Estimating Economic and Environmental Impacts At the National, Regional, and Watershed Levels: The Linked ASM/HUMUS Modeling System[a]

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[a]Presented July 28, 1997 in the Organized Symposium "Incorporating Environmental Consequences into National Agricultural Policy Analysis: A Regional Perspective" held at the Annual Meeting of the American Agricultural Economics Association, Toronto, Canada.

HUMUS is the acronym for the Hydrologic Unit Modeling of the United States system; ASM is the acronym for the Agricultural Sector Model.

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INTRODUCTION

Objective

Agricultural economists working in the government agencies are often called upon to make combined economic and environmental appraisals of program performance, policy initiatives, and potential changes in economic conditions surrounding U.S. agriculture. In this paper we present some experience arising from efforts to satisfy such needs within the policy analysis activities of the USDA Natural Resource Conservation Service (NRCS, formerly the Soil Conservation Service). And in particular, we describe a linked policy/environmental/economic analysis system which is arising as a result of a NRCS Cooperative agreement with the Texas Agricultural Experiment Station (TAES) involving hydrologic models developed by USDA, Agricultural Research Service (ARS), crop simulation models, and economic assessment models. The paper is focused on the linkages between the Agricultural Sector Model (ASM) economic assessment model (McCarl et al.) and the Hydrologic Unit Modeling of United States (HUMUS) hydrology assessment model (Srinivasan).

In the presentation, we will first provide background on the issues facing the NRCS. Secondly, we will illustrate some of the modeling issues and cover the analytical system that is emerging for use in policy analysis in the NRCS setting.

The Mandate for Economic and Environmental Analysis of Agency Goals

The "Government Performance and Results Act of 1993" (GPRA) (U. S. Congress, 1993) requires that federal agencies establish program goals and show the progress due to expenditures. Full compliance is required in 1999 with some preliminary reporting and planning requirements in 1997 and 1998. A major step in NRCS compliance with GPRA is development of a strategic plan for federal fiscal years 1996-2002 (U.S.Dept. Agric., 1997). The plan identifies mission area, stakeholders, agency activities, core processes, and indicators that can be used to measure progress (U.S. Gov. Gen. Accounting Office, 1996).

The linked policy/environmental/economic analysis system developed by NRCS and TAES is used to evaluate the feasibility and potential economic costs and environmental impacts associated with the alternative program implementation rules, policy proposals, and strategic goal alternatives. By evaluating a number of alternatives NRCS is able to understand the impacts of targeting of certain types of land, the differing marginal economic and environmental impacts of different standard levels, and the potential impacts of the establishment of some form of erosion rights trading institutions. Through establishment of baselines for1995 and future years NRCS is better able to understand current and expected trends in resource management and conditions and the influence that NRCS programs could be expected to have on those trends.

Soil Erosion as a Water Quality Policy Problem

Soil erosion has been recognized as an important federal policy issue since the 1930s (Morgan, 1965; Sampson, 1985; Magleby et. al, 1995; U.S. Dept. Agric. 1994a, 1996; U.S. Government Accounting Office, 1995). In the 1980s federal erosion policy was expanded to address off-site water quality impacts due to two types of studies: 1) an assessment showing little danger to national welfare from soil productivity losses due to erosion (U.S. Dept. Agric. 1989, p. 25); and 2) findings in various studies that agricultural non-point source pollution was a significant contribution to impaired water quality in both rivers and lakes (U.S. Dept. Agric., 1994a, p. 60).

Soil erosion is related to water quality in ways other than just the sediment loading (Clark et. al, 1985). However, the exact contribution of erosion to sediment loading and other aspects of non-point source pollution is an unresolved issue currently being addressed by a variety of research programs. Eroded soil particles carry attached nutrients, organic matter, and pesticide residues. Also, soil erosion rates are indicators of the degree to which the landscape is unable to assimilate and slow the runoff associated with large precipitation events. With adequate surface protection, the soil acts as a buffer; a larger portion of the precipitation infiltrates into the soil, is temporarily stored in the vegetative material on the soil surface, and then slowly released to water bodies, without carrying a load of eroded materials. When runoff rates are greater, the runoff, with greater embodied energy, transports more soil, nutrients, and organic matter, and cuts larger channels in the landscape. The linked modeling system used in this study is an attempt to trace the impact of policy changes from the point of their influence on farm management, through the impact on erosion rates, on to the impact on sediment and runoff, and finally, the impact on indicators of water quality.

Despite the progress made with recent programs such as Conservation Compliance and the Conservation Reserve, erosion still remains a significant policy concern (Bull and Sandretto, 1996; Magleby et al., 1995; Osborn et al., 1995, U.S. Dept. Agric., 1994; andU.S. Dept. Agric., 1996). The NRCS has been the lead agency for providing technical assistance to the private sector for addressing soil erosion. Even when financial assistance is given to landowners through other agency's programs, NRCS is typically required to provide technical assistance, including certifying that planned management practices meet prescribed erosion limits. The NRCS has also had a major role in community based watershed protection efforts and in assisting other federal, state, and local governments and non-profit organizations in addressing soil erosion and water quality concerns. The 1985 FSA (U.S. Congress, 1985), 1990 FACTA (U.S. Congress, 1990), and 1996 FAIRA (U.S. Congress, 1996) all continued both funding and program area mission definition for the NRCS.

Modeling Issues In Soil Erosion Policy Analysis

The Office of Technology Assessment, and other interest groups, has recommended that agricultural/environmental programs be more targeted (U.S. Congress, 1995).

