Model Environment

The REAP model is written and maintained in GAMS modeling language (see, for example, GAMS Development Corporation, 2006) and employs a nonlinear solver.[2] GAMS permits the compact representation of programming model by using concise algebraic statements that are easily read by model users. The equations that compose REAP are written in terms of “defined parameters”. This means that REAP's equations are written in symbolic terms and the values of data objects represented by these symbols (defined parameters) determine the specific form of REAP that is used in a model run.

Whenever REAP is run, GAMS generates a model based on whatever data exist in various REAP data objects. For example, the form and existence of domestic demand functions for commodities depend on the values of several coefficients in a demand parameter table, called DEMSUP (table 3). DEMSUP contains price, quantity, and either demand or supply elasticities for all final commodities represented in REAP. The existence of a price-quantity-elasticity combination for a commodity in DEMSUP will allow REAP to generate a supply or demand curve for that commodity in the market for which the price-quantity-elasticity combination exists. If there is only a price-quantity combination with no elasticity, then the price for that commodity in that market is kept constant.

In this section, we describe the major components of REAP using verbal, algebraic, and actual REAP model tables, as well as lists, equations, and statements.[3] We presume that readers have some familiarity with GAMS code conventions. We use several typographic conventions to differentiate elements of REAP presented in this bulletin. GAMS keywords appear in uppercase: EQUATION, for example. All GAMS identifiers (names of SETS, PARAMETERS, VARIABLES, EQUATIONS, and so on) and labels (names of SET elements) used in REAP are in a block font. Portions exceeding one line are separate text blocks as shown in example 1.

Example 1—REAP code Fragment (%%%%% indicates that portions of the list have been left out. This is used when the bulk of the list can be mentally filled in.)

```
$STITLE REAP MODEL REGIONAL PRODUCTION ACTIVITY SUBSETS

 SET BC(B) CROP ENTERPRISES /
```

[2] Note the solver(s) must be purchased separately from the GAMS modeling language. Nonlinear solvers such as CONOPT (ARKI Consulting and Development, 2006) or MINOS (Stanford Business Software, Inc., 2006) have successfully been used but their mention here should not be construed as a USDA recommendation over others that maybe suitable.

[3] This represents the basic formulation for REAP. The formulation can and has been adjusted to represent different types of government policies, such as income support programs coupled to production, environmental credit trading, and agrienvironmental compliance requirements. The formulation can also be easily adjusted to include the introduction of alternative production activities, such as the introduction of sustainable cropping systems, genetically modified crops and carbon sequestering activities. The means of accessing these modules and using them for analyses are described in Appendix B.

```
CORN,    SORGHUM,  BARLEY,  OATS,    WHEAT,   RICE,    SOYBEANS
SUNFLOWER,  COTTON,   SILAGE,  HAY,   SUGBEET,  SUGCANE
MILKWEED,  MEADOWFM,  KENAF,   GUYAULE,  OTHERC
RCCC,    RBBB,    RWWW,    RSSS,    RTTT,    RRRR,
RLLL,    RHHH,    RGGG
RCB,     RCBW,    RCBWO,   RCBWL,   RCBWH,   RCBWG,
%%%%
/;
```

In the REAP program, we first define the sets, then declare the various data objects (parameters, tables, and scalars) and assign data. Explanatory text is used in the declaration of sets, parameters, variables, and equations. All information needed to understand REAP is in the GAMS list file. As a result, the GAMS program represents a portion of the model documentation. All equations and data transformations are written in algebraic form. This procedure not only permits data to be entered in the form in which they are in the originating sources, but also makes the transformation of these data and the derivation of model parameters transparent to model users. Many secondary components of REAP are not presented—for example, calculations that convert published data into the model components. Full details of these secondary components are in the REAP code files.

Indexes (GAMS SETS)

SETS in the GAMS programming language serve as the model's building blocks—in other words the indexes represent the heart of the model. The indexes define the dimensions of the model with respect to commodities produced, inputs and production systems represented, regional sources of supply, and end-use markets. The parameters, variables, and equations defining REAP are all indexed by elements of REAP sets. The number of sets used in defining parameters, variables, and equations, along with the number of elements in the sets, determine the dimensions of the model. For example, commodity balance equations are defined over the set P; if set P is defined to contain only the elements CORN and SOYBEANS, then REAP would generate two commodity balance equations—one for corn and one for soybeans. In addition, SETS facilitate model formulation by permitting parameter calculations, solution algorithms, and more efficient reporting of results.

In the GAMS language, set declaration consists of a SET name and description followed by a list of the set elements. The first text on each row is the ELEMENT; everything following the next space is a description field. Comment lines (beginning with an asterisk, *) add documentation and aids in reading the model. The description field of set elements (and other GAMS objects) is also used in formatting and reporting model output.

Production Activities

The code below lists a portion of SET B—the primary production enterprises in REAP. Two features of B's elements are presented in the description field: "DESCRIPTION" clarifies what the element is, beyond GAMS's 10 character limit on element names. PIGFIN, for example, is FEEDER PIG FINISHING. "UNIT ON WHICH NORMALIZED" indicates the unit level of the activity for which inputs and outputs will be specified. For example, the unit level of a CORN enterprise is 1 acre. Yield and inputs used to produce corn will be specified on a per-acre basis.

b regional production activity, $b = 1,\ldots,B$

```
SET B   REGIONAL ENTERPRISE PRODUCTION PROCESS (ACTIVITY) SUPERSET /
* ---------------------------------------------------------------------------------
*                                                                   UNIT ON WHICH
*  NAME      DESCRIPTION                                              NORMALIZED
* ---------- --------------------------------------------------- ------------------
*  ---- TRADITIONAL FIELD CROPS
  CORN       CORN                                                 ACRE  PLANTED
  SORGHUM    SORGHUM                                              ACRE  PLANTED
  BARLEY     BARLEY                                               ACRE  PLANTED
  OATS       OATS                                                 ACRE  PLANTED
  WHEAT      WHEAT                                                ACRE  PLANTED
  RICE       RICE                                                 ACRE  PLANTED
  SOYBEANS   SOYBEANS                                             ACRE  PLANTED
  COTTON     COTTON                                               ACRE  PLANTED
  SILAGE     SILAGE                                               ACRE  PLANTED
  HAY        HAY                                                  ACRE  PLANTED
*  ---- ROTATIONS
  RCCC       CONTINUOUS CORN                                      ACRE  PLANTED
  RSSS       CONTINUOUS SORGHUM                                   ACRE  PLANTED
  RLLL       CONTINUOUS BARLEY                                    ACRE  PLANTED
  ROOO       CONTINUOUS OATS                                      ACRE  PLANTED
  RWWW       CONTINUOUS WHEAT                                     ACRE  PLANTED
  RTTT       CONTINUOUS COTTON                                    ACRE  PLANTED
  RRRR       CONTINUOUS RICE                                      ACRE  PLANTED
  RBBB       CONTINUOUS SOYBEANS                                  ACRE  PLANTED
  RHHH       CONTINUOUS HAY                                       ACRE  PLANTED
  RGGG       CONTINUOUS SILAGE                                    ACRE  PLANTED
  RCB        CORN SOYBEANS                                        ACRE  PLANTED
  RCBW       CORN SOYBEANS WHEAT                                  ACRE  PLANTED
  RCBWO      CORN SOYBEANS WHEAT OATS                             ACRE  PLANTED
...
...
*  ---- PRIMARY LIVESTOCK ENTERPRISES
  DAIRY       DAIRY                                               DAIRY COW
  FAROFIN     FARROW TO FINISH  HOGS                              HOG SLAUGHTER 10 CWT
  FEEDRPIG    FEEDER PIG PRODUCTION                               PIG PRODUCTION 10 CWT
  PIGFIN      FEEDER PIG FINISHING                                HOG SLAUGHTER  10 CWT
  BFCOWEN     BEEF COW ENTERPRISE                                 BEEF COW
*             (COW-CALF, 17 WESTERN STATES)
  BFCOWCF     BEEF COW-CALF HERD                                  BEEF COW
*             (COW-CALF, 31 EASTERN STATES)
  FEEDLOT     FARMER CATTLE FEEDING                               FED SLAUGHTER  CWT
  CFEEDLOT    COMMERCIAL FEEDLOT                                  FED SLAUGHTER  CWT
  STOCKER     STOCKER (BEEF CALF TO YEARLING)                     BEEF YEARLING  CWT
  OTHRLVSTK   OTHER LIVESTOCK  (SHEEP AND HORSES)                 GCAU
  EGGS        EGG PRODUCTION                                      DOZEN EGGS
  BROILERS    BROILER PRODUCTION (CARCASS)                        LBS BROILER CARCASS
  TURKEY      TURKEY PRODUCTION (CARCASS)                         LBS TURKEY CARCASS
  OTHERL      LIVESTOCK NOT OTHERWISE SPECIFIED                   DEPENDENT ON REPORT

  TOTAL       TOTAL USED FOR REPORTING PURPOSES                     DEPENDENT ON REPORT
  OTHER       ENTERPRISES NOT OTHERWISE SPECIFIED                   DEPENDENT ON REPORT
* -----------------------------------------------------------------------------------------

 ALIAS(B,BA);  ALIAS (B,BA1),(B,BA2);;
```

Subheadings such as “Traditional Field Crops” and “Primary Livestock Enterprises” divide set B elements into similar groups. Enterprise set B includes primary field crops such as CORN and SOYBEANS, livestock such as DAIRY, and several OTHER and control TOTAL categories that are used for summary reporting.

Following the definition of set B, the ALIAS command is used to create sets BA, BA1, and BA2, which contain all the same elements as set B. The ALIAS command gives another name to a previously declared set. Alias sets are used in a GAMS statement or equation when subsequent code involves interactions of elements within the same set.

Set B is further subdivided into subsets of production activities for crops and livestock. Set BC encompasses crop production activities, while BL includes livestock production activities.

Set bc(b) crop production activity, $bc \subset b$

```
SET BC(B) CROP ENTERPRISES /

  CORN,     SORGHUM,  BARLEY,   OATS,     WHEAT,    RICE,     SOYBEANS
  COTTON,   SILAGE,   HAY
  RCCC,     RBBB,     RWWW,     RSSS,     RTTT,     RRRR,     ROOO
  RLLL,     RHHH,     RGGG
  RCB,      RCBW,     RCBWO,    RCBWL,    RCBWH,    RCBWG,    RCBWX,   RCBH
   ....
  /;
```

Set bl(b) livestock production activity, $bl \subset p$

```
SET BL(B)  REGIONAL LIVESTOCK PRODUCTION PROCESSES /
       DAIRY
       FAROFIN,   FEEDRPIG,  PIGFIN
       BFCOWEN,   BFCOWCF
       FEEDLOT,   CFEEDLOT
       STOCKER,   OTHRLVSTK
       EGGS,      BROILERS,  TURKEY
       /;
```

Processing Activities

Set C describes processing activities, which are specified at the national level. Numerous processing activities in REAP perform widely different functions; their common characteristic is that they are specified only at the national level. This implies, for instance, that all finished hogs are sent to a central processing plant for processing, and then the resulting meat is sent out to domestic and export markets; the processing sector does not distinguish its inputs or outputs on the basis of the regions in which those inputs were produced.

Set c national processing activity, $c = 1,\ldots,C$

```
SET C  NATIONAL LEVEL PROCESSING PROCESSES (ACTIVITIES) /
* -------------------------------------------------------------------------------------
*                                                                     UNIT ON WHICH
*    NAME               DESCRIPTION                                     NORMALIZED
* ---------- --------------------------------------------------- ----------------------
*              LIVE ANIMALS TO MEAT (RETAIL WEIGHT)
  HOGTOPORK  SLAUGHTER HOGS                                           CWT    PORK
  SOWTOPORK  SLAUGHTER CULL SOWS                                      CWT    PORK
  FSLATOFBEF SLAUGHTER FED BEEF FROM FARMER CATTLE FEEDLOTS           CWT    FED BEEF
  FSCFTOFB   SLAUGHTER FED BEEF FROM COMMERCIAL FEEDLOT               CWT    FED BEEF
```

```
  DCOWNFBF   SLAUGHTER CULLED DAIRY COW                              CWT    NONFED BEEF
...
...
*             DAIRY PRODUCTS

  FLUIDMLK   FLUID MILK PROCESSING                                CWT WHOLE FARM MILK
  MFGMILK    MANFACUTURED (MFG) MILK PROCESSING                   CWT WHOLE FARM MILK
  BUTTER     BUTTER AND NONFAT DRY MILK PROCESSING                CWT MANUFACTURING MILK
  AMCHEESE   AMERICAN CHEESE PROCESSING                           CWT MANUFACTURING MILK
  OTCHEESE   OTHER   CHEESE PROCESSING                            CWT MANUFACTURING MILK
  ICECREAM   ICE CREAM PROCESSING                                 CWT MANUFACTURING MILK
  EVDRYMLK  " EVAPORATED, DRY, AND CONDENSED MILK"                CWT MANUFACTURING MILK

*             OILSEED CRUSH AND HIGH PROTEIN FEED ACTIVITIES

  SOYCRUSH1  SOYBEAN CRUSHING                                        BU     SOYBEANS

...

...
  BNMLTOHIPR SOYBEAN MEAL PROCESSING FOR HIPROTEIN FEED              CWT    BEANMEAL
  OOSMTOHIPR OTHER OIL SEED MEAL PROCESSING FOR HIPROTEIN FEED       CWT    BEANMEAL
  ANPRTOHIPR ANIMAL PROTEIN TANKAGE FOR HIPROFEED CONVERSION         CWT    BEANMEAL

*             FEED MIX AND PROTEIN SUPPLEMENT PRODUCTION

  GRAIN1     GRAIN FEED MIX 1 FOR CATTLE FEED                        CWT    GRAIN

*           (GRAIN1A TO GRAIN3 REPRESENT ALTERNATE COMBINATIONS
*            OF FEED GRAINS TO CREATE CATTLE PROTEIN AND ENERGY)
  GRAIN1A    GRAIN FEED MIX 1A FOR CATTLE FEED                       CWT    GRAIN
  GRAIN1B    GRAIN FEED MIX 1B FOR CATTLE FEED                       CWT    GRAIN
...
...
  CATPRO1    LOW PROTEIN BEEF CATTLE FEED PROD  (32% PROTEIN)        CWT    PROTSUP
*           (CATPRO2 TO CATPRO4 REPRESENT ALTERNATE COMBINATIONS
*           OF FEED GRAINS AND SOYBEAN MEAL TO CREATE CATTLE FEED)
  CATPRO2    LOW PROTEIN BEEF CATTLE FEED PROD  (32% PROTEIN)        CWT    PROTSUP
...
...
  DAIRYSUP1  DAIRY PROTEIN SUPPLEMENT PRODUCTION (16% PROTEIN)       CWT    PROTSUP

*           (DAIRYSUP2 TO DAIRYSUP6 REPRESENT ALTERNATE
*           COMBINATIONS OF FEED GRAINS AND SOYBEAN MEAL TO
*           CREATE DAIRY PROTEIN AND ENERGY.)
  DAIRYSUP2 DAIRY PROTEIN SUPPLEMENT PRODUCTION (16% PROTEIN)       CWT    PROTSUP
  DAIRYSUP3 DAIRY PROTEIN SUPPLEMENT PRODUCTION (16% PROTEIN)       CWT    PROTSUP
...
...
 LOPROSWN1  LOW PROTEIN SWINE FEED (19%-20% PROTEIN)                CWT    PROTSUP
*           (LOPROSWN2 REPRESENTS AN ALTERNATE COMBINATION OF
*           FEED GRAINS AND MEAL TO CREATE SWINE PROTEIN AND ENERGY)
  LOPROSWN2 LOW PROTEIN SWINE FEED (19%-20% PROTEIN)                CWT    PROTSUP

*             FEED PROTEIN AND ENERGY RELATED ACTIVITIES


  HIPROCAT   CONVERSION OF BEANMEAL TO CATTLE PROTEIN AND ENERGY     CWT    BEANMEAL
  HIPROSWI   CONVERSION OF BEANMEAL TO SWINE PROTEIN AND ENERGY      CWT    BEANMEAL
  HIPRODAI   CONVERSION OF BEANMEAL TO DAIRY PROTEIN AND ENERGY      CWT    BEANMEAL

  CORNSWI    CORN CONVERSION TO PROTEIN AND ENERGY                   CWT    CORN
  SORGSWI    SORGHUM  CONVERSION TO SWINE PROTEIN AND ENERGY         CWT    CORN
```

```
  CNSGSWI    CORN AND SORGHUM CONVERSION TO SWINE PROTEIN AND ENERGY CWT    CORN
...
...
*              ETHANOL PROCESSING ACTIVITIES

  ETHWMLCUR  CORN WETMILLING FOR ETHANOL (CURRENT STATE OF THE ART)   BU     CORN
  ETHWML95   CORN WETMILLING FOR ETHANOL (1995 STATE OF THE ART TECH) BU     CORN
  ETHWML20   CORN WETMILLING FOR ETHANOL (2000 STATE OF THE ART TECH) BU     CORN

  ETHDMLCUR  CORN DRYMILLING FOR ETHANOL (CURRENT STATE OF THE ART)   BU     CORN
  ETHDML95   CORN DRYMILLING FOR ETHANOL (1995 STATE OF THE ART TECH) BU     CORN
  ETHDML20   CORN DRYMILLING FOR ETHANOL (2000 STATE OF THE ART TECH) BU     CORN
...
...
* ------------------------------------------------------------------------------------------
```

"Live animals to meat" represents slaughter and processing activities that convert live animals to retail cut weight. Dairy-processing activities convert whole farm and manufacturing milk into retail products. Oilseed crush activities convert soybeans into soybean meal and soybean oil. High-protein feed activities convert various protein sources to high-protein livestock feed. Feed mix and protein supplement activities convert various individual feeds such as CORN and BEANMEAL into animal feed rations. Feed protein and energy activities convert livestock feed rations into protein and energy components in which animal nutrition requirements are satisfied. Ethanol-processing activities convert corn to ethanol and various coproducts.

