of Mexico, and increasing production of greenhouse gasses. We cannot afford to sacrifice future agricultural productivity for the sake of short-term increases in commodity production. Dealing with worldwide food shortages will require a future agriculture that produces rather than consumes ecosystem services. By taking steps to encourage the production of ecosystem services, US agriculture could become a model for many other parts of the world.

## Acknowledgments

This project was part of a study titled "Economic Analysis of Agriculture for Multiple Benefits," funded by the Legislative Commission on Minnesota Resources (approved by the Minnesota Legislature, 1999 Minnesota Laws, ch. 231, sec. 15, subd. 7[n], as recommended by the Commission from the future resources fund); the Joyce Foundation; the Sustainable Agriculture Research and Education Program (supported by the Cooperative State Research, Education, and Extension Service, the US Department of Agriculture, and the Nebraska Agricultural Experiment Station, University of Nebraska–Lincoln, under Cooperative Agreement no. 99-COOP-1-7686); the Minnesota Institute for Sustainable Agriculture; the National Fish and Wildlife Foundation; and FoodRoutes Network. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and should not be interpreted as representing the opinions or policies of the US government, the National Fish and Wildlife Foundation, or other funding partners. We thank our other team members, without whom this project would not have been completed: Cornelia Flora, Jan Flora, and Kristen Corselius for their work on the social and human capital aspects of the study; Steve Light for work on scenarios; farmers Dan French and Paul Homme for contributing information on grazing scenarios and perspectives on the project as a whole; and others who contributed valuable insights and information, including Larry Gates, Mary Hanks, Frances

Homans, Beth Knudsen, David Mulla, Kylene Olson, Mark Schultz, Kathleen Storms, Caroline van Schaik, Bill Vorley, and Wynne Wright. We also thank Prasanna Gowda for his assistance with the ADAPT simulations, Marin Byrne for researching wetlands literature, and Cecilia Berg for assistance with GIS. Earlier drafts were improved by Kendra McLauchlan, Matthew Liebman, Wilfred M. Post, and two anonymous reviewers.

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