Issues in Targeting a Subset of Cropland

When a restriction on farming practices is imposed on a subset of the cropland in one or more regions the following events occur.

1. Management of the targeted land changes since additional practices add expenses, less of that land class and more of other classes of land are planted and harvested in each region;

2. Less production from the region enters the market since the supply is relatively more costly than before;
3. The lower production results in increased prices paid to producers who use the non-targeted cropland;
4. Who also produce more than before in response to the higher prices;
5. Rent for the targeted cropland falls while rent increases for the non-targeted land, inducing some management changes on all cropland;
6. Environmental impacts change;
7. Livestock producers may produce less due to higher feed costs; and
8. Consumers pay more for food and other agricultural products.

Both equity and efficiency concerns arise with targeted policies, as will be shown in the results of this study. Efficient policy design may dictate that large erosion reductions come from the land that has the highest erosion potential. Politically, however, equity issues may dictate that at a higher cost, smaller erosion reductions be applied to a much larger acreage of less erodible land. In particular, HEL cropland has been the target of erosion reduction programs since the 1985 FSA and, politically it may be impossible to attempt additional reductions on that cropland, even if the benefit/cost ratio is much higher than if non-HEL were targeted. Another problem with targeting is that as the changing economic conditions result in higher production on non-targeted lands, erosion on the non-targeted lands may increase by more than enough to offset the benefits of the targeted program.

Issues of Regional Total Erosion Limits

Imposition of total erosion limits by NRCS regions implies the existence of some institution whereby the allowable regional total is divided among producers in the region. A variety of equity and efficiency issues are raised, including the distribution of ability to pay versus severity of erosion problem. Economic theory suggests that if erosion allowances were initially distributed along with allowed trading between producers, trading would occur and the equilibrium price of a ton of soil would be equal to the marginal cost of controlling it. The analysis reported in this paper estimates a “shadow price” on the regional erosion limit that can be interpreted as the equilibrium marginal erosion control cost for the region. Assuming that the producers settled on a distribution of the allowable erosion, then the resource use, management, environmental, and market impacts described above for the targeting would also occur.

Overview of the Linked Modeling System

Given the diverse nature of the agricultural sector in the U.S. and the variety of policy instruments available for affecting resource management, NRCS needs to be able to appraise the environmental and economic implications of the various instruments that could be used to control erosion. A modeling system is evolving which contains:

- crop growth simulators which are used to develop data on the per-acre implications of agricultural practices;
- a soil sensitive agricultural sector model which is used to simulate the economic and cropping patterns implications of incentive programs, restrictions, etc.; and
- a hydrologic model which simulates implications for sediment loadings, water quality, and other factors.

A fundamental item of concern in this project is the efficient inter-relationship of these model components in a computerized fashion. This is complicated by differences in geographic scope, coverage of the resource base, data requirements, and focus between models (see Figure 1). The following characteristics of the U.S. agricultural sector and the limitations inherent in mathematical modeling simulations result in a variety of spatial, temporal, and functional aggregation that had to be addressed in setting up the ASM/HUMUS modeling system:

- the reaches of a typical large watershed can extend from a coastal plain up across a piedmont area and into the mountains, crossing several distinct climate and soil resource regimes and perhaps across several political boundaries (Figure 1). Consequently the hydrologic model, simulating watershed regions, and the economic model, simulating political areas or areas defined by predominant farming practices, have different spatial delineations.
- agricultural sector models such as ASM are typically set up based on data availability which ordinarily means some conformance to political boundaries.
- the economic model may represent the mix of cropland soils in each region by several selected representative soils, with the choice being conditioned on yield, cost, or erosion response. The hydrologic model may be based on only one representative soil per crop in each watershed, but also have information on the soils in range, pasture, and forestland uses.
- temporal changes are simulated differently in the economic and hydrologic models. The economic model may represent agricultural production a year at a time while the weather generator in hydrologic model may apply daily weather events. Excess applied fertilizers and chemicals may accumulate through several months of dry weather and then be flushed into the water bodies by a few large storms.
- farm by farm management decisions such as tillage choice, crop rotation choice, timing of management operations, etc., may or may not be included in the hydrologic model. On the other hand it may not be possible to capture in the economic model all of the within season precipitation impacts on water availability, yields and environmental outcomes that are simulated in the hydrologic model.

In this paper we will review the characteristics of the hydrologic and economic models discussed as well as a third bridging model which allows us to carry ASM crop mixes into the HUMUS system. Figure 2 shows an overview of the modeling components and the information flows in the system.

As shown in Figure 2, four separate models are used in the system (separate sections of the paper present detail on each model):

- ASM, the Agricultural Sector Model, is a spatial equilibrium model of U.S. agriculture;
- EPIC, the Erosion Productivity Impact Calculator, is a per-acre simulation model for weather, crop growth, nutrient and water balances, and erosion;
- CLAM, the County Land Allocation Model, distributes the subregion level crop mixes determined in ASM to the county level, accounting for both dry and irrigated production; and
- SWAT, the Soil and Water Assessment Tool, simulates the interaction of climate, weather, landuse, and water and pollutant movement at the watershed level, including the routing of water and pollutants through series of watershed reaches.