Regional Indexes

Set U encompasses all geographic regions that can be used in REAP: Farm Production Regions, Land Resource Regions; and 2-, 4- and 8-digit U.S. Geological Service hydrological units (HUCS). REAP production activities are specified at either the Farm Production Region (mainly livestock) or Land Resource Region level (crops). Summary results are typically reported at the Farm Production Region level. HUCS are used primarily for tracking results at the watershed level after a solution has been obtained. As such, HUCS do not play a role in how the model is specified. HUCS could be used to specify the model at the watershed level if the supporting information on production activities to do so were available. Currently, results from model regions are distributed to the HUCS based on the share of cropland of each HUCS in the model region. The Land Resource Regions can be further divided into highly erodible land (HEL) and nonhighly erodible land (NHEL) if desired.

u   all regions

```
SET U   "REGIONS AND US TOTAL SUPERSET" /
* -------------------------------------------------------
*         ELEMENT  REGION NAME
*         ------- ------------
*   FARM PRODUCTION REGIONS

      NT      NORTHEAST
      LA      LAKE STATES
      CB      CORN BELT
      NP      NORTHERN PLAINS
      AP      APPALACHIA
      SE      SOUTHEAST
      DL      DELTA STATES
      SP      SOUTHERN PLAINS
      MN      MOUNTAIN STATES
      PA      PACIFIC STATES

      US      UNITED STATES
```

* LAND RESOURCE REGIONS

NTL	NORTHEAST LAKE STATES FRUIT TRUCK AND DAIRY
NTN	NORTHEAST EAST AND CENTRAL FARMING AND FOREST
NTR	NORTHEAST NORTHEAST FORAGE AND FOREST
NTS	NORTHEAST NORTH ATLANTIC SLOPE DIVERSIFIED FARMING
NTT	NORTHEAST ATLANTIC AND GULF COAST LOWLAND FOREST AND CROP
LAF	LAKE STATES NORTH GREAT PLAINS SPRING WHEAT
LAK	LAKE STATES NORTH LAKE STATES FOREST AND RANGE
LAL	LAKE STATES LAKE STATES FRUIT TRUCK AND DAIRY
LAM	LAKE STATES CENTRAL FEED GRAINS AND LIVESTOCK
CBL	CORN BELT LAKE STATES FRUIT TRUCK AND DAIRY
CBM	CORN BELT CENTRAL FEED GRAINS AND LIVESTOCK
CBN	CORN BELT EAST AND CENTRAL FARMING AND FOREST
CBO	CORN BELT MISSISSIPPI DELTA COTTON AND FEED GRAINS
CBR	CORN BELT NORTHEAST FORAGE AND FOREST
NPF	NORTHERN PLAINS NORTH GREAT PLAINS SPRING WHEAT
NPG	NORTHERN PLAINS WEST GREAT PLAINS RANGE AND IRRIGATED
NPH	NORTHERN PLAINS WEST GREAT PLAINS WINTER WHEAT AND RANGE
NPM	NORTHERN PLAINS CENTRAL FEED GRAINS AND LIVESTOCK
APN	APPALACHIA EAST AND CENTRAL FARMING AND FOREST
APO	APPALACHIA MISSISSIPPI DELTA COTTON AND FEED GRAINS
APP	APPALACHIA S ATL AND GULF SLOPE CASH CROPS FORES AND LVST
APS	APPALACHIA NORTH ATLANTIC SLOPE DIVERSIFIED FARMING
APT	APPALACHIA ATLANTIC AND GULF COAST LOWLAND FOREST AND CROP
STN	SOUTHEAST EAST AND CENTRAL FARMING AND FOREST
STP	SOUTHEAST S ATL AND GULF SLOPE CASH CROPS FORES AND LVST
STT	SOUTHEAST ATLANTIC AND GULF COAST LOWLAND FOREST AND CROP
DLN	DELTA STATES EAST AND CENTRAL FARMING AND FOREST
DLO	DELTA STATES MISSISSIPPI DELTA COTTON AND FEED GRAINS
DLP	DELTA STATES S ATL AND GULF SLOPE CASH CROPS FORES AND LVST
DLT	DELTA STATES ATLANTIC AND GULF COAST LOWLAND FOREST AND CROP
SPH	SOUTHERN PLAINS WEST GREAT PLAINS WINTER WHEAT AND RANGE
SPI	SOUTHERN PLAINS SW PLATEAUS AND PLAINS RANGE AND COTTON
SPJ	SOUTHERN PLAINS SW PRAIRIES AND COTTON
SPM	SOUTHERN PLAINS CENTRAL FEED GRAINS AND LIVESTOCK
SPN	SOUTHERN PLAINS EAST AND CENTRAL FARMING AND FOREST
SPP	SOUTHERN PLAINS S ATL AND GULF SLOPE CASH CROPS FOREST AND LVST
SPT	SOUTHERN PLAINS ATLANTIC AND GULF COAST LOWLAND FOREST AND CROP
MNB	MOUNTAIN NW WHEAT AND RANGE
MND	MOUNTAIN WESTERN RANGE AND IRRIGATED
MNE	MOUNTAIN ROCKY MOUNTAIN RANGE AND FOREST
MNF	MOUNTAIN NORTH GREAT PLAINS SPRING WHEAT
MNG	MOUNTAIN WEST GREAT PLAINS RANGE AND IRRIGATED
MNH	MOUNTAIN WEST GREAT PLAINS WINTER WHEAT AND RANGE
PAA	PACIFIC NW FOREST, FORAGE AND SPEC CROPS
PAB	PACIFIC NW WHEAT AND RANGE
PAC	PACIFIC CAL SUBTROP FRUIT TRUCK AND SPECIALTY CROPS
PAD	PACIFIC WESTERN RANGE AND IRRIGATED
PAE	PACIFIC ROCKY MOUNTAIN RANGE AND FOREST

* LAND RESOURCE REGIONS HIGHLY ERODIBLE LAND

NTLH	NORTHEAST LAKE STATES FRUIT TRUCK AND DAIRY HEL
NTNH	NORTHEAST EAST AND CENTRAL FARMING AND FOREST HEL
NTRH	NORTHEAST NORTHEAST FORAGE AND FOREST HEL
NTSH	NORTHEAST NORTH ATLANTIC SLOPE DIVERSIFIED FARMING HEL
NTTH	NORTHEAST ATLANTIC AND GULF COAST LOWLAND FOREST AND CROP HEL
LAFH	LAKE STATES NORTH GREAT PLAINS SPRING WHEAT HEL
LAKH	LAKE STATES NORTH LAKE STATES FOREST AND RANGE HEL
LALH	LAKE STATES LAKE STATES FRUIT TRUCK AND DAIRY HEL

```
      LAMH    LAKE STATES CENTRAL FEED GRAINS AND LIVESTOCK HEL
      CBLH    CORN BELT LAKE STATES FRUIT TRUCK AND DAIRY HEL
      CBMH    CORN BELT CENTRAL FEED GRAINS AND LIVESTOCK HEL
      CBNH    CORN BELT EAST AND CENTRAL FARMING AND FOREST HEL
      CBOH    CORN BELT MISSISSIPPI DELTA COTTON AND FEED GRAINS HEL
      %%%%%%

 *   LAND RESOURCE REGIONS NON-HIGHLY ERODIBLE LAND

      NTLN    NORTHEAST LAKE STATES FRUIT TRUCK AND DAIRY NON-HEL
      NTNN    NORTHEAST EAST AND CENTRAL FARMING AND FOREST NON-HEL
      NTRN    NORTHEAST NORTHEAST FORAGE AND FOREST NON-HEL
      NTSN    NORTHEAST NORTH ATLANTIC SLOPE DIVERSIFIED FARMING NON-HEL
      NTTN    NORTHEAST ATLANTIC AND GULF COAST LOWLAND FOREST AND CROP NON-HEL
      LAFN    LAKE STATES NORTH GREAT PLAINS SPRING WHEAT NON-HEL
      LAKN    LAKE STATES NORTH LAKE STATES FOREST AND RANGE NON-HEL
      LALN    LAKE STATES LAKE STATES FRUIT TRUCK AND DAIRY NON-HEL
      LAMN    LAKE STATES CENTRAL FEED GRAINS AND LIVESTOCK NON-HEL
      CBLN    CORN BELT LAKE STATES FRUIT TRUCK AND DAIRY NON-HEL
      CBMN    CORN BELT CENTRAL FEED GRAINS AND LIVESTOCK NON-HEL
      CBNN    CORN BELT EAST AND CENTRAL FARMING AND FOREST NON-HEL
      CBON    CORN BELT MISSISSIPPI DELTA COTTON AND FEED GRAINS NON-HEL
      CBRN    CORN BELT NORTHEAST FORAGE AND FOREST NON-HEL
      NPFN    NORTHERN PLAINS NORTH GREAT PLAINS SPRING WHEAT NON-HEL
      NPGN    NORTHERN PLAINS WEST GREAT PLAINS RANGE AND IRRIGATED NON-HEL
      NPHN    NORTHERN PLAINS WEST GREAT PLAINS WINTER WHEAT AND RANGE NON-HEL
      %%%
```

Major region schemes used in REAP are defined as subsets of U. Set R contains only the 10 USDA Farm Production Regions, while RL contains only the Land Resource Regions (LRRs). The LRRs are defined by the intersection of the USDA's 10 Farm Production Regions with the USDA's 26 LRRs. Thus, RL breaks each Farm Production Region into subregions defined by the portion of each Land Resource Region that it contains.

r farm production region $r \subset u$, $r = 1,\ldots,$R

```
SET R(U)  FARM PRODUCTION REGIONS /
         NT,LA,CB,NP,AP,SE,DL,SP,MN,PA
           /
```

rl land resource region region, $rl = 1,\ldots,$RL

```
SET RL(U)  LAND RESOURCE REGIONS /
      NTL     NORTHEAST LAKE STATES FRUIT TRUCK AND DAIRY
      NTN     NORTHEAST EAST AND CENTRAL FARMING AND FOREST
      NTR     NORTHEAST NORTHEAST FORAGE AND FOREST
      NTS     NORTHEAST NORTH ATLANTIC SLOPE DIVERSIFIED FARMING
      NTT     NORTHEAST ATLANTIC AND GULF COAST LOWLAND FOREST AND CROP
      LAF     LAKE STATES NORTH GREAT PLAINS SPRING WHEAT
      LAK     LAKE STATES NORTH LAKE STATES FOREST AND RANGE
      LAL     LAKE STATES LAKE STATES FRUIT TRUCK AND DAIRY
      LAM     LAKE STATES CENTRAL FEED GRAINS AND LIVESTOCK
      CBL     CORN BELT LAKE STATES FRUIT TRUCK AND DAIRY
      CBM     CORN BELT CENTRAL FEED GRAINS AND LIVESTOCK
      CBN     CORN BELT EAST AND CENTRAL FARMING AND FOREST
      CBO     CORN BELT MISSISSIPPI DELTA COTTON AND FEED GRAINS
      CBR     CORN BELT NORTHEAST FORAGE AND FOREST
...
...
        /
;
```

Set RL is defined above without differentiating between highly erodible and nonhighly erodible land. It is possible to define set RL so that it differentiates between highly erodible and nonhighly erodible land or so that it includes all three land types. The definition used depends on the type of analysis being run. For ease of exposition, we use RL as defined above in the rest of this section.

Mappings are multidimensional GAMS sets that relate elements of one set to elements of another set. Set ER2RR, for example, relates REAP Farm Production Regions to the Land Resource Regions. Mapping sets in REAP are generally named mnemonically to suggest linking the first set to, or "2," the second. Set ER2RR, which maps Land Resource Regions into Farm Production Regions, is shown below.

```
SET ER2RR(U,UR) FARM PRODUCTION REGION TO FARM RESOURCE PRODUCTION REGION MAP /

   (NTL, NTN, NTR, NTS, NTT)              .NT
   (LAF, LAK, LAL, LAM)                   .LA
   (CBL, CBM, CBN, CBO, CBR)              .CB
   (NPF, NPG, NPH, NPM)                   .NP
   (APN, APO, APP, APS, APT)              .AP
   (STN, STP, STT)                        .SE
   (DLN, DLO, DLP, DLT)                   .DL
   (SPD, SPH, SPI, SPJ, SPM, SPN, SPP, SPT).SP
   (MNB, MND, MNE, MNF, MNG, MNH)         .MN
   (PAA, PAB, PAC, PAD, PAE)              .PA
   /;
```

This mapping allows you to define operations to be applied over only those members of U that map to a specific region UR. Other regional mappings relating HUCS to each other and to Farm Resource Regions are in the REAP listing files. There are also mappings that separate Mississippi Basin HUCS from non-Mississippi Basin HUCS.

Government Program Indexes

Set G depicts government program attributes of REAP production enterprises. For example, NP portrays "nonparticipant" or "normal" activities, depending on the context where it appears.

Set g government program attribute category, $g = 1,\ldots,G$

```
SET G     GOVERNMENT PROGRAM ATTIBUTE CATEGORY /
           NP NONPARTICIPANT OR NORMAL
           P1 PARTICIPANT LEVEL 1
           /
```

A production activity for a crop such as CORN—for which a government program exists—can be either "participating in government programs" (P1) or "nonparticipating" (NP). An enterprise such as FEEDLOT for which no government program exists, has only one relevant category: "normal" (NP). Since the changes in the commodity programs that took place with the 1996 Farm Bill, the differentiation of crop production activities by their participation or nonparticipation in farm programs has not been used.

Production Types

Two sets, Y and H, are reserved (but not currently used) to differentiate alternative production regimes and methods of production. All variables and parameters, where these sets appear in the declaration, are defined with default values. Set Y refers to regimes with PRD, representing predominant systems, and AL1, refers to alternative sustainable practices that have been defined for cropping systems. The default value for production regimes is PRD. AL1 systems are available for use in scenario analysis, but availability of those regimes would need to be switched on. Alternative systems denoted "AL2" have not yet been defined; this set element was created as a placeholder to create flexibility for inclusion of additional systems in the future.

Set y system of production, y = 1,…,Y

```
SET Y     SYSTEM OF PRODUCTION
           PRD     PREDOMINANT
           AL1     ALTERNATE 1
           AL2     ALTERNATE 2
           /
```

Set H denotes the use of irrigation for production activities. Crop enterprises might be either D (dry) or I (irrigated) if irrigation is modeled for a crop. Its default value is A.

Set h method of production, h = 1,…,H

```
SET H     METHOD OF PRODUCTION /
           D DRYLAND
           I IRRIGATED
           A ALL OR NORMAL
           /
```

Element A applies to those production activities in REAP not differentiated by irrigation method. Element A also applies to all livestock enterprises. Although REAP permits the specification of separate dry/irrigated crop production activities, in its current formulation it does not do so. Thus, H is set at A for "all crop production activities." This does not mean that the crop production activities specified with an A represent an average of irrigated and dryland practices. Usually, the production activity represented with an A will be either irrigated or dryland, depending on whether dryland or irrigated production for this crop predominates in a Farm Resource Production Region. The exception to this is for production of cotton in the Southern Plains, where the division between irrigated and dryland acreage is split fairly evenly. In this case the production activities used in the model represent a weighted average of irrigated and dryland production activities.

Set T covers tillage practice alternatives. All crop production activities are defined with one of the five tillage practices represented. ATL is used as the default setting for all livestock production activities, and those crop production activities, with no tillage-specific information.

Set t tillage practice, *t* = 1,…,T

```
SET T     STRATA OF PRODUCTION /
           CNV     CONVENTIONAL WITHOUT MOLDBOARD
           MLD     CONVENTIONAL WITH MOLDBOARD
           MCH     MULCH TILLAGE
           NTL     NO TILL
           RDG     RIDGE TILLAGE
           ATL     ALL TILLAGE TYPES
           /
```

Set FT specifies the fertilizer application rates available for a crop production activity. The element 1 represents the initial or base fertilizer application rate, while the remaining elements represent reduced application rates. Currently, REAP includes only the option of reducing nitrogen fertilizer application rates to 60 percent of the base rate.

Set ft fertilizer application rate, ft = 1,…,FT

```
SET ft      FT FERTLIZER APPLICATION RATE LEVELS /
1       BASE APPLICATION RATE (100 PERCENT)
9       NINETY PERCENT OF BASE APPLICATION RATE
8       EIGHTY PERCENT OF BASE APPLICATION RATE
7       SEVENTY PERCENT OF BASE APPLICATION RATE
```

```
6      SIXTY PERCENT OF BASE APPLICATION RATE
```

Market Types

Set M includes all product supply and use market categories modeled in REAP.

m supply and use market category, m = 1,…,M

```
SET M   PRODUCT SUPPLY AND USE MARKET CATEGORIES /
* --------------------------------------------
* CATEGORY    DESCRIPTION
* --------------------------------------------
*   SUPPLY CATEGORIES

   STB       TOTAL BEGINNING STOCKS (COMPOSED OF SGB & SCB)
     SGB     BEGINNING GOVERNMENT STOCKS (RHS VARIABLE)
     SCB     BEGINNING COMMERCIAL STOCKS (RHS VARIABLE)
   PRDN      DOMESTIC PRODUCTION (EXPLICIT SUPPLY)
   IMP       IMPORTS (EXPLICIT SUPPLY)
   RESS      RESIDUAL SUPPLY (USED IN CALIBRATION)

*   USE CATEGORIES

   DOM       DOMESTIC CONSUMPTION (EXPLICIT DEMAND THAT EXCLUDES PRPC)
   PRPC      PRODUCTION & PROCESSING USE (IMPLICIT DERIVED DEMAND)
   EXP       EXPORTS (EXPLICIT DEMAND) EXCLUDING EEP
   EEP       EXPORTS UNDER EXPORT ENHANCEMENT PROGRAM (EEP) (EXPLICIT DEMAND)
   STE       TOTAL ENDING STOCKS (COMPOSED OF SGE & SCE)
     SGE     ENDING GOVERNMENT STOCKS
     SCE     ENDING COMMERCIAL STOCKS (EXPLICIT DEMAND)
   RESD      RESIDUAL USE (USED IN CALIBRATION)

*   OTHER GOVERNMENT STOCK ACTION CATEGORIES
   SGA       GOVERNMENT STOCK ACCUMULATIONS (INCREASE OVER PERIOD)
   SGO       GOVERNMENT STOCK CARRYOVER FROM PREVIOUS PERIOD
   SGR       GOVERNMENT STOCK RELEASE TO THE COMMERCIAL MARKET (DECREASE OVER PERIOD)
   SGV       GOVERNMENT NET STOCK REMOVALS FROM THE COMMERCIAL MARKET (PURCHASES)
   SGD       GOVERNMENT STOCK DOMESTIC DONATIONS (FOOD DISTRIBUTION PROGRAMS)
   SGX       GOVERNMENT STOCK EXPORT   DONATIONS (CCC EXPORTS)
   /
```

Beginning stocks, STB, are comprised of government and commercial stocks, SGB and SCB. PRDN refers to production, and IMP refers to imports. A residual supply category, RESD, is used in model calibration to account for cases where baseline total supply and use fail to balance precisely. Domestic use of products includes final domestic demand, DOM, intermediate input or production and processing use, PRPC, and ending stocks, STE (comprised of commercial and government ending stocks, SCE and SGE). Export use includes both commercial and export enhancement program exports, EXP and EEP. Certain other stock categories account for government stock transactions for selected commodities. These include stock accumulation, carryover, release to commercial markets, and net stock removals from commercial markets (SGA, SGO, SGR, and SGV), as well as government stock domestic and foreign donations (SGD and SGX).

Inputs and Outputs

Set IO contains the all the items that appear in REAP production activities as either inputs or outputs. These are commodities, production inputs, and miscellaneous coefficients that describe production activities.

io input or output of a production activity, *io* = 1,…, IO

```
SET IO  PRODUCTION INPUT-OUTPUT ITEMS /
* ---------------------------------------------------------------------------------------
*                                                           PRODUCTION      SOLUTION
* COMMODITY           DESCRIPTION                         ACTIVITY UNITS   REPORT UNITS
* ----------- ------------------------------------------- -------------- --------------
*              PRIMARY (FARM PRODUCED) COMMODITIES, CROPS

  CORN        CORN                                                BU      MILLION BU
  SORGHUM     SORGHUM                                             BU      MILLION BU
  BARLEY      BARLEY                                              BU      MILLION BU
  OATS        OATS                                                BU      MILLION BU
  WHEAT       WHEAT                                               BU      MILLION BU
  RICE        RICE                                                CWT     MILLION CWT
  SOYBEANS    SOYBEANS                                            BU      MILLION BU
  COTTON      COTTON                                              BALE    MILLION BALES

  PCORN       GOVT PROGRAM CORN                                   BU      MILLION BU
  PSORGHUM    GOVT PROGRAM SORGHUM                                BU      MILLION BU
  PBARLEY     GOVT PROGRAM BARLEY                                 BU      MILLION BU
  POATS       GOVT PROGRAM OATS                                   BU      MILLION BU
  PWHEAT      GOVT PROGRAM WHEAT                                  BU      MILLION BU
  PRICE       GOVT PROGRAM RICE                                   CWT     MILLION CWT
  PSOYBEANS   GOVT PROGRAM SOYBEANS                               BU      MILLION BU
  PCOTTON     GOVT PROGRAM COTTON                                 BALE    MILLION BALES

  SILAGE      SILAGE                                              TON     MILLION TONS
  HAY         HAY                                                 TON     MILLION TONS

  LCORN       LONG TERM CORN                                      BU      MILLION BU
  LSORGHUM    LONG TERM SORGHUM                                   BU      MILLION BU
  LBARLEY     LONG TERM BARLEY                                    BU      MILLION BU
  LOATS       LONG TERM OATS                                      BU      MILLION BU
  LWHEAT      LONG TERM WHEAT                                     BU      MILLION BU
  LRICE       LONG TERM RICE                                      CWT     MILLION CWT
  LSOYBEANS   LONG TERM SOYBEANS                                  BU      MILLION BU
  LCOTTON     LONG TERM COTTON                                    BALE    MILLION BALES
  LSILAGE     LONG TERM SILAGE                                    TON     MILLION TONS
  LHAY        LONG TERM HAY                                       TON     MILLION TONS


*              ACREAGE SHARE INDICATORS (FOR ROTATION BUDGETS)

  SCORN       SHARE OF ACTIVITY DEVOTED TO CORN                     PROP    NA
  SSORGHUM    SHARE OF ACTIVITY DEVOTED TO SORGHUM                  PROP    NA
  SBARLEY     SHARE OF ACTIVITY DEVOTED TO BARLEY                   PROP    NA
  SOATS       SHARE OF ACTIVITY DEVOTED TO OATS                     PROP    NA
  SWHEAT      SHARE OF ACTIVITY DEVOTED TO WHEAT                    PROP    NA
  SRICE       SHARE OF ACTIVITY DEVOTED TO RICE                     PROP    NA
  SSOYBEANS   SHARE OF ACTIVITY DEVOTED TO SOYBEANS                 PROP    NA
  SCOTTON     SHARE OF ACTIVITY DEVOTED TO COTTON                   PROP    NA

  SSILAGE     SHARE OF ACTIVITY DEVOTED TO SILAGE                   PROP    NA
  SHAY        SHARE OF ACTIVITY DEVOTED TO HAY                      PROP    NA

*              PRIMARY (FARM PRODUCED) COMMODITIES, LIVESTOCK PRODUCTS

  CLDARYCF    CULL DAIRY CALVES FOR VEAL                          HEAD    MILLION HEAD
  CLDARYCW    CULL DAIRY COWS FOR SLAUGHTER                       HEAD    MILLION HEAD
  MILK        WHOLE FARM MILK                                     CWT     MILLION CWT

  FEEDERPIG   FEEDER PIGS                                         CWT LW  MILLION CWT
  CULLSOW     CULL SOWS FOR SLAUGHTER                             CWT LW  MILLION CWT
```

HOGSLAUGH	SLAUGHTER HOGS	CWT LW	MILLION CWT
LIVCALF	BEEF FEEDER CALVES	CWT LW	MILLION CWT
BFYRLINGS	BEEF FEEDER YEARLINGS	CWT LW	MILLION CWT
CALFSLA	CULL BEEF CALVES FOR SLAUGHTER	CWT LW	MILLION CWT
CLBFCOW	CULL BEEF COWS FOR SLAUGHTER	CWT LW	MILLION CWT
CLBULLSTAG	CULL BULLS & STAGS FOR SLAUGHTER	CWT LW	MILLION CWT
NONFDSL	NONFED BEEF FOR SLAUGHTER	CWT LW	MILLION CWT
FEDSLA	FED BEEF FOR SLAUGHTER	CWT LW	MILLION CWT
FEDSLACF	FED SLAUGHTER COMM FEEDLOT	CWT LW	MILLION CWT
OTHRLVSTK	OTHER LIVESTOCK	GCAU	MILLION GCAU
*	SECONDARY (PROCESSED AND/OR CONVERSION) PRODUCTS		
BEANMEAL	SOYBEAN MEAL	CWT	MILLION CWT
BEANOIL	SOYBEAN OIL	CWT	MILLION CWT
OOSMEAL	OTHER OILSEED MEAL	CWT	MILLION CWT
ANPROTEIN	ANIMAL PROTEIN (TANKAGE) BEANMEAL EQUIVALENT	CWT	MILLION CWT
HIPROFEED	HIGH PROTEIN FEED BEANMEAL EQUIVALENT	CWT	MILLION CWT
*	ANIMAL PRODUCTS		
FEDBEEF	FED BEEF (RETAIL WEIGHT)	CWT	MILLION CWT
NONFDBEEF	NONFED BEEF (RETAIL WEIGHT)	CWT	MILLION CWT
VEAL	VEAL (RETAIL WEIGHT)	CWT	MILLION CWT
PORK	PORK (RETAIL WEIGHT)	CWT	MILLION CWT
FLUIDMLK	FLUID MILK-CREAM (MILK EQUIVALENT)	LBS	MILLION LBS
MFGMILK	MANUFACTURING MILK	CWT	MILLION CWT
BUTTER	BUTTER (PRODUCT WEIGHT)	LBS	MILLION LBS
AMCHEESE	AMERICAN CHEESE (PRODUCT WEIGHT)	LBS	MILLION LBS
OTCHEESE	OTHER CHEESE (PRODUCT WEIGHT)	LBS	MILLION LBS
ICECREAM	ICE CREAM (PRODUCT WEIGHT)	LBS	MILLION LBS
NFDMILK	NONFAT DRY MILK (PRODUCT WEIGHT)	LBS	MILLION LBS
EVDRYMLK	EVAPORATED, DRY, AND CONDENSED MILK (PRD. WEIGHT)	LBS	MILLION LBS
MILKFAT	ALTERNATIVE ACCOUNTING METHOD FOR DAIRY PRODUCTS	LBS	MILLION LBS
EGGS	EGG PRODUCTION	DOZEN	MILLION DOZ
BROILERS	BROILER PRODUCTION (CARCASS WEIGHT)	LB	MILLION LBS
TURKEY	TURKEY PRODUCTION (CARCASS WEIGHT)	LB	MILLION LBS
PBUTTER	BUTTER PURCHASED BY GOVT	LBS	MILLION LBS
PAMCHEESE	AMERICAN CHEESE PURCHASED BY GOVT	LBS	MILLION LBS
PNFDMILK	NONFAT DRY MILK PURCHASED BY GOVT	LBS	MILLION LBS
*	ETHANOL AND SWEETENER PRODUCTS AND COPRODUCTS		
STARCH	CORN STARCH	CWT	MILLION CWT
CORNOIL	CORN OIL	CWT	MILLION CWT
GLUTMEAL	GLUTEN MEAL (60% PROTEIN)	CWT	MILLION CWT
GLUTFEED	GLUTEN FEED (21% PROTEIN)	CWT	MILLION CWT
DDG	DISTILLERS DRIED GRAINS	CWT	MILLION CWT
ETHWML	ETHANOL FROM WET-MILLING	GAL	MILLION GAL
ETHDML	ETHANOL FROM DRY-MILLING	GAL	MILLION GAL
ETHANOL	ETHANOL	GAL	MILLION GAL
*	PROTEIN, ENERGY ANIMAL NUTRITION COMPONENTS		
CATPROT	CATTLE CRUDE PROTEIN AVAILABLE	LB	MILLION LBS
SWIPROT	SWINE CRUDE PROTEIN AVAILABLE	LB	MILLION LBS
DAIPROT	DAIRY CRUDE PROTEIN AVAILABLE	LB	MILLION LBS
CATENER	CATTLE METABOLIZABLE ENERGY AVAILABLE	MCAL	MILLION MCAL
SWIENER	SWINE METABOLIZABLE ENERGY AVAILABLE	MCAL	MILLION MCAL
DAIENER	DAIRY METABOLIZABLE ENERGY AVAILABLE	MCAL	MILLION MCAL
SWILINO	SWINE LINOLEIC ACID AVAILABLE	LB	MILLION LBS

```
  SWILYSI     SWINE  LYSINE AVAILABLE                                   LB      MILLION LBS

  EGGPROT     EGG PROD CRUDE PROTEIN AVAILABLE                          LB      MILLION LBS
  EGGENER     EGG PROD METABOLIZABLE ENERGY AVAILABLE                   MCAL    MILLION LBS
  BROPROT     BROILER PROD CRUDE PROTEIN AVAILABLE                      LB      MILLION LBS
  BROENER     BROILER PROD METABOLIZABLE ENERGY AVAILABLE               MCAL    MILLION LBS
  TRKPROT     TURKEY PROD CRUDE PROTEIN AVAILABLE                       LB      MILLION LBS
  TRKENER     TURKEY PROD METABOLIZABLE ENERGY AVAILABLE                MCAL    MILLION LBS

*               LIVESTOCK MANURE
  MANAU       MANURE EXCRETED                                           TON     MILLION TONS
  prenit      NITROGEN IN EXCRETED MANURE ALL LIVESTOCK OPERATIONS LB      MILLION LBS
  MANNIT      NITROGEN AVAILABLE IN AFTER HANDLING                      LB      MILLION LBS
  prephs      PHOSPHOROUS IN EXCRETED                                   LB      MILLION LBS
  MANPHS      PHOSPHOROUS AVAILABLE AFTER HANDLING                      LB      MILLION LBS
* -------------------------------------------------------------------------------------
```