Figure 2 also shows a variety of data used in the system, including:

- Census of Agriculture;
- NASS county crop production surveys;

- NASS/ERS farming practices and input use surveys;
- Conservation Tillage Information Center residue management surveys;
- Market data including domestic, export, and import markets;
- Projections data for agriculture from World Outlook Board and other sources;
- the National Resources Inventory (NRI);
- spatial GIS layer data;
- weather data; and
- soil survey data.

Figure 2 indicates several possible iterative application routes for the integration of ASM and SWAT, depending on the resource issue being addressed:

- in simulating years of abnormal precipitation or other weather events, changes from the baseline water availability and per-acre supplemental irrigation requirements could be passed from SWAT to ASM; ASM would then be applied to estimate economic impacts which could include substantial changes in cropping patterns and irrigation methods resulting in per-acre crop cover and irrigation use requirements passed back to SWAT for further simulation;
- for an evaluation of alternative crop management technology, data could be passed from ASM to SWAT on altered per-acre water applications and the resulting changed crop mix due to new irrigation technology so that SWAT can estimate the impact on stream and water bodies; and
- for a variety of scenarios with altered agricultural management (such as integrating the management of livestock waste and crop fertilizer requirements), pass the new crop mixes and the associated per-acre changes in practices and input use to SWAT where the watershed level environmental implications could be estimated.

THE AGRICULTURAL SECTOR MODEL (ASM)

ASM Characteristics

The Agricultural Sector Model (ASM) (McCarl et al.) is a spatial equilibrium model of the U.S. commodity and agricultural resource markets. Parameters typically adjusted when the model is applied for policy simulation include crop yields, cropland availability, export and domestic demand curve locations, production activity input and cost coefficients, and features federal farm commodity programs. A baseline version of the model is calibrated closely to recent observed market data. Output of the model includes the standard economic surplus measures for consumers, producers, and foreigners (exporters and importers); government program costs; prices, production and disposition of each commodity; and resource use and price.

On the resource side, the nation is simulated as consisting of 63 homogeneous production subregions: subregions are states, except that California, Illinois, and Indiana are each divided into two subregions; Ohio is divided into three subregions; Iowa is divided into four subregions; and Texas is divided into eight subregions. In each production subregion, price dependent supply functions are specified for cropland, pastureland, private grazing land, hired labor, and ground water for irrigation. Fixed quantities of public grazing and surface water are at constant cost. A fixed quantity of family farm labor is available at a minimum reservation wage. Additional restrictions are conformance with the subregional historical crop mixes, showing the proportion of total subregion cropland in each crop for each of the last twenty years. When the model is solved, the solution crop mix must be a linear combination (weighted average) of one or more of the proportional mixes of past years. These constraints account for various specific resource, technology, asset financing and fixity, and managerial considerations not explicitly specified in ASM. Production activities in each subregion for crops and livestock are developed from enterprise budgets and other costs and returns data from U.S. Dept. Agric. publications. In each subregion, there are also up to four alternative crop activities accounting for irrigation or not and farm program participation or not.

On the commodity demand side, price dependent demand functions are specified for domestic consumption and export demand and supply. Processed commodity activities convert primary commodities like corn into products like corn oil and corn sweetener. The detail of the model is continually being enhanced; the 1996 version included 36 primary commodities and 39 secondary or processed commodities. Two significant recent model developments are the division of wheat production, demand, and import supply into four categories and the division of export demand into components from approximately 20 different world regions.

The "Soil" Version of ASM

A soil version of the ASM was created to help address issues on non-point source pollution arising from crop production (Appendix 1 compares the resource unit definition and management simulation components of ASM to those of HUMUS). The two main features of the soil version are that (1) within each subregion the cropland supply was divided into four classes related to soil erodibility and wetness hazard and (2) the existing set of enterprise budgets was augmented with alternatives for soil erosion control. All resulting budgets were each then assigned to a representative soil and associated EPIC data sets were created.

The 1992 National Resources Inventory (NRI) data (U.S. Dept. Agric., 1994b) is used to divide cropland into the following four classes:

- first, all cropland with Land Use Class III-VIII and subclass "w" was designated "w3-8";
- secondly, the remaining cropland was divided using the erosion index (ei) as defined in the 1985, 1990, and 1996 Farm Bills:
  - "loei" has ei value of less than 8.0;
  - "mdei" has ei value equal to 8.0 or greater, but less than 20.; and
  - "svei" has ei value greater than or equal to 20.

The set of existing crop budgets were expanded to allow up to 36 alternative combinations of tillage, erosion control practice, and crop rotation:

- tillage methods are the 1992 average, conservation, and no-till;
- erosion practices are the 1992 average, contouring, strip cropping, and terracing; and
- crop rotations are the 1992 average, after one year of grain, and after 3 years of hay.

For each crop the budget with 1992 average for tillage, erosion practice, and crop rotation is the original ASM budget, while all other budgets are the originals with adjustments using EPIC and other data.

Establishing the ASM Baseline for Comparison to Scenarios

A major step in application of the modeling system is the development of a baseline to which policy options can be compared. Simulating that baseline involves first calibrating the ASM to the most current data (1995 in this version) and then extending the baseline to the future by accounting for predicted trends, conditions and the FAIRA provisions, as shown in Table 1. The following procedures were used to develop the ASM baseline:

1. Calibrated cost and yields to increase use of conservation tillage, supporting practice, and conservation rotation usage from the 1992 NRI levels to approximately the 1995 Conservation Technology Information Survey (CTIC) (1996) levels;
2. Accounted for the erosion control predicted to be achieved by Conservation Compliance (CC), Conservation Reserve, and Coastal Zone Non-Point Source (CZ) programs from about 1996 into the near future;
3. Adjusted yields and input uses according to statistically estimated trends;
4. Included an updated CRP distribution based on U.S. Dept. of Agric., Farm Services Agency projections made in August 1996; and
5. Calibrated the baseline markets to the USDA World Outlook Board projections for the desired year.

THE EROSION PRODUCTIVITY IMPACT CALCULATOR/ ENVIRONMENTAL POLICY INTEGRATED CLIMATE (EPIC)

The EPIC model was originally developed to assess the impact of cropping practices on crop productivity of soils in the U.S. (Sharpley and Williams, 1990). The scope of EPIC has been expanded to cover the effect of a variety of land use management decisions on soil, water, nutrient, and pesticide movements and their combined impact on soil loss, water quality, and crop yields. The use of the model has also spread to more than fifty other countries, resulting in French and Spanish language versions being supported by cooperating institutions in other countries.

EPIC is used in this system to develop the alternative enterprise budgets for each crop by soil and management system. The original ASM had for each crop in each subregion an average budget for dryland production and one for irrigated production, but no estimates of associated environmental impacts. A representative soil was chosen for each cropland class in each subregion and then a series of EPIC runs were made for each grown in the subregion. These runs included simulations of the alternative rotations, tillage methods, and use of supporting practices. For a wide variety of policy alternatives, EPIC data sets can be modified and new estimates of per-acre yields, nutrient and water use, and environmental loadings generated for use in the ASM.

The basic geographical scale of EPIC is for a homogeneous field, i.e., a field site with homogeneous soil, landscape, weather, and cropping characteristics. The movement of water and associated chemicals, soil, and organic matter is then to “the edge of field” and “bottom of root zone”. The more commonly used features of EPIC include surface runoff; return flow; percolation; evapotranspiration; lateral subsurface flow and snow melt; sheet and rill erosion,; wind erosion; N & P loss in runoff; N leaching; organic N & P transport by sediment; N & P mineralization; immobilization; and uptake; denitrification; mineral P cycling; N fixation, pesticide fate and transport; and crop growth and yield for over 60 crops.

EPIC is a daily time step model and has been used for long term simulations of up to 15,000 years (summary output can automatically be produced daily, monthly, annually, or by aggregates of these periods). An internal weather generator, based on local weather patterns, generates random probabalistic weather events, which combined with user specified crop management events results in plant growth and all the above mentioned nutrient, weather, and soil component changes.

HYDROLOGIC UNIT MODELING OF THE U.S. (HUMUS Project)

The HUMUS project was designed to address water quality and quantity policy issues at the U.S. regional and national level while accounting for the diversity and heterogeneity of the U.S. climate, geography, natural resources, and farming systems (Srinivasan 1993). The HUMUS project system consists of four major components (see also Appendix 1):

1) a Geographic Information System (GIS) to collect, manage, analyze, and display the spatial and temporal resource information;
2) a basin scale Soil and Water Assessment Tool (SWAT) (Arnold and Allen, 1992) to model surface and sub-surface water quality and quantity by watersheds and basins;
3) a relational database system to manage the non-spatial data; and
4) interface programs designed to create input data for the SWAT model from the GIS and relational data bases and to create reports and graphics derived from the SWAT model runs.

Watershed spatial delineations in the SWAT input data sets can be as detailed as data availability and budget allow. For the HUMUS project the spatial data have been assembled at the scale of 1:250,000 and the SWAT model is being run for the 2,077 major watersheds in the 48 conterminous states that have been delineated by the U.S. Geological Survey as 8-digit Hydrologic Cataloging Units (HCU). Water flows from those 2,077 watersheds are routed by the SWAT model through 18 major U.S. river basins. Each watershed is divided using the GIS and relational databases into a number of subbasins, each representing a type of crop, soil, and vegetative cover. Some management practices, such as alternate tillage practices, fertilizer and pesticide applications, irrigation, and tree cutting can also be simulated with SWAT. SWAT accounts for runoff, evaporation, transpiration, infiltration, lateral flow, ground water flow, stream and river flow, and sediment and chemical movement through ponds, reservoirs, streams, and valleys. SWAT operates on a daily time step and is capable of simulating periods of up to 100 years or more.

Some of the SWAT input data include 30 years of historical weather, soil properties for each selected soil, topography, natural vegetation, cropped areas, irrigation, political boundaries, estimates of reservoir management, and agricultural practices. Spatially classified data include topography, landuse, soils, political and water shed boundaries, stream networks, weather station locations, aquifer maps, and stream gauge stations locations. Relational input data include data from the NRI, agricultural census, soil properties, weather parameters, stream flows, crop management from enterprise budgets, etc.

THE COUNTY LAND ALLOCATION MODEL (CLAM)

Moving the cropped acreage mixes from ASM to HUMUS is a two step procedure. First, the subregional crop mixes from the ASM solution must be disaggregated to county level estimated crop mixes. Second, the county crop mixes are reaggregated to the 8 digit hydrologic unit cataloging (HUC) areas. The County Land Allocation Model (CLAM) was developed to convert ASM estimates of subregion crop mixes to county crop mixes. The HUC acreage of a crop is the sum of county acres of the crop multiplied by the proportion of the cropland in the HUC that the county represents.