$STITLE REAP MODEL'S INPUTS AND OUTPUTS: INPUTS

```
* -------------------------------------------------------------------------------------
*                                                                 PRODUCTION     SOLUTION
*      INPUT           DESCRIPTION                                ACTIVITY UNITS REPORT UITS
* ---------------- ----------------------------------------- -------------- -----------
* -------------------------------------------------------------------------------------

*                                 INPUTS

  CROPLAND    LAND (CROP)                                         ACRE        MILLION ACRES
  PASTURE     LAND (PASTURE)                                      ACRE        MILLION ACRES
  AUM         LAND (ANIMAL UNIT MONTHS)                           AUM         MILLION AUMS
  WATER       IRRIGATION WATER (GROUND)                           ACRE FT     MILLION ACFT
  NITROGEN    NITROGEN FERTILIZER                                 US$         MILLION US$
  PHOSPHAT    POTASSIUM FERTILIZER                                US$         MILLION US$
  POTASH      POTASH FERTILIZER                                   US$         MILLION US$
  LIME        LIME                                                US$         MILLION US$
  OVARCOST    OTHER VARIABLE COSTS                                US$         MILLION US$
  PUBGRAZG    PUBLIC GRAZING LAND                                 AUMS        MILLION AUMS
  CUSTOM      CUSTOM FARMING OPERATIONS                           US$         MILLION US$
  CHEMICAL    CHEMICALS                                           US$         MILLION US$
  SEEDCOST    SEED COST                                           US$         MILLION US$
  OPERCAP     INTEREST ON OPERATING CAPITAL                       US$         MILLION US$
  REPAIRS     MACHINERY & EQUIPMENT REPAIR                        US$         MILLION US$
  VET+MED     VETERINARY & MEDICAL COST                           US$         MILLION US$
  MKT+STO     MARKETING AND STORAGE                               US$         MILLION US$
  INS+FEES    INSURANCE AND FEES                                  US$         MILLION US$
  OWNRSHIP    CASH OWNERSHIP COSTS                                US$         MILLION US$
  OWNNONC     NONCASH OWNERSHIP COSTS                             US$         MILLION US$
  MANAGEMT    MANAGEMENT COSTS                                    US$         MILLION US$
  ESTMGMT     OTHER EST. MANAGEMENT COSTS                         US$         MILLION US$
  OVERHEAD    GENERAL FARM OVERHEAD                               US$         MILLION US$
  VARCNCSH    VARIABLE NONCASH COSTS                              US$         MILLION US$
  PURWATER    IRRIGATION WATER PURCHASED                          US$         MILLION US$
  TOTIRAPP    IRRIGATION WATER APPLICATION                        ACRE FT     MILLION ACFT
  ENERGY      ENERGY COSTS                                        US$         MILLION US$
  IRENERGY    IRRIGATION PUMPING COSTS                            US$         MILLION US$
  LANDTAX     LAND TAXES                                          US$         MILLION US$
  LANDRENT    LAND RENT                                           US$         MILLION US$
  CONSVCOP    CONSERVING USE PROD. COST                           US$         MILLION US$
  DIVPMT      ACREAGE DIVRSN PMTS (NEG COST)                      US$         MILLION US$
  LABOR       LABOR (FAMILY AND HIRED)                            US$         MILLION US$
  IRRLABOR    IRRIGATION LABOR (FAM & HRD)                        US$         MILLION US$
  MISCCOST    MISCELLANEOUS PRODUCTION COSTS                      US$         MILLION US$
```

PROCCOST	PROCESSING COSTS	US$	MILLION US$
INGRED	INGREDIENTS OTHER THAN CORN	US$	MILLION US$
MANAG	"MANAGEMENT, ADMINISTRATION, INSURANCE AND TAXES	US$	MILLION US$"
OPERAT	LABOR AND MAINTENANCE	US$	MILLION US$
KIA	INCREMENTAL ADDITIONS TO WET MILLING	US$	MILLION US$
KAD	ADAPTION OF ABANDONED CAPACITY	US$	MILLION US$
KNP	BUILDING NEW PLANT	US$	MILLION US$

* LVSK COP UPDATE REVISION TO THIS FILE 2/11-92)

AI	ARTIFICIAL INSEMINATION	US$	MILLION US$
BY-PRODZ	BY-PRODUCTS (Z)	US$	MILLION US$
DHIA	DAIRY HERD IMPROVEMENT ASSOCIATION FEES	US$	MILLION US$
DAIRASSE	DAIRY ASSESSMENT	US$	MILLION US$
DAIRYSUP	DAIRY SUPPLIES	US$	MILLION US$
FUEL+ELE	FUEL LUBE AND ELECTRICITY	US$	MILLION US$
HAUL	LIVESTOCK HAULING	US$	MILLION US$
MILKHAUL	MILK HAULING AND MARKETING	US$	MILLION US$
TAX+INSU	TAXES AND INSURANCE	US$	MILLION US$
BEDDING	BEDDING	US$	MILLION US$
FEEDMIX	CUSTOM FEED MIXING	US$	MILLION US$
MANURE	MANURE CREDIT	US$	MILLION US$
HAYLAGEZ	HAYLAGE ($)	US$	MILLION US$
MANAGEM	HIRED MANAGEMENT	US$	MILLION US$
MISCELLA	MISCELLANEOUS	US$	MILLION US$
PUBGRAZE	PUBLIC GRAZING	US$	MILLION US$
MINERALZ	SALT AND MINERALS ($)	US$	MILLION US$
CROPRESI	CROP RESIDUE	US$	MILLION US$
INTEREST	INTEREST	US$	MILLION US$

*ECONOMIC COST ITEM DESCRIPTION

CAPIREPL	CAPITAL REPLACEMENT COST	US$	MILLION US$
OPERCAPC	OPERATING CAPITAL COST	US$	MILLION US$
OTHECAP	OTHER NONLAND CAPITAL COST	US$	MILLION US$
LANDCOST	LAND OPPORTUNITY COST	US$	MILLION US$
LABUNPDZ	COST OF UNPAID LABOR	US$	MILLION US$
TECONCOS	TOTAL ECONOMIC COST	US$	MILLION US$
RESIDUAL	RESIDUAL RETURN TO MANAGEMENT AND RISK	US$	MILLION US$

*BUDGETED ENDOGENOUS DESCRIPTION

CONCZ	BUDGETED COST OF CONCENTRATES	US$	MILLION US$
HAYZ	BUDGETED COST OF HAY ($)	US$	MILLION US$
SILAGEZ	BUDGETED COST OF SILAGE ($)	US$	MILLION US$
GRAINZ	BUDGETED COST OF GRAIN ($)	US$	MILLION US$
PROTSUPZ	BUDGTD COST OF PROT SUPPLEMENT	US$	MILLION US$

*QUANTITIES DESCRIPTION

GRAIN	GRAIN (COP BUDGET UNITS)	CWT	MILLION CWT
GRAINCORN	GRAIN CORN COMPONENT IN CORN EQ UNITS	CWT	MILLION CWT
GRAINSBM	GRAIN BEANMEAL COMPONENT IN CORN EQ UNITS	CWT	MILLION CWT
CONC	CONCENTRATES (DAIRY)	CWT	MILLION CWT
PROTSUP	PROTEIN SUPPLEMENT	CWT	MILLION CWT
LABUNPDH	HOURS OF UNPAID LABOR	HR	MILLION HRS

* REAP MODEL'S INPUTS AND OUTPUTS: ENVIRONMENTAL SET IO ELEMENTS

EMENERGY	EMBODIED ENERGY	UNITS	MILLION UNITS
SOILDEP	SOIL DEPRECIATION ALLOWANCE	US$	MILLION US$
EROSION	SOIL LOSS FROM WATER EROSION	TONS	MILLION TONS
ERSNCOST	OFF-SITE SOIL EROSION COST	US$	MILLION US$
WINDERSN	SOIL LOSS FROM WIND EROSION	TONS	MILLION TONS

```
  NUSE        NITROGEN FERTILIZER USE                           LBS         MILLION LBS
  NSOLN       NITROGEN LOSS IN SOLUTION (SURFACE RUNOFF)        LBS         MILLION LBS
  NSEDMNT     NITROGEN LOSS WITH SEDIMENTS                      LBS         MILLION LBS
  NLEACH      NITROGEN LEACHING POTENTIAL                       LBS         MILLION LBS
  NDENITE     NITROGEN LOSS BY DENITRIFICATION                  LBS         MILLION LBS
  NVOL        NITROGEN VOLATALIZATION                           LBS         MILLION LBS
  NLOSS       TOTAL NITROGEN LOSS TO THE ENVIRONMENT            LBS         MILLION LBS
  NFLUX       NITROGEN FLUX                                     TONS        MILLION TONS
  NFLUXVAL    NITROGEN FLUX VALUE                               US$         MILLION US$
  NCRED       NITROGEN CREDIT                                   LBS         MILLION LBS
  XN          EXCESS NITROGEN BALANCE                           LBS         MILLION LBS
  PSOLN       PHOSPHORUS LOSS IN SOLUTION (SURFACE RUNOFF)      LBS         MILLION LBS
  PSEDMNT     PHOSPHORUS LOSS WITH SEDIMENTS                    LBS         MILLION LBS
  PLEACH      PHOSPHORUS LEACHED                                LBS         MILLION LBS
  PLOSS       TOTAL PHOSPHORUS LOSS TO THE ENVIRONMENT          LBS         MILLION LBS
  CFLUX       CARBON FLUX                                       TONS        MILLION TONS
  CFLUXVAL    CARBON FLUX VALUE                                 US$         MILLION US$

*      EXTENDED ENVIRONMENTAL INDICATORS

  IRGA         IRRIGATION WATER APPLIED
* LIME        LIME ADDED TO SOIL
  MUST

  PRCP         PRECIPITATION

  SRUNOFF
  SSFN

*      NITROGEN AND PHOSPHOROUS BALANCE DETAIL

  N-NVOL       NITROGEN LOSS BY VOLITILIZATION      LBS         MILLION LBS
  N-BTN NITORGEN BEGINNING TOTAL IN SOIL      LBS         MILLION LBS
  N-NDENITE  NITROGEN LOSS BY DENITRIFICATION       LBS         MILLION LBS
  N-FNH3       NITROGEN FERTILIZER ANHYDROUS AMMONIA LBS         MILLION LBS
  N-FNO3       NITROGEN FERTLIZER  NITRATE   LBS         MILLION LBS
  N-FTN NITROGEN TOTAL FERTILIZER USE LBS         MILLION LBS
  N-FX  NITROGEN FIXED LBS         MILLION LBS
  N-NBAL       NITROGEN BALANCE      LBS         MILLION LBS
  N-NLEACH     NITROGEN LEACHING POTENTIAL   LBS         MILLION LBS
  N-RN  NITROGEN CONTAIEND IN RAINFALL       LBS         MILLION LBS
  N-SSFN       NITORGEN LOSS IN SUBSURFACE FLOW     LBS         MILLION LBS
  N-TFO NITROGEN FERTLIZER ORGANIC    LBS         MILLION LBS
  N-YLN NITROGEN CONTAINED IN CROP YIELD      LBS         MILLION LBS
  N-NSOLN      NITROGEN LOSS IN SOLUTION (SURFACE RUNOFF    LBS         MILLION LBS
  N-NSEDMT     NITROGEN LOSS WITH SEDIMENT   LBS         MILLION LBS
  P-BTP PHOSPHOROUS BEGINNING TOTAL IN SOIL   LBS         MILLION LBS
  P-FTP PHOSPHOROUS TOTAL FERTILIZER APPLIED  LBS         MILLION LBS
  P-PBAL       PHOSPHOROUS BALANCE   LBS         MILLION LBS
  P-PLAB       PHOSPHOROUS LABILE    LBS         MILLION LBS
  P-PLEACH     PHOSPHOROUS LEACHING POTENTIAL       LBS         MILLION LBS
  P-PSOLN      PHOSPHORUS LOSS IN SOLUTION (SURFACE RUNNOFF)       LBS         MILLION LBS
  P-YLP PHOSPHOROUS CONTAIED IN CROP YIELD   LBS         MILLION LBS
  P-PSEDMT     PHOSPHOROUS LOSS WITH SEDIMENTS      LBS         MILLION LBS

*      PESTICIDE APPLICATION COMPONENTS
  PAPL  PESTICIDE APPLIED     LBS         MILLION LBS
  PDGF  PESTICIDE APPLIED FOLIAR      LBS         MILLION LBS
  PDGS  PESTICIDE APPLIED SOIL LBS         MILLION LBS
  PLCH  PESTICIDE LEACH POTENTIAL     LBS         MILLION LBS
  PSED  PESTICIDE LOSS WITH SEDIMENT  LBS         MILLION LBS
  PSRO  PESTICIDE LOSS WITH RUNOFF    LBS         MILLION LBS
  PSSF  PESTICIDE LOSS IN SUBSURFACE FLOW    LBS         MILLION LBS
```

```
  PTAI  PESTICIDE APPLIED ACTIVE INGEDIENT    LBS         MILLION LBS
  PIAI  PESTICIDE APPLIED INSECTICIDE ACTIVE INGREDIENT      LBS         MILLION LBS
  PHAI  PESTICIDE APPLIED HERBICIDE ACTIVE INGREDIENT       LBS         MILLION LBS
  PFAI  PESTICIDE APPLIED FUNGICIDE ACTIVE INGREDIENT       LBS         MILLION LBS
  POAI  PESTICIDE APPLIED OTHER ACTIVE INGREDIENT    LBS         MILLION LBS

*      PESTICIDE APPLICATION BY CROP AND PESTICIDE TYPE         LBS         MILLION LBS

* TOTAL        INSECTICIDE  HERBICIDE    FUNGICIDE    OTHER
  PTCORN,      PICORN     , PHCORN     , PFCORN     , POCORN
  PTSORGHUM  , PISORGHUM  , PHSORGHUM  , PFSORGHUM  , POSORGHUM
  PTBARLEY   , PIBARLEY   , PHBARLEY   , PFBARLEY   , POBARLEY
  PTOATS     , PIOATS     , PHOATS     , PFOATS     , POOATS
  PTWHEAT    , PIWHEAT    , PHWHEAT    , PFWHEAT    , POWHEAT
  PTRICE     , PIRICE     , PHRICE     , PFRICE     , PORICE
  PTSOYBEANS , PISOYBEANS , PHSOYBEANS , PFSOYBEANS , POSOYBEANS
  PTCOTTON   , PICOTTON   , PHCOTTON   , PFCOTTON   , POCOTTON
  PTHAY      , PIHAY      , PHHAY      , PFHAY      , POHAY
  PTSILAGE   , PISILAGE   , PHSILAGE   , PFSILAGE   , POSILAGE
```

Output Subsets

Final products, or outputs of production or processing, are defined as a subset **P** of set **IO**. Set **P** is further disaggregated into crops, livestock, and processed product subsets: **PC** (crop products), **PL** (livestock products), and **PX** (processed products).