The CLAM is designed to overcome four data issues that prevent the straightforward disaggregation of subregion crop mixes to the county level. First, the ASM operates at the state level and a disaggregation scheme to the county level must take into account physical characteristics of the counties, including suitability for crops, and irrigation incidence, among other factors. Historical year by year crop mixes at the county level corresponding to the twenty years of subregion crop mixes in ASM are not available; Census of Agriculture and other data series are only collected at five year intervals. Year by year data is only published at the state level. Second, the subregion crop mixes in the ASM are by dry and irrigated but within some subregions, a particular crop may only be irrigated in some counties and only produced without irrigation in other counties. Third, a linear mathematical model of subregion decomposition may show large discrete changes at county lines and it is desirable that some smoothing of results across county lines be enforced, since in the real world discrete changes in crop mixes rarely occur at county lines. Fourth, ASM projections for future crop mixes at the subregional level have no counterparts in real or projected data at the county level. We decided to base these disaggregation procedures on historical land uses, i.e., making the county crop mix consistent with the state level crop mix in ASM and historic data from each county.

The total acreage of each crop in each state for each of historical year is available from various U.S. Dept. of Agric. publications. For the five states divided into subregions, data are available for those subregions in state agricultural statistic publications. Irrigated and non-irrigated acreage by crop and county are available at five year intervals (1982, 1987, and 1992) from two sources, the Census of Agriculture and the NRI (the NRI data are considered to not be statistically accurate at the county level). The Census also includes a more limited coverage of data at five-year intervals extending back to the 1940s. Since the surveys in these two sources are of different statistical type and design, they do not report exactly the same crop acreage data for a given crop and county. Also, each contains some crops that the other omitted and vice versa. If an acre was double cropped and both crops irrigated then the Census estimate of irrigated acreage has double counting. The NRI surveyors recorded the acreage as being irrigated if they observed irrigation systems in place, leading to large estimate errors in some regions where water availability and drought conditions have varied. For CLAM a variety of extrapolation and averaging techniques were used to first build a county level data set with acreage by crop and irrigation status for 1982, 1987, and 1992 and then to extrapolate data to fill in data to produce an annual data set for both irrigated and non-irrigated crop acreage's.

CLAM is an optimization model in which deviations from past norms are minimized as ASM subregion crop mixes are disaggregated to the county level within the constraint of available cropland resources and other constraints as explained below.

The decision variables in CLAM are the following:

- allocation of cropland in each county for each crop with and without irrigation
- positive and negative deviations from historic norms between a county and each adjacent county for each crop
- positive deviation from historic irrigated acreage in each county
- largest deviation from historic acreage in counties in each ASM subregion
- positive and negative deviations from historic maximum and minimum acreage of each crop in each county
- positive and negative deviations from the acreage allocation derived from the ASM crop mix for each crop in each county, based on the years for which crop mixes are used in the ASM solution

- positive and negative deviations from the acreage allocation in CLAM base scenario for each crop in each county and for irrigated and not
- largest deviation across counties in each ASM subregion for crop acres from extrapolated mix

The data parameters in CLAM are the following:
- historic average ratio of acreage between adjacent counties for each crop
- historic minimum and maximum acreage of each crop and of all crops in each county
- ASM solution acreage of each crop in each subregion for irrigated and not irrigated
- ASM crop mix extrapolation of acreage of each crop in each county
- ASM crop mix extrapolation of acreage (total) in each county
- Solution from CLAM application to base run giving deviation of current application from base solution for counties targeted in a given study
- historic maximum irrigated acreage in each county
- weights assigned to all the deviation variables listed above

The minimization of the objective function (sum of deviations) is subject to the following constraints:
- sum of acreage allocated to counties in each ASM subregion for each crop and irrigation status must equal the ASM subregion acreage of each crop by irrigation status
- the sum across irrigation types of acreage allocated to counties in each ASM subregion for each crop and irrigation status plus and minus the deviations must equal the ASM acreage for each county and crop
- for each county and crop, the deviation from the ASM crop mix must be less than the largest deviation across counties in each ASM subregion for crop acres from extrapolated mix
- in each county the sum of irrigated acreage must be less than historic maximum irrigation
- across counties in each subregion, the deviation from irrigated acreage must be less than the largest irrigated acreage deviation for the subregion
- the sum across all crops and irrigation types in each county must be less than historic maximum and more than historic minimum of cropped acreage in the county
- the sum across irrigation types for each crop in each county must be less than historic maximum acreage and larger than the historic minimum acreage of each crop in each county
- an accounting equation for acreage in adjacent counties deviating from the historic average relationship between counties
- an accounting equation for how acreage by county, crop, and irrigation status varies from the baseline

THE INTERFACE BETWEEN HUMUS AND ASM

Appendix 1 outlines the way in which different aspects of resource management simulation are handled in ASM and HUMUS. Regardless of the specific route taken for a particular scenario simulation, fixed weights must be used for some aspects of relating data elements across differing spatial and temporal delineations. For example, for some data elements, the exact numerical representation cannot be reconciled between the two models. However, satisfactory modeling results can be achieved by passing percentage change values between the model. For example, in one model “corn” may include corn silage, corn grain, seed corn, and sweet corn, while in the other corn is “corn grain”. By knowing the proportion of corn grain in all corn, from a given baseline data year, the predicted change in corn grain can be passed to the other model for use in making the appropriate change in all corn.

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Table 1. ASM parameter settings for establishing the calibrated pre-FAIR baseline, the 2002 predicted baseline, and the erosion goals.

Parameter or Component	calibrated pre-FAIR baseline	predicted 2002 baseline	erosion goal scenarios[a]
Farm Bill	1990 FACTA	FAIRA	FAIRA
EQIP	na	ignored	ignored
Supply and Demand Elasticities	current estimate	same	same
Market price and quantities – calibrated starting points prior to solutions (for commodities and resources)	1995 markets	2002/03	2002/03
CRP (million acres)	36.	28.	28.
Other reserve programs	ignored	ignored	ignored
Coastal Zone Management Act (see discussion)	no	yes	yes
Conservation Compliance (see discussion)	yes	yes	yes
Technology year for enterprise budgets	1992	1992	1992
- dynamic updating to year of	1995	2002	2002
Erosion control technologies:	cons., zero, & avg till	same	same
	cont., strip., terr., & avg prac.	same	same
	w/1yr sml grn, w/3y hay, & avg rot	same	same
Allowable subreg crop mix:	linear prop comb of 20 y of hist. data	same	same
Reallocate crops by subregion, soil, and dry/versus irrigated?	yes, if tech defined	same	same

[a]For scenarios based on T, budgets with higher erosion rates are screened out of model prior to solution.
For the regional erosion reduction scenarios, regional upper limits on erosion are included in the model formulation.

APPENDIX A. COMPARING FEATURES OF ASM AND THE HUMUS PROJECT SYSTEM

DATA ITEM	ASM	HUMUS PROJECT SYSTEM
Topography	Slopes and slope lengths are calculated from data reported at sample points in the USDA Natural Resources Inventory (NRI). The NRI points are first grouped by four soil classes (see below) and the average slope and slope lengths are calculated for each soil class in each subregion (also see below).	Elevations, slopes, and aspects are part of the Digital Elevation Model (DEM) data for every 200 meter square cell of land area in the GIS data maps of the 48 States. Additional information about slopes and distances is derived by overlaying digital line graphs (DLG) of streams, roads, watershed boundaries, and other linear features over the DEM. Average slopes for the whole watersheds or for parts of watersheds may be derived either from the DEM or from the STATSGO soils data. Slope lengths are computed with a formula derived from statistical correlations of slope lengths to slopes from experimental watershed data and other available sources.
Watershed Boundaries	Watersheds are not modeled. The basic areal units for modeling are the nation and 63 ASM Subregions therein. Sub regions are States except there are 2 subregions each in California, Illinois, and Indiana, 3 in Ohio, 4 in Iowa, and 8 in Texas. All watershed areas in each subregion are assumed to have homogeneous characteristics.	Watershed boundaries are those defined by the USGS as Hydrologic Cataloging Units (HCU). Each HCU is labeled with an 8-digit numerical code as follows: Regions Accounting Units | | 18 00 02 01 | | Subregions Cataloging Units The basic maps are published as digital line graphs at the 1:250,000 scale. Within each HCU, "virtual subbasins" (with known or estimated areas with somewhat imprecise boundary locations) are defined for each selected crop area and for each area of other kind of land use.
Land Uses	Land resources accounted for in each ASM subregion include cropland (cropped and idle), rangeland (in terms of animal unit months of grazing (AUM) divided by private and public grazing, and pasture. Cropland is divided by four classes of soil as explained below. Public grazing supply is limited to a fixed quantity, but the other land types are modeled as having rent dependent supply functions with the base price	The Land Use/Land Cover (LULC) maps derived from LANSAT imagery in the early to mid 1980's provide baseline estimates of areas of: 3 types of forest 3 types of range 2 types of wetlands water areas urban/urbanizing areas other land uses The 3 types of agricultural uses are subdivided into as many as 7 irrigated crops and 7 non-irrigated crops in each HCU. Crop areas may be derived for individual

	and quantity calibrated to USDA agricultural statistics for 1992. The CLAM program is used to disaggregate these subregional area estimates to individual counties for alternative scenarios. Shifts in land uses are allowed between cropland; pasture, range, and forests.	watersheds by apportioning the county crop data from Census records or as derived for the counties from the ASM projections using the CLAM Program. The apportionment ratios are derived by computing the LULC acreages of agricultural lands in each county part of each watershed.
Crops	The ASM is set up to model 16 major crops. These are: corn (grain), rice, oats, hay, silage, barley, cotton, potatoes, sorghum (grain), soybeans, sugarbeets, sugarcane, wheat, tomatoes, oranges and grapefruit. Land in the Conservation Reserve Program (CRP) and other idle uses such as summer fallow are also accounted for. Irrigated and non-irrigated areas in each of the crops are accounted for. Total acreages are allowed to increase and decrease, and to shift between regions, but the proportional mix of crops in each subregion is constrained to be a linear combination of the annual proportional crop mixes occurring during the previous 20 years. However, in cases in which water supply issues are addressed, the proportional crop mix contraints are pre-specified for irrigated and dry crops in each subregion.	The complete crop data bases include acreages for 24 crop classes, each of which has separate data for irrigated and non-irrigated areas. The crop classes are: Corn, Rice, Oats, Hay, Silage, Barley, Cotton, Potatoes, Sorghum, Soybeans, Sugarbeets, Sugarcane, Wheat, Tomatoes, Oranges and Grapefruit, Corn Fodder, Dry Beans, Peanuts, Sunflower, Tobacco, Other Vegetables, Other Orchards, Pasture, and CRP and WRP. In each HCU, however, only as many as 7 virtual subbasins are actually used to simulate non-irrigated crops and as many as 7 to simulate irrigated crops. For example, if there is only one irrigated crop in an HCU, only one virtual subbasin (or “small basin (sbs)”) will be modeled to represent that area. More often, some crop areas have to be combined to keep the number of sbs to 7. When this happens, the following rules are used: 1. Pasture in each category (irrigated or non-irrigated), where it exists, is maintained as an sbs and CRP/WRP land, where it exists, is lumped with non-irrigated pasture. 2. One sbs in each category is usually reserved for “specialty” crops. These are defined as tomatoes, oranges and grapefruit, peanuts, tobacco, other vegetables, and other orchards. Currently these are being simulated hydrologically as if they were all tomatoes, partly because tomatoes are modeled in the ASM, but this assumption needs to be refined. 3. If there are 5 or fewer other kinds of crops in either category, they are each treated as an sbs. 4. If there are more than 5 other kinds of crops in either category the 4 crops in that category with the largest areas are treated as individual sbs and the remaining crops in that category