p commodity, $p \subset io$, $p = 1,\dots,$P

```
SET P(IO) COMMODITIES-OUTPUTS /

       CORN,      SORGHUM,   BARLEY,    OATS
       WHEAT,     RICE,      SOYBEANS,  COTTON
       PCORN,     PSORGHUM,  PBARLEY,   POATS
       PWHEAT,    PRICE,     PSOYBEANS, PCOTTON

       SILAGE,    HAY

       CLDARYCF,  CLDARYCW,  MILK
       FEEDERPIG, CULLSOW,   HOGSLAUGH
       LIVCALF,   BFYRLINGS, CALFSLA,   CLBFCOW,   CLBULLSTAG
       NONFDSL,   FEDSLA,    FEDSLACF,  OTHRLVSTK
       BEANMEAL,  BEANOIL,   OOSMEAL,   ANPROTEIN, HIPROFEED
       STARCH,    CORNOIL,   GLUTMEAL,  GLUTFEED
       CATPROT,   SWIPROT,   DAIPROT
       CATENER,   SWIENER,   DAIENER
       SWILINO,   SWILYSI
       EGGPROT,   EGGENER,   BROPROT
       BROENER,   TRKPROT,   TRKENER

       DDG,
       ETHSOA, ETHWML, ETHDML, ETHANOL
*
```

pc crop commodity, $pc \subset p$

```
SET PC(IO) CROP PRODUCTS /

          CORN,      SORGHUM,   BARLEY,    OATS
          WHEAT,     RICE,      SOYBEANS,  COTTON,
          SILAGE,    HAY
          /
```

pl livestock commodity, $pl \subset p$

```
SET PL(IO)  LIVESTOCK PRODUCTS /

          CLDARYCF,  CLDARYCW,  MILK
          CULLSOW,   FEEDERPIG, HOGSLAUGH
          LIVCALF,   BFYRLINGS, CALFSLA,   CLBFCOW,   CLBULLSTAG
          NONFDSL,   FEDSLA,    FEDSLACF
          OTHRLVSTK
```

px processed commodity, $px \subset p$

```
PX(IO)  PROCESSED PRODUCTS /

          BEANMEAL,  BEANOIL,   OOSMEAL,   ANPROTEIN, HIPROFEED
          STARCH,    CORNOIL,  GLUTMEAL,   GLUTFEED
          DDG,
          ETHSOA, ETHWML, ETHDML, ETHANOL

*

          CATPROT,   SWIPROT,   DAIPROT
          CATENER,   SWIENER,   DAIENER
          SWILINO,   SWILYSI
          EGGPROT,   EGGENER,   BROPROT
          BROENER,   TRKPROT,   TRKENER

          FEDBEEF,   NONFDBEEF, VEAL,      PORK
          FLUIDMLK,  MFGMILK,   BUTTER,    AMCHEESE,  OTCHEESE,  ICECREAM
          NFDMILK,   EVDRYMLK,  EGGS,      BROILERS,  TURKEY
```

Input Subsets

Inputs are defined as a subset I of set IO. Set I is further disaggregated into national and regional input subsets: IN and IR. National inputs are specified with a single fixed price in any area of the U.S. Regional inputs specify a relationship between price and quantity used by Farm Production Region:

```
I(IO)    INPUTS EXCLUSIVE OF MODEL-ENDOGENOUS PRODUCTS /

          CROPLAND,  PASTURE,   AUM,       WATER
          NITROGEN,  PHOSPHAT,  POTASH
          LIME,      OVARCOST,  PUBGRAZG,  CUSTOM,    CHEMICAL,  SEEDCOST
          OPERCAP,   REPAIRS,   VET+MED,   MKT+STO,   INS+FEES,  OWNRSHIP
          IRENERGY
          MANAGEMT,  ESTMGMT,   OVERHEAD,  VARCNCSH,  PURWATER,  TOTIRAPP
          ENERGY,    LANDTAX,   LANDRENT,  CONSVCOP,  DIVPMT,    LABOR
          MISCCOST,  PROCCOST

*                                                LVSK ADDITION CASH COSTS
          AI,        BY-PRODZ,  DHIA,      DAIRASSE,  DAIRYSUP,  FUEL+ELE
          HAUL,      MILKHAUL,  TAX+INSU,  BEDDING,   FEEDMIX,   MANURE
          HAYLAGEZ,  MANAGEM,   MISCELLA,  PUBGRAZE,  MINERALZ,  CROPRESI
          INTEREST

*                                                LVSK ADDITION ECONOMIC COSTS
          CAPIREPL,  OPERCAPC,  OTHECAP,   LANDCOST,  LABUNPDZ
          TECONCOS,  RESIDUAL
          /

IR(IO)  REGIONAL INPUTS /
          CROPLAND,  PASTURE,   AUM,       WATER,     TOTAL
          /

IN(IO)  NATIONAL INPUTS /
```

```
          NITROGEN,  PHOSPHAT,  POTASH
          LIME,      OVARCOST,  PUBGRAZG,  CUSTOM,    CHEMICAL,  SEEDCOST
          OPERCAP,   REPAIRS,   VET+MED,   MKT+STO,   INS+FEES,  OWNRSHIP
          IRENERGY
          MANAGEMT,  ESTMGMT,   OVERHEAD,  VARCNCSH,  PURWATER,  TOTIRAPP
          ENERGY,    LANDTAX,   LANDRENT,  CONSVCOP,  DIVPMT,    LABOR
          MISCCOST,  PROCCOST,
*                                                    ETHANOL REVISION
          INGRED, MANAG, OPERAT, KIA, KAD, KNP
*                                                    LVSK ADDITION CASH COSTS
          AI,        BY-PRODZ,  DHIA,      DAIRASSE,  DAIRYSUP,  FUEL+ELE
          HAUL,      MILKHAUL,  TAX+INSU,  BEDDING,   FEEDMIX,   MANURE
          HAYLAGEZ,  MANAGEM,   MISCELLA,  PUBGRAZE,  MINERALZ,  CROPRESI
          INTEREST
*                                                    LVSK ADDITION ECONOMIC COSTS
          CAPIREPL,  OPERCAPC,  OTHECAP,   LANDCOST,  LABUNPDZ
          TECONCOS,  RESIDUAL
          /
```

Exogenous Variables (GAMS Parameters)

Since REAP's formulation is parameter-driven, it is necessary to be familiar with its key data parameters; i.e., exogenous variables. In GAMS, data are stored in objects called "PARAMETERS." SCALARS are PARAMETERS with a single dimension. TABLES are PARAMETERS with 2 to 10 dimensions. GAMS parameters with several dimensions are shown in this bulletin and in GAMS, input or output code as two-dimensional tables. Indexes for additional dimensions (that is, beyond two) appear either in the table row stub or column heading, depending on what most clearly illustrates the data in question. Here, we present only the minimum information necessary to understand the REAP equations. We list and discuss definitions and at least part of the contents for the most important REAP PARAMETERS. Where the PARAMETER contains a large amount of data, we present only a fragment or two of the data. REAP model PARAMETERS that contain raw input data or are used in intermediate calculations are not presented or discussed here (but are present in the REAP source and listings).

Production Activity Data

REAP crop and livestock production activity coefficients reside in table `PP`. Production activity coefficients represent the quantity of outputs produced or inputs used per unit of each production activity. The production activity data to produce the coefficients come from the ERS Farm Costs and Returns Survey data, the USDA baseline, the agricultural census, and other sources.

`PP` is indexed over seven dimensions: input-output item, enterprise, government program category, method of production (not active), system of production (not active), tillage type, and region. The rows of the `PP` crops fragment refer to input-output items, and columns refer to the other indexes.

Example 2—PP(IO,B,G,H,Y,T,RL,R) Crop Fragment

PARAMETER PP(IO,B,G,H,Y,T,RL,R) ENTERPRISE TECHNICAL COEFFICIENTS

	RCCC	RCB	RCB	RCBW	RCBW
	NP	NP	NP	NP	NP
	A	A	A	A	A
	PRD	PRD	PRD	PRD	PRD
	CNV	CNV	MCH	CNV	NLL
	CBM	CBM	CBM	LAL	APP
	CB	CB	CB	LA	AP
CORN	132.582	136.690	136.470	129.979	89.953
WHEAT				43.092	51.948
SOYBEANS		47.318	47.171	51.219	19.759
LCORN	132.960	137.099	137.189	131.408	90.014
LWHEAT				42.957	51.967
LSOYBEANS		47.649	47.459	51.227	19.766
SCORN	1.000	0.500	0.500	0.333	0.500
SWHEAT				0.333	0.500
SSOYBEANS		0.500	0.500	0.333	0.500
CROPLAND	1.000	1.000	1.000	1.000	1.000
NITROGEN	41.480	20.360	19.980	17.560	31.940
PHOSPHAT	13.620	13.670	13.670	13.590	9.490
POTASH	8.740	5.110	5.110	2.200	8.940
LIME	1.040	0.060	0.060		0.090
CHEMICAL	16.110	10.670	15.680	9.300	17.770
SEEDCOST	22.900	18.110	18.110	19.700	24.010
OPERCAP	2.200	1.520	1.570	1.480	2.000
REPAIRS	8.680	7.720	7.150	8.950	9.440
INS+FEES	19.750	18.920	18.920	17.590	11.970
OWNRSHIP	14.200	12.980	12.170	13.020	16.540
OVERHEAD	12.440	14.560	14.560	19.370	19.980
ENERGY	5.580	4.790	4.270	6.270	4.860
LANDRENT	90.350	90.350	90.350	57.290	46.390
LABOR	5.180	4.460	4.000	5.510	5.660
EMENERGY	47.330	25.585	25.957	21.966	39.317
SOILDEP	-0.304	-0.507	-0.587	-0.339	-0.042
EROSION	3.925	4.587	3.325	2.411	0.529
WINDERSN	0.081	0.049	0.025	0.016	
NSOLN				3.000	
NSEDMNT	12.202	14.487	11.198	3.766	0.457
NLEACH	11.000	11.000	10.000	6.000	13.000
NDENITE	52.328	53.500	52.647	29.389	10.441
NLOSS	75.529	78.988	73.845	42.155	23.898
PSOLN	1.000	1.000	1.000	3.000	
PSEDMNT	1.744	2.043	1.552	0.534	0.064
PLEACH	1.872	1.833	1.830	1.518	1.586
PLOSS	4.616	4.876	4.382	5.052	1.650
CFLUX	-3.448	-3.314	-3.024	-2.380	2.060
SUSTOTAL	1.000	1.000	1.000	0.999	1.500
SUSFLEX	1.000	1.000	1.000	0.999	1.000

In example 2 above, the label for column 1 refers to a continuous corn, nonprogram, normal, predominant production system, using conventional tillage in the Land Resource Region M portion of the Corn Belt Farm Production Region (CBM). The other four columns present activities that differ from the first by crop, rotation, tillage practice, and region. The column lists the input-output coefficients for each activity. The first index of PP is IO, input-output items that appear as row stubs in the listing. Set IO includes the subsets P (products), IN (national inputs), IR (regional inputs), and environmental indicators.

In the crops PP fragment, corn yield per planted acre is 132.582 bushels in the Corn Belt region. The share coefficient SCORN is 1.000, indicating that corn's share of this production activity is 100 percent. This happens for all continuous crop enterprises or production activities. If this were a multiplecrop rotation, then the value of SCORN would be less than 1. If it were a two-crop rotation as represented in the second column, then SCORN would be 0.500, indicating the proportion of corn yield in the PP table for this activity that would be attributed to this rotation. The NITROGEN coefficient indicates that nitrogen fertilizer used costs $41.480 per acre. The EROSION coefficient indicates that soil loss from water erosion averages 3.925 tons per acre on an annual basis. Likewise, the NLOSS coefficient indicates that nitrogen loss to water and the atmosphere for this system averages 75.529 pounds per acre annually.

Dairy, feeder pig, and beef cow enterprises are abstracted in the PP fragment in example 3. Although the dimensions of the PP table are the same for livestock production activities as for the crop production activities, several of the production strata sets are not relevant and are set to the same value for all livestock production activities. These include sets G, H, Y, and T.

Example 3—PP(IO,B,G,H,Y,T,R,R) Livestock Fragment

TABLE PP(IO,B,G,H,Y,T,R,R) ENTERPRISE TECHNICAL COEFFICIENTS

	DAIRY	FEEDRPIG	BFCOWEN
	NP	NP	NP
	A	A	A
	PRD	PRD	PRD
	ALT	ALT	ALT
	NT	CB	CB
	NT	CB	CB
SILAGE	-7.250		-0.380
HAY	-2.626		-1.090
CLDARYCF	0.328		
CLDARYCW	0.189		
MILK	216.495		
FEEDERPIG		7.970	
CULLSOW		2.030	
LIVCALF			1.866
BFYRLINGS			2.063
CLBFCOW			0.624
CATPROT			-117.789
SWIPROT		-855.389	
DAIPROT	-950.019		
CATENER			-521.485
SWIENER		-7675.991	
DAIENER	-9869.950		
SWILINO		-89.487	
SWILYSI		-41.152	
PASTURE	0.414		
REPAIRS	59.160	49.800	21.790
VET+MED	36.780	17.000	7.400
MKT+STO		17.900	5.780
OVERHEAD	157.520	70.900	56.410
LABOR	160.130	26.100	13.850
AI	26.710		
BY-PRODZ	11.450		
DHIA	11.520		
DAIRYSUP	31.520		
FUEL+ELE	40.920	76.900	15.420
HAUL	1.800	2.600	1.790
MILKHAUL	121.680		
TAX+INSU	60.810	19.000	26.860

BEDDING		4.700	
FEEDMIX		10.700	0.630
MANURE		-1.900	
PUBGRAZE			0.950
MINERALZ			2.050
CROPRESI			0.220
INTEREST	147.420	59.900	41.170
CAPIREPL	270.960	120.100	61.280
OPERCAPC	12.860	12.100	7.110
OTHECAP	119.480	35.500	33.170
LANDCOST	40.510	4.700	84.380
LABUNPDZ	114.600	195.900	79.860
TECONCOS	2056.650	1060.400	525.830
RESIDUAL	214.810	-444.600	-141.040
CONCZ	562.430		
HAYZ	109.190		26.920
SILAGEZ	99.190		6.250
GRAINZ		186.300	8.770
PROTSUPZ		211.500	29.540
GRAIN		-43.980	-1.860
CONC	-72.721		
PROTSUP		-12.060	-2.280

In example 3, the label for column 1 refers to dairy production activity, nonprogram, normal, predominant system in the Northeast Farm Production Region. The other two columns present activities for hogs and beef. Since the livestock production activities are disaggregated only to the Farm Production Region, the Land Resource Region index is set to be the same as used for the Farm Production Region. Set T is set at ALT since tillage systems do not apply to livestock production activities. The column lists the input-output coefficients for each activity and uses the same signing conventions as used for crops. The first index of PP is IO, input-output items, which appear as row stubs in the listing.

In the livestock PP fragment in example 3, milk production per cow in the Northeast is 216.495 cwt. per cow per year. Fuel and electricity use total $40.92 per cow, while each cow requires 950.019 pounds of protein and 9,869.950 million calories of energy from feed per year.

Processing Activity Data

Processing activity coefficients reside in the table PPC. Four general types of processing activities are represented: livestock slaughter, dairy product conversion, feed ration mixing, and corn and oilseed crushing. Coefficients for these activities come from various Situation and Outlook reports, National Academy of Science publications or are derived from the baseline data or agriculture census data. References for these sources can be found in the model code.

Example 4—Processing activity livestock slaughter fragment

PARAMETER PPC(P,C) PROCESSING ACTIVITIES (CONT.)

	HOGTOPORK	FSLATOFBEF	FSCFTOFB	DCOWNFBF	BCOWNFBF	NFSLATONFB	CLBLTONFBF
CLDARYCW				-0.200			
CULLSOW							
HOGSLAUGH	-1.432						
CLBFCOW					-2.406		
CLBULLSTAG							-2.406
NONFDSL						-2.406	
FEDSLA		-2.247					
FEDSLACF			-2.288				
FEDBEEF		1.000	1.000				

NONFDBEEF				1.000	1.000	1.000	1.000
PORK	1.000						

In example 4, the column headings list the types of slaughter activities, and the row labels give the inputs and outputs. Examples 5 to 7 follow a similar format, with column headings listing the processing activities and the row labels giving the inputs and outputs.

Example 5 shows dairy-processing activities found in parameter PPC. Fluid milk (FLUIDMLK) is converted directly to fluid milk. In contrast, manufactured milk (MFGMILK) is converted to butter (BUTTER), American cheese (AMCHEESE), other cheese (OTCHEESE), ice cream (ICECREAM), and evaporated dry milk (EVDRYMLK).