		are lumped together and treated either as though they were all row crops (coded AGRR and treated as if they were all corn) or as close grown crops (coded AGRC and treated as if they were winter wheat). The choice of whether the lumped crops are coded as AGRR or AGRC depends on which of the lumped together crops has the largest area. If that crop is corn, silage, cotton, potatoes, sorghum, soybeans, sugarbeets, or sugarcane, the lumped crops are treated as AGRR. Otherwise, they are treated as AGRC.
Apportionment of Crop Areas from County to HCU and vice versa.	The ASM input data base relies on historical crop data in the Agricultural Census. These are generally county level data aggregated to the subregions. The County Land Allocation Model (CLAM) is used to disaggregate the subregional crop acreages estimated with the ASM scenario runs back to the individual counties.	County level data, whether from original Census reports or from alternative estimates derived with CLAM from the ASM model runs, must be apportioned to the HCU. The areas of agricultural lands in the LULC maps are used to make this apportionment. The GIS is used to find the total amount of agricultural land (AGC) in each county. Then GIS is used to find how much of that agricultural land is in each HCU within each county (AGHCUc). The ratios (AGRATIOS) of AGHCUc/AGC are calculated for each HCU part of each County. The individual crop acreages reported from the Census or the CLAM derived estimates (or from other sources if desired) are multiplied by the AGRATIOS to calculate the estimates of individual crop acreages in each HCU part of each County. Finally, the total acreages of each crop in each HCU are obtained by summing the crop acreages calculated for each county part of each HCU. The same AGRATIOS could be used to reallocate HCU crop acreages back to Counties, if for some reason this process might be needed.
Soils	All of the NRI cropland points in each subregion are lumped into 4 classes according to the relative erodibility or possibility of a wetness limitation as follows: A. All points having soils in Land Capability Classes (lcc) IIIw to VIIIw regardless of erodibility. The remaining points are classed as follows:	Data on soil characteristics are derived from the STATSGO soil mapping and classification system. The LULC map is laid over the STATSGO map to report the area of each STATSGO map unit under each major type of land use. Under all areas other than cropland, the dominant component soil in the dominant STATSGO map unit (by area) is selected to represent the soil conditions under each land use. Under crops, the individual component soils are ranked in descending order by area they occupy

	B. loei = erodibility index less than 8 C. mei = erodibility index from 8 through 20 D. svei = erodibility index greater than 20 Statistics on crop yields, tillage practices, agricultural inputs, etc are derived from the data reported for the NRI points within each soil group or from other sources, such as results from runs of the EPIC model, SWAT model, or data from other USDA reports.	under agricultural land, each of the selected irrigated and non-irrigated crop areas are also ranked in descending order, and then each crop area is matched to a correspondingly ranked component soil. Soil properties for the selected component soils are extracted from a specially created relational data base of the properties of the component soils. This data base was developed with a program designed to provide estimates for missing data, to estimate discrete numbers in lieu of soil property ranges, and to correct obvious errors in the original soils data files.

Weather	Weather events are not explicit. The effects and limitations of weather are implicit in the history of annual crop yields. They are also implicit in the estimates of average annual erosion rates reported in the NRI and in the erodibility indexes computed for the NRI points.	A 30 year daily record of maximum and minimum temperatures and precipitation for about 9,000 Weather Service gaging stations is used for the validation and calibration runs for the SWAT model. This record is also used for most of the scenario runs of the model, although it is possible to substitute historical weather data with a weather generator that can simulate up to 100 years of daily weather at any of over 1,000 locations in the 48 States. Other weather factors, such as solar radiation, daily heat units, and wind speed and direction are estimated for each station from statistical correlations between first order station records and factors such as elevation, latitude, and longitude. Station data are adjusted within each watershed for factors such as elevation and topography by correlation with monthly and annual spatially distributed relationships developed by the NRCS/Oregon State University PRISM Project.
Irrigation Water	Each crop on each soil class in each subregion is divided into part that is irrigated and part that is not. The exact acreage of a crop that is irrigated depends on the per-acre production costs associated with irrigation, yields, and water cost and availability. The estimates of availability of irrigation water supply are taken from USDA report.	Potential evapotranspiration for both irrigated and non-irrigated areas of vegetation are simulated by the SWAT model on a daily basis. The simulation formulas are based on known and estimated relationships between characteristics of the plants and soils involved and the daily weather conditions. Actual evapotranspiration rates for non-irrigated crops and other vegetation are constrained to the amounts of moisture computed as being available in their root zones. This constraint is relaxed for irrigated crops. When the soil moisture drops to below field moisture holding capacity, the SWAT model adds enough water to the root zone to replace that extracted by the crops in the irrigated sbs each day. An efficiency factor is applied to increase this amount to account for incidental losses in the water delivery systems and the resulting estimated irrigation water requirements are withdrawn from other sources in the HCU according to the following priorities: 1. surface streams 2. reservoirs 3. groundwater. Limits can be placed on each of these sources (to account for factors such as legal instream flow requirements) and transfer functions can be used

		to resupply streams and reservoirs from sources in other HCU, but these features generally have not yet been used in the HUMUS Project system because of the complexities involved in developing all of the information that would be needed for detailed watershed by watershed simulations.
Crop Management	In addition to being irrigated or not, each crop on each soil class has portions of its area in each of as many as 36 combinations of tillage practices, erosion control practices, and crop rotations. Tillage can be either average, conservation tillage, or zero tillage. Erosion control practices can include average, contour cropping, strip cropping, or terraces. Rotations can be classed as average, crop after one year of small grain, or crop after 3 years of hay.	Unless otherwise over-ridden by manually inputed data, the SWAT model is designed to compute the C Factor for each crop or other kind of vegetation on a daily basis. The C Factor is computed as a function of available above ground soil cover in biomass in live plants and available residues. The C values change through the year as the crops grow and are harvested. For crops, the default minimum values are those associated with the amounts of residues expected to be present with typical crop rotations. In SWAT, the default values of residue and/or canopy cover can be altered to account for more than 100 different kinds of tillage processses and/or crop management systems.. In the HUMUS Project, an input data table has been developed to modify soil cover simulations for 3 levels of tillage (conventional, conservation till, and no-till). Canopy cover and residues in crop rotations are simulated by having portions of each County and HCU in each kind of crop in the rotation over its share of the total area in the HCU and changes can be made by changing the crop acreage mixes. The conservation practice effects can be changed in each HCU by modifying the P factors in the input data. The default value of P = 1.
Erosion by water	Estimates of cropland sheet and rill erosion by water are based on the Universal Soil Loss Equation (USLE) an empirical formula in common use by the Natural Resources Conservation Service (NRCS) that has been used to make erosion estimates at the NRI sample points. The USLE is: $A=RK(LS)CP$ The RKLS factors are taken as those that average from the	The SWAT model includes subroutines for surface sheet and rill erosion, overland sediment deposition, nutrient enrichment, channel transport, reservoir deposition, etc. The surface sheet and rill erosion rate is estimated using MUSLE, a modification of the USLE that substitutes estimates of daily water runoff intensities for the R value in the USLE.

	NRI data for each crop and soil class in each subregion. C, the crop management factor and P, the erosion practice factor are estimated from the management and practice information described above to represent the various erosion control scenarios evaluated with the ASM. T, defined as a "tolerance" erosion rate, is also averaged from the soils data related to the soils at the NRI sample points for each crop and soil class. This is used to compute the "erodibility index (ei)" for each crop and soil class by the equation: $ei = RK(LS)/T$ These estimates are used to define the soil classes described under "soils" above. There are no estimates of gully or channel erosion used in the ASM.	

Erosion by wind	Wind erosion estimates are also averaged from NRI data for each crop and soil class.	No attempt has yet been made in this project to simulate erosion by wind or the effects of the resulting sediment deposition in water bodies.
Sediment Delivery	Sediment delivery ratios are derived from a generalized curve that relates watershed sediment delivery ratios to the size of the drainage area as found in NRCS National Engineering Handbook, Section 3, Chapter 6 (1989). Delivery ratios for each subregion are based on estimates of typical minimum watershed areas of "significant streams (streams large enough to support possible water supply uses)" in each subregion.	Sediment deposition and deliveries are estimated by multiplying erosion estimates in each HCU by a sediment delivery ratio derived from the formula: $DR = 0.267*DA^{-0.2237}$ where DA is the area of the HCU in square kilometers. Sediment is then routed down the streams and rivers using a stream power function that estimates the ability of the streams to transport the sediments available from channel and gully erosion as well as from land surface sheet and rill erosion.
Fertilizers	Historical data on uses of fertilizers for each crop in each subregion are used in congjunction with simulation models to develop fertilizer rates for each crop, soil, and mangement situation.	(To be explained later.)
Pesticides	A "dominant" or "representative" pesticide application schedule with its related expenses has been estimated for each crop in each subregion.	(To be explained later.)
Erosion Control Policies	The assumption for the baseline scenario is that all acreage enrolled in or affected by the provisions of the 1995 Farm Bill will continue to be farmed in a manner that will meet the conseration compliance erosion control provisions (CC) of that Act. The cropland areas covered by the Coastal Zone Program are also assumed to be managed in a manner that will meet the	(To be explained later.)

	CC. To meet the CC require-ments, farmers are assumed to have applied practices that will meet T or to meet the standards of locally accepted “Alternative Conservation Systems (ACS)” where these have been adopted and allow erosion rates greater than T. The estimates of erosion rates allowed under the CC were derived from the “after treatment” rates developed in the 1966 FSA status review. The estimated erosion rates are calculated as the average “after” rate plus 75 percent of the difference between the average “after” and the maximum “after” rates at each NRI point. Area-weighted averages of the rates at the NRI points were used to develop the County and subregion rates for each crop and soil class. The calculated CC rates varied from T to as high as five times T. Erosion rate limits for alternative erosion control scenarios are developed as ratios of the baseline CC rates.	