Example 5—Processing activity milk processing fragment

PARAMETER PPC(P,C) PROCESSING ACTIVITIES (CONT.)

+	FLUIDMLK	MFGMILK	BUTTER	AMCHEESE	OTCHEESE	ICECREAM	EVDRYMLK
FLUIDMLK	102.000						
MFGMILK		1.000	-1.000	-1.000	-1.000	-1.000	-1.000
BUTTER			4.805				
NFDMILK			3.105				
AMCHEESE				10.825			
OTCHEESE					18.253		
ICECREAM						8.430	
EVDRYMLK							25.288
MILK	-1.000	-1.000					

Example 6 shows the feed ration processing activities for fed cattle. The rations use crops as input and produce protein (CATPROT) and energy (CATENER). Similar types of rations are specified for dairy, hogs, and poultry.

Example 6—Processing activity feed mix fragment

PARAMETER PPC(P,C) PROCESSING ACTIVITIES (CONT.)

+	GRAIN1	GRAIN2	GRAIN3	GRAIN1A	GRAIN1B	GRAIN1C	GRAIN1D
CORN	-1.231	-1.364	-1.366	-1.231	-1.364	-1.366	-1.350
SORGHUM	-0.234	-0.163	-0.225	-0.399	-0.326	-0.321	
BARLEY	-0.096	-0.060	-0.069	-0.128	-0.099	-0.092	-0.024
OATS	-0.262	-0.183	-0.203	-0.087	-0.031	-0.030	-0.004
WHEAT	-0.082	-0.095	-0.018				-0.200
CATPROT	9.519	9.438	9.222	9.150	9.075	9.017	8.580
CATENER	126.559	127.519	127.141	126.907	127.965	127.330	115.105

Example 7 shows the processing activities for soybeans and ethanol. The soybean-processing activity (SOYCRUSH1) converts soybeans into bean meal (BEANMEAL) and oil (BEANOIL). The ethanol-processing activities take corn and convert it into ethanol and its byproducts—corn starch (STARCH), corn gluten meal (GLUTMEAL), corn gluten feed (GLUTFEED), and distiller's dried grains (DDG). Ethanol-processing activities include wet milling (ETHWMLCUR, ETHWML95) and dry milling (ETHDMLCUR, ETHDML95).

Example 7—Processing Activity corn-soybean crushing

PARAMETER PPC(P,C) PROCESSING ACTIVITIES (CONT.)

+	SOYCRUSH1	ETHWMLCUR	ETHWML95	ETHDMLCUR	ETHDML95	ETHSOA
SOYBEANS	-1.000					
CORN		-1.000	-1.000	-1.000	-1.000	
ETHSOA		2.500	2.500	2.600	2.600	-1.000
BEANMEAL	0.477					

```
BEANOIL          0.113        0.020       0.020
STARCH                        0.315       0.315
GLUTMEAL                      0.026       0.026
GLUTFEED                      0.135       0.135
DDG                                                   0.175       0.175
ETHANOL                                                                       1.000
```

Processing and Production Activity Costs

w_c cost of processing activity c

SCR(C,*) PROCESSING ACTIVITY COST-RETURNS SUMMARY TABLE

Input costs are not explicitly represented for most of the model's processing activities. Processing activity cost (example 8) is determined as value added in production or net return to production. Net return for production is determined as the difference between revenue at base prices received for all outputs from the processing activity minus the value of intermediate inputs at base prices used by the processing activity. In a few instances, primarily ethanol processing, the processing costs are explicitly represented in the production activity. These costs are included in the calculation of net returns (value added) for these processing activities. The formula for calculating processing cost is shown here.

```
SCR(C,      "COST")          = SUM(IN, PPC(IN,C)* INPUTN(IN,"PBASE"))
                              -SUM(P,  PPC(P,C) * DEMSUP(P,"DOM","PBASE")
                         $(PPC(P,C) LT 0));
*                            ETHANOL CALCULATION
 SCR("ETHWMLCUR ","COST")    = SCR("ETHWMLCUR ","COST") - PPC("KIA","ETHWMLCUR ");
 SCR("ETHWML95  ","COST")    = SCR("ETHWML95  ","COST") - PPC("KAD","ETHWML95  ");
 SCR("ETHWML20  ","COST")    = SCR("ETHWML20  ","COST") - PPC("KNP","ETHWML20  ");
*                                                ETHANOL REVISION END
 SCR(C,   "REVENUE")         = SUM(P,  PPC(P,C) * DEMSUP(P,"DOM","PBASE")
                              $(PPC(P,C) GT 0));
 SCR(C, "NETRETURN")         = SCR(C,"REVENUE") - SCR(C,"COST");
```

Example 8 – Processing activity net return fragment

SCR(C, " NETRETURN ") PROCESSING ACTIVITY COST-RETURNS SUMMARY TABLE

Processing activity	Net Return ($/unit)
HOGTOPORK	217.621
SOWTOPORK	204.828
FSLATOFBEF	187.379
FSCFTOFB	184.170
DCOWNFBF	161.051
BCOWNFBF	141.291
NFSLATONFB	141.291
CLBLTONFBF	141.291
DCLFVEAL	415.507
FLUIDMLK	-0.481
MFGMILK	-2.158
BUTTER	-3.422
AMCHEESE	2.375
OTCHEESE	16.158
ICECREAM	-0.311
EVDRYMLK	3.327
SOYCRUSH1	1.338
ETHWMLCUR	0.925
ETHWML95	0.845

```
ETHDMLCUR              0.962
ETHDML95               0.892
-------------------------------------------------
```

$w^{vc}_{b,g,h,t,,rl,r}$ variable cost of production activity ***b,g,h,t*** in region ***rl,r***

Production activity costs are reported in `PCR(B,G,H,Y,T,U,UR, "VCOST")`. Costs are calculated for each production activity at base period prices. The calculations for production activity costs can be found in file A1A0C.GMS in the root model directory. Cropping activity `VCOST` is determined by multiplying the inputs from the crop production budgets in `PP` by the input prices in parameter `INPUTN` and summing up over the inputs contained in set `INVC`. Since the input items contained in the production activity budgets represent expenditures and are already expressed in terms of dollar value, the prices in `INPUTN` are set at one. `VCOST` is adjusted by adding a credit equal to the rental rate for cropland in the base period. This credit is added to ensure that net returns for production activities are positive, a requirement for CET parameters to be calculated. Differences among regions in cropland costs will still affect any changes in cropland use from the base since any expansion or reduction in cropland use will cause crop price to change.

Crops:
```
PCR(B,G,   H,Y,T,U,UR,     "VCOST")    $ XCROPP(B,G,H,Y,T,U,UR)
*                                        ADD CREDIT FOR REGIONAL LAND PRICES FOR ENVIRONMENTAL VERSION
                                   =- (PP("CROPLAND",B,G,   H,Y,T,U,UR) * INPUTR(UR,"CROPLAND","PBASE")
                                    $ ((INPUTR(UR,"CROPLAND","PBASE") GT 0) AND (INPUTR(UR,"CROPLAND","PFXP") GE 0)))
                                    + SUM(INVC, PP(INVC,B,G,   H,Y,T,U,UR) * INPUTN(INVC,"PBASE"));
```

Livestock:
```
PCR(B,G,   H,Y,T,U,UR,      "VCOST")    $ XLVSTP(B,G,H,Y,T,U,UR)
                                  = SUM(INVC, PP(INVC,B,G,H,Y,T,U,UR) * INPUTN(INVC,"PBASE"));
```

Similar calculations are done for livestock production activities. Examples of the results of the calculations are shown in example 9 below.

Example 9–`PCR(B,G,H,Y,T,U,UR, 'VCOST')` cost of production fragment

	CB.CB	CBLN.CB	CBMN.CB	CBNN.CB	CBON.CB	CBRN.CB
RCCC .NP.CNV		167.854	167.934	169.187	167.854	168.015
RCCC .NP.MLD		161.600	161.680	162.261		162.331
RCCC .NP.MCH		163.688	163.748	163.768		163.798
RCCC .NP.NLL		151.929	151.989	152.520		152.570
RTTT .NP.CNV					283.074	
RBBB .NP.CNV			113.542		113.482	
RBBB .NP.NLL			145.134			
RHHH .NP.MLD		92.001	95.709	93.584		92.001
RGGG .NP.CNV			165.180			
RGGG .NP.MCH			162.021			
RCB .NP.CNV		137.960	137.970	137.970		138.561
RCB .NP.MLD		151.580	151.590	152.782		152.191
RCB .NP.MCH		146.925	146.935	146.925		147.526
RCB .NP.NLL		142.277	142.287	142.878		142.878
RCBW .NP.CNV		114.043	114.043		114.043	
RCBW .NP.MLD		125.153	125.153			
RCBW .NP.MCH		129.446	129.446			
RCBW .NP.NLL		122.435	122.435			
RCBWH .NP.CNV		115.718	115.738	117.371		

%%%%%%

$w^{n}_{b,g,t,ft,rl,r}$ nitrogen fertilizer cost for production activity ***b,g,t,ft*** in region **rl,r**

```
PCRNIT(B,G,H,Y,T,FT,U,UR,"NCOST") NITROGEN FERTILIZER COSTS PER UNIT ACTIVITY
```

Nitrogen fertilizer costs (example 10) for rotations and tillage practice pairings are the same across all Land Resource Regions within a Farm Production Region. This is because fertilizer use by rotation and tillage practice was derived at the Farm Production Region level.

Example 10—Nitrogen fertilizer costs fragment

PCRNIT(B,G,H,Y,T,FT,U,UR,"NCOST") NITROGEN FERTILIZER COSTS PER UNIT ACTIVITY

	CBLN.CB	CBMN.CB	CBNN.CB	CBON.CB	CBRN.CB
RCCC .NP.A.PRD.CNV.1	41.480	41.480	41.480	41.480	41.480
RCCC .NP.A.PRD.CNV.9	37.332	37.332	37.332	37.332	37.332
RCCC .NP.A.PRD.CNV.8	33.184	33.184	33.184	33.184	33.184
RCCC .NP.A.PRD.CNV.7	29.036	29.036	29.036	29.036	29.036
RCCC .NP.A.PRD.CNV.6	24.888	24.888	24.888	24.888	24.888
RCCC .NP.A.PRD.MLD.1	42.500	42.500	42.500		42.500
RCCC .NP.A.PRD.MLD.9	38.250	38.250	38.250		38.250
RCCC .NP.A.PRD.MLD.8	34.000	34.000	34.000		34.000
RCCC .NP.A.PRD.MLD.7	29.750	29.750	29.750		29.750
RCCC .NP.A.PRD.MLD.6	25.500	25.500	25.500		25.500
RCCC .NP.A.PRD.MCH.1	42.750	42.750	42.750		42.750
RCCC .NP.A.PRD.MCH.9	38.475	38.475	38.475		38.475
RCCC .NP.A.PRD.MCH.8	34.200	34.200	34.200		34.200
RCCC .NP.A.PRD.MCH.7	29.925	29.925	29.925		29.925
RCCC .NP.A.PRD.MCH.6	25.650	25.650	25.650		25.650
RCCC .NP.A.PRD.NLL.1	34.350	34.350	34.350		34.350
RCCC .NP.A.PRD.NLL.9	30.915	30.915	30.915		30.915
RCCC .NP.A.PRD.NLL.8	27.480	27.480	27.480		27.480
RCCC .NP.A.PRD.NLL.7	24.045	24.045	24.045		24.045
RCCC .NP.A.PRD.NLL.6	20.610	20.610	20.610		20.610

$w^{\sigma}_{b,g,t,ft,rl,r}$ risk premium charged for nitrogen fertilizer use in production activity ***b,g,t,ft*** in region ***rl,r***

PCRNIT(B,G,H,Y,T,FT,U,UR,"RSKADJ") NITROGEN RISK ADJUSTMENT PER UNIT ACTIVITY

The risk premium (example 11) represents the amount producers would need to receive to make them indifferent between using the reduced rate of fertilizer application and the base rate of fertilization. The risk premium represents producers' perceptions about having sufficient fertilizer available for meeting crop needs in order to achieve yield targets. The risk premium associated with reduced nitrogen fertilizer use varies across rotation/tillage management pairings even for pairings in the same Farm Production Region. This is because the yield response curve for nitrogen fertilizer varies across all regions.

Example 11—Nitrogen fertilizer risk premium fragment

PCRNIT(B,G,H,Y,T,FT,U,UR,"RSKADJ") RISK ADJUSTMENT COST PER UNIT ACTIVITY

	CBLN.CB	CBMN.CB	CBNN.CB	CBON.CB	CBRN.CB
RCCC .NP.A.PRD.CNV.9	2.863	6.470	8.695		4.609
RCCC .NP.A.PRD.CNV.8	5.216	11.790	15.844		8.398
RCCC .NP.A.PRD.CNV.7	12.204	27.583	37.069		19.648
RCCC .NP.A.PRD.CNV.6	30.016	67.844	91.175		48.327
RCCC .NP.A.PRD.MLD.9	6.434	8.110	9.946		7.563
RCCC .NP.A.PRD.MLD.8	11.724	14.778	18.123		13.780
RCCC .NP.A.PRD.MLD.7	27.430	34.576	42.402		32.241
RCCC .NP.A.PRD.MLD.6	67.467	85.043	104.291		79.299
RCCC .NP.A.PRD.MCH.9	4.064	7.652	10.597		6.923
RCCC .NP.A.PRD.MCH.8	7.405	13.943	19.309		12.614
RCCC .NP.A.PRD.MCH.7	17.324	32.621	45.176		29.513
RCCC .NP.A.PRD.MCH.6	42.610	80.236	111.114		72.590

$w^{crp}_{ir,r}$ CRP rental rate for regional input *ir* in region *r*

ACRESDY("TOTAL","HST","CRPR","A","2005",R) CROP PLANTINGS AND ACREAGE BASE

CRP rental rates (example 12) are fixed in the formulation of the model because rental rates are set by the government, based on prevailing local market rental rates.

Example 12—CRP rental rate

```
ACRESDY("TOTAL","HST","CRPR","A","2005",R) CROP PLANTINGS AND ACREAGE BASE

NT      72.826
LA      71.833
CB      90.115
NP      46.411
AP      60.787
SE      44.317
DL      40.497
SP      35.082
MN      35.358
PA      43.843
```

Demand and Supply Function Data

Commodity demand and supply relationships are incorporated explicitly and implicitly in REAP. The parameters for the explicitly defined demand and supply equations are derived from supply and demand elasticities and base year prices and quantities. This information is contained in the DEMSUP parameter (see table 3). The prices and quantities contained in DEMSUP are updated automatically to the baseline year selected for the analysis. The absence of an elasticity indicates that no explicit supply or demand curve is specified for that particular commodity in that particular market—i.e., the price remains constant. The absence of a price indicates that the value or price of the commodity in that market is determined implicitly. A positive sign on elasticity indicates that it is a supply, elasticity, and a negative sign indicates it is a demand elasticity. MIN and MAX indicate lower and upper bounds on quantity to be imposed in that market. Sources of demand and supply elasticities in DEMSUP are also in the REAP calibration run listing or in the A1A0A.gms file.

The formulas used to derive the commodity demand and supply function parameters are provided here.

$\beta_{m,p}$ slope for commodity ***p*** demand or supply equation in market ***m***

```
BETA(P,M)             DEMAND AND SUPPLY FUNCTION SLOPES BY MARKET
```

$\beta_{m,p} = (P_{m,p}/Z_{m,p}) * (1/e_{m,p})$ such $e_{m,p} \neq 0 \;\forall\; p = 1,\ldots,P;\; m = 1,\ldots,M;$

```
BETA(P,M)  = (DEMSUP(P,M,"PBASE") / DEMSUP(P,M,"QBASE")
/ DEMSUP(P,M,"ELAS")) $ DEMSUP(P,M,"ELAS");
```

$\alpha_{m,p}$ intercept on commodity ***p*** demand or supply equation in market ***m***

```
ALPHA(P,M)            DEMAND AND SUPPLY FUNCTION INTERCEPTS BY MARKET
```

$\alpha_{m,p} = P_{m,p} - \beta_{m,p} * Z_{m,p}$

```
ALPHA(P,M) = (DEMSUP(P,M,"PBASE") - BETA(P,M) * DEMSUP(P,M,"QBASE"))
```

where $P_{m,p}$ and $Z_{m,p}$ represent base year price and quantity, respectively, for commodity ***p*** in market ***m*** and $e_{p,m}$ equals the price elasticity for commodity ***p*** in market ***m***.

The parameters on the input supply equations are also derived from supply and demand elasticities and base year prices and quantities. This information is contained in the INPUTR parameter (table 4). The prices reported in this table are not updated automatically but on a periodic basis. Quantity information is not from an outside data source but is derived from baseline information on crop and livestock production. This information is updated automatically to the baseline year. The formulas used to derive the input supply functions are provided here.

$\beta_{ir,r}$ slope for regional input ***ir*** supply equation in farm production region ***r***

```
BETAI(R,IR)          INPUT SUPPLY FUNCTION SLOPES
```

$\beta_{ir,r} = (w_{r,ir}/VI_{r,ir}) * (1/e_{r,ir})$ such that $e_{r,ir} > 0 \ \forall \ r = 1,\ldots,R;\ ir = 1,\ldots,IR;$

```
BETAI(R,IR)  = (INPUTR(R,IR,"PBASE")  / INPUTR(R,IR,"QBASE")
/ INPUTR(R,IR, "ELAS")) $ INPUTR(R,IR, "ELAS");
```

$\alpha_{ir,r}$ intercept on regional input *ir* supply equation in farm production region *r*

```
ALPHAI(R,IR)         INPUT SUPPLY FUNCTION INTERCEPTS
```

$\alpha_{r,ir} = w_{r,ir} - \beta_{ir,r} * VI_{r,ir}$

```
ALPHAI(R,IR) = (INPUTR(R,IR,"PBASE")-BETAI( R,IR) * INPUTR(R,IR,"QBASE"))$ INPUTR(R,IR,"QBASE");
```

where $w_{r,ir}$ and $VI_{r,ir}$ represent base year price and quantity, respectively, for variable input *ir* in region *r*, and $e_{r,ir}$ equals the price elasticity of supply for variable input *ir* in region *r*.

The parameters on CRP land supply equations are also derived from cropland supply elasticities. The derivations, however, depend on base year CRP rental rates and CRP enrollment acreage. Information about CRP rental rates and enrollment is contained in ACRESDY (see example 12).

$\beta^{crp}_{ir,r}$ slope for regional CRP input ***ir*** supply equation in farm production region ***r***

```
BETAC( IR,YR,UR)          PMP CRP FUNCTION SLOPES BY PROCESS AND REGION
```

$\alpha^{crp}_{ir,r}$ intercept on regional CRP input ***ir*** supply equation in farm production region ***r***

```
ALPHAC(IR,YR,UR)          PMP CRP FUNCTION INTERCEPTS BY PROCESS AND REGION
```

CRP supply parameters are set at zero since CRP acreage is fixed in the base version of the model. CRP can be made endogenous by specifying values for these parameters and setting the CRP rental rate parameter to zero. National CRP enrollment is updated by the baseline data. CRP rental rates and distributions of enrollment acreage are updated periodically.

CET Parameters

The parameters for the CET allocation functions are derived from an elasticity of transformation and information on the value of the production activities. The transformation elasticities are given, while the value of the production activities is determined from shadow prices obtained by solving REAP, with constraints imposed on allocation of production activities associated with the level of CET function being derived. The elasticities of transformation are fixed for both the rotation CET function and the tillage CET function.

$\sigma_{b,rl}$ Elasticity of transformation.

```
SIGMA            CET FUNCTION ROTATION ACREAGE ELASTICITY OF SUBSTITUTION
SIGMAT           CET FUNCTION TILLAGE ACREAGE ELASTICITY OF SUBSTITUTION

SIGMAT(BA,U)        $RACD(BA,U)
                 = -10;

SIGMA(B,U)         = -2  $SUM(BA, BSBROT(B,BA,U));
```

$\rho_{b,rl}$ CET substitution parameter for crop or rotation ***b*** acres in farm resource region ***rl***

```
RHOT             CET FUNCTION TILLAGE SUBSTITUTION PARAMETER
RHO              CET FUNCTION ROTATION SUBSTITUTION PARAMETER
```

$\rho_{b,rl} = (1-\sigma_{b,rl})/\sigma_{b,rl}$ where $\sigma_{b,rl}$ is the elasticity of transformation among rotations used to produce crop ***b*** or among tillage practices used by rotation *b* in farm resource production region ***rl***.

```
RHOT(BA,U)                    $SIGMAT(BA,U)
= (1-SIGMAT(BA,U))/SIGMAT(BA,U);

RHO(BA,U)                     $SIGMA(BA,U)
                       o       = (1-SIGMA(BA,U))/SIGMA(BA,U);
```

$\delta_{b,t,rl}$ CET allocation parameter for *t* tillage acres planted to rotation ***b*** acres in farm resource production region ***rl***

```
DELTAT            CET FUNCTION TILLAGE DISTRIBUTION PARAMETER
```

$$\delta_{b,t,rl} = \frac{NR_{b,t,rl} * (\sum_g \sum_h \sum_y \sum_r X_{b,g,h,y,t,rl,r})^{1+\rho_{b,rl}}}{\sum_{ta} NR_{b,ta,rl} * \sum_g \sum_h \sum_y \sum_r X_{b,g,h,y,ta,rl,r})^{1+\rho_{b,rl}}}, \quad b=1,\ldots,B;\ t,ta=1,\ldots,T;\ rl=1,\ldots,RL$$

```
DELTAT(BA,T2,U)$(XACTD(BA,T2,U) > 0)

               = (MPRICET(BA,T2,U)
                  * SUM(XCROPP(BA,G,H,Y,T2,U,UR), XACT.L(XCROPP))**(1+RHOT(BA,U)))
                / SUM(T2A, MPRICET(BA,T2A,U)
                  * SUM(XCROPP(BA,G,H,Y,T2A,U,UR), XACT.L(XCROPP))**(1+RHOT(BA,U)));
```

where $NR_{b,t,rl}$ equals net return per acre to rotation ***b*** under tillage practice *t* in region ***rl***. $NR_{b,rl}$ is derived from the shadow value of constraints placed on the allocation of production activities in each ***rl*** region. In the model code, `$(XACTD(BA,T2,U) > 0)` is used to ensure that `DELTAT` is calculated only for systems with positive acreages. `(MPRICET(BA,T2,U)` represents the marginal price on production practices constrained to their base levels (`XACT.L(B,G,H,Y,T,RL,R`).

$\delta_{b,rl}$ CET allocation parameter for crop ***b*** acres in farm resource region ***rl***

```
DELTA             CET FUNCTION ROTATION DISTRIBUTION PARAMETER
```

$$\delta_{b,rl} = \frac{NR_{b,rl} * (\sum_b X_{b,rl})^{1+\rho_{b,rl}}}{\sum_{ba} NR_{ba,rl} * (\sum_{ba} X_{ba,rl})^{1+\rho_{ba,rl}}}, \quad b,ba=1,\ldots,B; \quad rl=1,\ldots,RL$$

```
MPRICER(BA,U)                     = CETT.M(BA,U);
MPRICEPX(B,BA,U)                  = BSBROT(B,BA,U)*CETT.M(BA,U);

BBASACS(B,BA,RL) $CAC(RL)

       ▪   = SUM(XCROPP(BA,G,H,Y,T2,RL,UR), XSB7(B,XCROPP) * XACT.L(XCROPP))
       ▪   / CAC(RL);

MPRICEP(B,RL)   = SUM(BA$RCROP4(BA,RL), MPRICEPX(B,BA,RL) * BBASACS(B,BA,RL));

LAMDA(BA,RL)    $RACD2(BA,RL)
       ▪   = SUM(B$BSBAS(B,BA,RL), BSBROT(B,BA,RL) * MPRICEP(B,RL) *
ACLRRL(B,RL,"CK4")**(1+RHO(B,RL)) * RAC.L(BA,RL)**(-RHO(B,RL) - 1) );

LAMINV(BA,U)  $LAMDA(BA,U)
       ▪   = LAMDA(BA,U)**(-1);

DELTA(BA,U)   $SUM(B, LAMINV(B,U)* MPRICER(B,U))
       ▪   = (LAMINV(BA,U) * MPRICER(BA,U)) / SUM(B, LAMINV(B,U)* MPRICER(B,U));
```

where $NR_{b,rl}$ equals net return per acre to rotation ***b*** in region ***rl***. $NR_{b,rl}$ is derived from the shadow value of constraints placed on the allocation of rotation acreage in each ***rl*** region. In the model code, the dollar control variables (`$RACD2(BA,RL)`, `BSBAS(B,BA,RL)`, `$LAMDA(BA,U)` & `$SUM(B, LAMINV(B,U)* MPRICER(B,U))`) are used to ensure that the calculations are performed only for those activities with nonzero values for the control variable. `MPRICEP(B,RL)` represents the average net returns to crop ***b*** planted in farm resource region ***rl*** , and `CETT.M(BA,U)` is the shadow price of the tillage function and represents net returns to those rotations.

$\alpha_{b,rl}$ CET scale parameter for crop or rotation ***b*** acres in farm resource region ***rl***

```
AT                  CET FUNCTION TILLAGE SHIFT PARAMETER
A                   CET FUNCTION ROTATION SHIFT PARAMETER
```

Tillage and Rotation Strata

$$\alpha_{b,rl} = \sum_g \sum_h \sum_y \sum_t \sum_r X_{b,g,h,y,t,rl,r} / (\sum_{ta} \delta_{b,ta,rl}\, g \sum_b \sum_h \sum_y \sum_r X_{b,g,h,y,ta,rl,r}{}^{-\rho_{b,rl}})^{-1/\rho_{b,rl}}$$

```
AT(BA,U)        $RACD(BA,U)
         ▪   =  SUM(XCROPP(BA,G,H,Y,T2,U,UR), XACT.L(XCROPP))
         ▪   /(SUM(T2A, DELTAT(BA,T2A,U) * SUM(XCROPP(BA,G,H,Y,T2A,U,UR), XACT.L(XCROPP))
                  **(-RHOT(BA,U)))**(-1/RHOT(BA,U)));
```

$\alpha_{b,rl} = \sum_b X_{b,rl} / (\sum_{ba} \delta_{b,rl} s_{b,ba,rl} RAC_{ba,rl}{}^{-\rho_{b,rl}})^{-1/\rho_{b,rl}}$ where $s_{b,ba,rl}$ is the crop enterprise ***b*** share of one unit of rotation ***ba*** acres in region ***rl*** .

```
A(B,U)          $ACLRRL(B,U,"CK4") = ACLRRL(B,U,"CK4")
                 /(SUM(BA, DELTA(BA,U) * BSBROT(B,BA,U) * RAC.L(BA,U)**(-RHO(B,U)))
                                   **(-1/RHO(B,U)));
```

The scale parameters for both the tillage and rotation CET functions are obtained directly from the relevant CET function once the substitution ($\rho_{b,rl}$) and allocation parameters ($\delta_{b,rl}$) have been obtained.

PMP Cost Parameters

The crop and livestock PMP functions used differ from each other by the level in the model at which they are specified. The crop PMP functions are part of a nested system of CET functions that determine the substitution behavior among crop rotations and tillage practices. The CET functions aggregate individual production activities that differ by crops produced, rotations used, and tillage practices employed into a crop production index `ACLRR` that is used in the PMP function for crops. The PMP function for livestock, in contrast, is specified for each livestock production activity represented in the model. The formulas for deriving the parameters for the PMP functions for crops and livestock are shown here.

$\beta_{b,rl}$ slope for crop production activity **b** supply equation in farm resource region **rl**

```
BETA3(B,U)          PMP AGGREGATE ACREAGE COST FUNCTION SLOPES LRR LEVEL CET FORMULATION
```

$\alpha_{b,rl}$ intercept on crop production activity *b* supply equation in farm resource region *rl*

```
ALPHA3(B,U)         PMP AGGREGATE ACREAGE COST FUNCTION INTERCEPTS LRR LEVEL CET FORMULATION

SCALAR ACCFAF       AGGR CROP AC COST FUNCTION ACREAGE FACTOR
```

$\beta_{b,rl} \quad = \sum_{p \in p2b} ((P_{'dom',p} / X_{b,rl}) * (1/e_p) * (X_{b,rl} / \sum_{ba} X_{ba,rl}) * YLD_{p,rl})$ such that

$e_{p,,rl} > 0 \; \forall p, \; p \in pc, b \in bc, p = 1,\ldots,P; b = 1,...,BC; rl = 1,\ldots,RL;$

```
BETA3( B,RL)    $YCROP3(B,RL)
= PES(B,"BPLNTP")* ACCFAF * (SUM(RLA, ACLRR.L(B,RLA))
/ACLRR.L(B,RL))       {WGHT LRR RESP BY CROP LRR ACRES}
               •    SUM(P$P2B(P,B), YLDTPCLR(P,"CK5",RL));
```

$\alpha_{b,rl} \quad = w_{b,rl} - \beta_{b,rl-} * X_{b,rl}\ , \quad b = 1,\ldots,B; rl = 1,\ldots,RL;$

```
ALPHA3(B,RL)    $YCROP3(B,RL)
=  CETR.M(B,RL) - BETA3(B,RL) * ACLRR.L(B,RL);
```

$\beta_{b,g,h,r}$ slope for livestock production activity ***b*** supply equation in farm production region ***r***

```
PARAMETERS   BETAP( B,G,H,UR)  PMP COST FUNCTION SLOPES BY PROCESS AND REGION
```

$\alpha_{b,g,h,rl}$ intercept on livestock production activity ***b*** supply equation in farm production region ***r***

```
▪   ALPHAP(B,G,H,UR)  PMP COST FUNCTION INTERCEPTS BY PROCESS AND REGION

PARAMETER    PMPLCL(B,*,U)     OPTIMAL AGGREGATE LIVESTOCK PRODUCTION LEVELS
▪   PMPLCM(B,*,U)     SHADOW PRICES ON OPTIMAL LVSK PRODUCTION LEVELS

SCALAR      ALCFAF            AGGREGATE LIVESTOCK PRODUCTION COST FUNCTION FLEXIBILITY FACTOR
```

$$\beta_{b,g,h,r} \quad = (\sum_{p \in p2b} P_{'dom',p} \,/ \sum_{g}\sum_{h}\sum_{y}\sum_{t}\sum_{rl} X_{b,g,h,y,t,rl,r}) * (1/e_p)$$

$$\bullet \; (\sum_{ba \in xlvstp} \sum_{g}\sum_{h}\sum_{y}\sum_{t}\sum_{rl}\sum_{ra} X_{ba,g,h,y,t,rl,ra} \; / \; \sum_{b \in xlvstp} \sum_{g}\sum_{h}\sum_{y}\sum_{t}\sum_{rl} X_{b,g,h,y,t,rl,r} \;)$$

$$o \quad * \quad \mathrm{YLD}_{p,rl} \;)$$

```
BETAP( B,"NP","A",R)   $(PMPLCL(B,"CAL",R) GT 0)                      {SLOPE WRT PRODVAL BY REGN}
•   = SUM(P$PESL(B,P,"BPRDNP"), PESL(B,P,"BPRDNP")
•   ALCFAF * (PMPLCL(B,"CAL","US") / PMPLCL(B,"CAL",R))
•   *(SUM(XLVSTP(B,"NP",H,Y,T,U,R),   PP(P,XLVSTP))       <<SIMPLE AVG YIELD
•   /SUM(XLVSTP(B,"NP",H,Y,T,U,R), 1$PP(P,XLVSTP))));
```

$\alpha_{b,g,h,rl} \quad = w_{b,rl} - \beta_{b,rl-} * X_{b,rl}\ , \quad b = 1,\ldots,B; rl = 1,\ldots,RL;$

```
ALPHAP(B,"NP","A",R)   $ (PMPLCL(B,"CAL",R) GT 0)
•   = PMPLCM(B,"CAL",R) - BETAP(B,"NP","A",R) * PMPLCL(B,"CAL",R);
```

where $P_{'dom',p}$ is the price of commodity ***p*** in the domestic market (*'dom'*), e_p equals the supply elasticity for commodity ***p*** $\in$ ***pl*** or ***pc*** (see tables 5 and 6), ***p2b*** maps ***p*** commodities to the ***b*** commodity production activities that the ***p*** commodities come from, $\mathrm{YLD}_{p,u}$ represents the yield of commodity ***p*** in region ***r*** or ***rl*,** and $w_{b,rl}$ represents the price or net returns per unit of production activities *b* in region *r* or *rl*. The parameters `ACCFAF` and `ALCFAF` are scaling factors for the slopes. These factors can be used to adjust the slope of the supply functions if desired.

Endogenous Variables (GAMS Variables)

The POSITIVE VARIABLE or VARIABLE statement declares endogenous variables used in the REAP formulation. Each block of variables is indexed over one or more sets. For example, DOMESUSE(P) establishes a block of domestic demand variables over the set P of products; XACT(B,G,H,Y,T,RL,R) establishes production activity variables over the index space of sets B,G,H,Y,T,RL,R--that is, enterprise, government program category, method of production (not used), system of production (not used), tillage type, Land Resource Region and Farm Production Region. Activities are designated production activities if indexed over enterprise, geographic area, program category, and so on, or processing activities if indexed only over enterprises (and therefore formulated as a national-level input/output process, rather than differentiated by region). Variables in REAP represent commodity supply and demand levels, production and processing activity levels, variable input levels, and government programs.

Commodity Demand and Supply Variables

Commodity demand and supply variables in REAP are represented both explicitly and implicitly. Explicit variables are DOMESUSE(P), EXPORTUSE(P), EEPUSE(P), STKUSEC(P), STKUSEG(P), and RESIDUSE(P). Other supply and demand variables are represented implicitly in the model's formulation but do not exist as a specific variable. For example, livestock feed use of corn is determined through the accumulation of enterprises producing various livestock types in various regions across the country by using various feed rations and nutrient combinations that react to conditions in livestock and feed markets. Although no explicit variable exists, the amount of corn used to feed livestock could be calculated from the levels of these other enterprises.

DOMESUSE(P) represents primarily seed and industrial uses for each commodity. (EXPORTUSE(P), EEPUSE(P)) represent quantity of commodity exported, and (STKUSEC(P), STKUSEG(P)) represent commercial and government acquired stocks, respectively. Residual supply or use (RESIDUSE(P), RESIDSUP(P)) is specified during model calibration for commodities for which their baseline supply and use fails to balance precisely. Commodity use categories such as government stock accumulation, carryover, release, net removals, and domestic and foreign donations are used in presolution and postsolution calculations but are not endogenous model variables.

Commodities for which explicit supply and demand functions exist are shown in table 7. Commodity supply and demand variables are declared separately for each of the ***m*** markets represented in set M.

$Z_{p,m}$ Commodity supply or demand for commodity ***p*** in market ***m***

```
*    COMMODITY DEMAND AND SUPPLY
DOMESUSE(P)        DOMESTIC DEMAND
EXPORTUSE(P)       EXPORT DEMAND EXCLUDING EEP
EEPUSE(P)          EXPORT DEMAND -- EEP ONLY
IMPORTSUP(P)       IMPORT SUPPLY
PRDNSUP(P)         AGGREGATE PRODUCTION FUNCTION SUPPLY
STKUSEC(P)         COMMERCIAL STOCK DEMAND
STKUSEG(P)         GOVERNMENT STOCK DEMAND
RESIDUSE(P)        RESIDUAL DEMAND
RESIDSUP(P)        RESIDUAL SUPPLY
```

Variables YACT(C) represent processing activities in REAP. Example processing activities include SOYCRUSH, which converts soybeans into soybean meal and soybean oil, and DAIRYSUP5, which converts a specific mix of feed grains and soybean meal into the protein and energy nutrients available for dairy cattle. Processing activity variables are indexed only over C, indicating that they are only specified at the national level.

Y_c Quantity processing activity *c*

```
YACT(C)            PROCESSING ACTIVITY LEVELS
```

Regional Input Supply and Use Variables

REAP designates inputs as either regional or national. Inputs are modeled regionally if we can specify a reliable relationship between price and quantity used and model region. Examples are CROPLAND, PASTURE, AUM, and WATER.

National inputs are those specified with a single fixed price in any area of the United States in which they are used. Examples include LIME and CHEMICALS, which are specified in dollar units, and their prices are always in dollars. LIME and CHEMICALS are specified in dollars (instead of tons or another unit) in the ERS cost of production budget source data. Modeling input use in physical units (instead of value) and actual market prices is always preferred, but often not feasible. For example, LIME prices vary greatly even within one region, and there exist so many CHEMICAL types and compositions that one price would not be accurate. In these cases, the most accurate accounting of input cost for a production enterprise is cost per acre for the specified inputs.

National inputs require no model variable in REAP's formulation—their supply functions are implicit. By holding the prices of these inputs fixed, we are assuming that they have perfectly elastic supply curves. Because the cost per unit of using these inputs does not change, we do not explicitly represent them in the objective function. Rather, we calculate the total cost per unit for the production activity and include that in the objective function. Most input use takes place in the production and processing activities discussed below.

Two types of regional input variables are distinguished in REAP. Those variables with fixed prices (e.g., WATER) are tallied in INPUTRFSUP(R,IR). Input prices that vary with quantity supplied (e.g., CROPLAND, PASTURE, and AUM (animal unit months)) are tallied in two variables: the price-sensitive supply in INPUTRSUP(R,IR), and any optional quantity available in INPTRSUPFP(R,IR). The supply of each is represented with a kinked supply function. INPUTRSUP(R,IR) represents the portion of the regional input that is available at a fixed price, and INPTRSUPFP(R,IR) represents the portion beyond that, which is available at increasing prices.

CRPLND(R,IR,YR) represents the amount of cropland enrolled in the Conservation Reserve Program (CRP) in the base year (YR). This variable can be fixed or allowed to vary, with fixed default setting, meaning that the amount of land enrolled in CRP is not allowed to change in response to any scenario that may be run.

$VI_{ir,r}$ Variable supply of input *ir* in farm production region *r*

```
INPUTRSUP( R,IR)  REGIONAL PRICE SENSITIVE INPUTS
```

$FI_{ir,r}$ Fixed supply of input ***ir*** in region farm production region ***r***

```
INPTRSUPFP(R,IR)  REGIONAL NON-PRICE SENSITIVE PRICE SENSITIVE INPUTS
```

$CRAC_{ir,r}$[4] Acres of input ***ir*** in farm production region ***r*** placed in the Conservation Reserve Program (CRP)

```
CRPLND(R,IR,YR)      CROP LAND ENROLLED IN THE CRP IN THE YEAR DESIGNATED
```

[4] CRPLND indexed by 'YR' to indicate what year CRP is for

Production Activity Variables

Production activities combine inputs to produce a product. These variables are differentiated by enterprise, geographic area, program category, method, and other indexes. Crop and livestock production are tallied in variable XACT(B,G,H,Y,T,U,UR), which are indexed over enterprise or production activity, government program category, method of production (not used), system of production (not used), tillage practice, subregion, and region. In addition, SXACT(B, T,FT, U, UR) represents the proportion of acreage XACT that uses fertilizer application rate FT. SXACT ranges in value from 0 to 1, with the sum of SXACT over fertilizer application rates, FT, equal to 1.

$X_{b,g,h,y,,t,rl,r}$[5] Quantity of production activity b in government program ***g***, *using method h, in system y* utilizing tillage practice t in land resource region ***rl*** in farm production region ***r***

```
XACT(B,G,H,Y,T,U,UR) PRODUCTION ACTIVITY LEVELS
```

$S_{b,t,ft,rl,r}$ Share of fertilizer rate ***ft*** used in crop rotation ***b*** using tillage practice t in land resource region ***rl*** in farm production region ***r***

```
SXACT(B,T,FT,U,UR)     ALTERNATE NITROGEN ENTERPRISES SHARE OF CROPPING SYSTEM ACRES
```

Cropland Allocation Variables

The cropland allocation variables are part of the nesting structure for the CET functions that allocate cropland to rotations and tillage practices. ACLRR(B,U) is defined over crop (corn, soybeans, wheat, etc.) and Land Resource Regions, representing the total amount of acres planted to a crop across all rotations that produce that crop. RAC(B,U) is defined over crop rotations and Land Resource Regions and represents the total amount of acres planted to a particular rotation across all tillage practices.

$RAC_{b,rl}$ Quantity of rotation acres $\boldsymbol{b} \in \boldsymbol{bc}$ used in land resource region ***rl***

```
RAC(B,U)    ROTATION ACREAGE LEVEL--ROT:LRR:NPR
```

$X_{b,rl}$ Quantity of crop acres $\boldsymbol{b} \in \boldsymbol{bc}$ used in land resource region ***rl***

```
ACLRR(B,U)         AGGREGATE CROP ACREAGE PLANTED LRR LEVEL CET FORM
```

Objective Function Variable

CPS is a scalar variable that represents the value of the programming problem's objective function. CPS measures the sum of consumer and producer surplus, minus or plus any social costs/payoffs associated with system behavior, such as environmental emissions.

[5] This variable includes both livestock and crop production activities that were separated out in the presentation of the model given in Chapter 2 the Model Environment section of this report.

CPS Objective function value (net social payoff)

```
CPS              CONSUMER & PRODUCER SURPLUS (DOL) ;
```

Equations

EQUATION definition statements define how a GAMS model is generated—that is, what rows and what columns are generated to pass to the solver for execution.

Objective Function

The objective function represents net social benefit, or consumer plus producer surplus (CPS). Net social benefit equals the sum of the areas under the crop demand functions plus government payments, such as Conservation Reserve Program (CRP) rental payments, minus the areas under the supply functions for the quasi-fixed regional inputs, crop-specific PMP cost functions, CRP land supply functions, and production costs. The objective function is written as:

$$
\begin{aligned}
\text{Max CPS} = & \sum_m \sum_p \alpha_{m,p} Z_{m,p} + \frac{1}{2} \sum_m \sum_p \beta_{m,p} Z^2_{m,p} - \sum_c w_c Y_c \\
& - \sum_r \sum_{ir} \alpha_{ir,r} VI_{ir,r} - \frac{1}{2} \sum_r \sum_i \beta_{ir,r} VI^2_{ir,r} - \sum_r \sum_{ir} w_{ir,r} FI_{ir,r} \\
& - \sum\nolimits_{xlvstp(b,g,h,y,t,r,r)} \alpha_{b,g,h,r} X_{xlvstp} - \sum\nolimits_{xlvstp(b,g,h,y,t,r,r)} \beta_{b,g,h,r} X^2_{xlvstp} \\
& - \sum_{b \in bc} \sum_{rl} \alpha_{b,rl} X_{b,rl} - \sum_{b \in bc} \sum_{rl} \beta_{b,rl} X^2_{b,rl} \\
& - \sum\nolimits_{xcropp(b,g,h,y,t,rl,r)} X_{xcropp} \left[\sum\nolimits_{ft} S_{b,t,ft,rl,r} \left(w^n_{b,g,h,y,t,ft,rl,r} + w^{\sigma}_{b,g,h,y,t,ft,rl,r} \right) \right] \\
& - \sum\nolimits_{xcropp(b,g,h,y,t,rl,r)} X_{xcropp} w^{vc}_{xcropp} - \sum\nolimits_{xlvstp(b,g,h,y,t,r,r)} X_{xlvstp} w^{vc}_{xlvstp} \\
& + \sum_{ir} \sum_r w^{crp}_{ir,r} CRAC_{ir,r} - \sum_{ir} \sum_r \alpha^{crp}_{ir,r} CRAC_{ir,r} - \frac{1}{2} \sum_{ir} \sum_r \beta^{crp}_{ir,r} CRAC^2_{ir,r}
\end{aligned}
$$

The first terms in the objective function, $\sum_m \sum_p \alpha_{m,p} Z_{m,p} + \frac{1}{2} \sum_m \sum_p \beta_{m,p} Z^2_{m,p}$, represent the sum of the area under market demand and supply curves. The parameters for these curves are derived from the demand or supply for each commodity *p* in each market *m* in the base year ($Z^0_{m,p}$), the commodity price in the base year (P^0_p), and the price elasticity of demand or supply ($\varepsilon_{m,p}$). The formula for deriving the slope parameter is $\beta_{m,p}$= ($P^0_p / Z^0_{m,p}$) * ($1/\varepsilon_{m,p}$). The intercept is then obtained from the equation $\alpha_{m,p} = P^0_p - \beta_{m,p} * Z^0_{m,p}$.

The third term, $\sum_c w_c Y_c$, is the sum of production costs incurred by intermediate product processing activities. These are costs for labor and inputs separate from the cost of primary products used by the activities. For many of the processing activities, these costs are zero because the activities are assumed only to transform the initial product into another form. In other cases, such as ethanol production, costs of processing are explicitly represented.

The fourth and fifth terms, $\sum_r \sum_{ir} \alpha_{ir,r} VI_{ir,r} - \frac{1}{2} \sum_r \sum_i \beta_{ir,r} VI_{ir,r}^2$, represent the sum of areas under the quasi-fixed regional input supply curves. The parameters for these curves are derived from the supply of each input *ir* in each Farm Production Region *r* in the base year ($VI_{ir,r}^0$), the input price in each region in the base year ($w_{ir,r}^0$), and the price elasticity of supply ($\varepsilon_{ir,r}$). The slopes for these equations are then obtained from $\beta_{ir,r}$ = ($w_{ir,r}^0 / VI_{ir,r}^0$) * (1/ $\varepsilon_{ir,r}$), and the intercepts are obtained from $\alpha_{ir,r}$ = $w_{ir,r}^0$ - $\beta_{ir,r}$ * $VI_{ir,r}^0$.

The sixth and seventh terms, $\sum_{xlvstp(b,g,h,y,t,r,r)} \alpha_{b,g,h,r} X_{xlvstp} - \sum_{xlvstp(b,g,h,y,t,r,r)} \beta_{b,g,h,r} X_{xlvstp}^2$, represent the sum of areas under the PMP supply functions for livestock production activities. The parameters for the PMP functions are derived from the supply of each livestock commodity *pl* in each Farm Production Region *r* in the base year ($Q_{pl,r}^0$), the net return to the livestock production activity in the base year ($R_{bl,r}^0$), and the price elasticity of supply (ε_{pl}). Livestock production is represented only at the Farm Production Region (*r*) level. Net returns per production activity are obtained from shadow prices on calibration constraints.

The slopes for the livestock PMP functions are then obtained from $\beta_{b,g,h,r}$ = ($R_{bl,r}^0 / X_{xlvstp}^0$)*(1/ ε_{pl})*($X_{xlvstp}^0 / \sum_{b \in xlvstp} X_{xlvstp}^0$)* $\text{YLD}_{p,r}$), where $\text{YLD}_{p,r}$ = $Q_{pl,r}^0 / X_{xlvstp}^0$. The intercepts for the PMP functions are then obtained from $\alpha_{b,g,h,r}$ = $R_{bl,r}^0$ - $\beta_{b,g,h,r}$ * X_{xlvstp}^0 .

The eighth and ninth terms in the function, $\sum_{b \in bc} \sum_{rl} \alpha_{b,rl} X_{b,rl} - \sum_{b \in bc} \sum_{rl} \beta_{b,rl} X_{b,rl}^2$, are the sum of the areas under the PMP supply functions for crops. The parameters for these PMP functions are derived from the supply of crop acreage *bc* in each Land Resource Region *rl* in the base year ($X_{bc,rl}^0$), the net return to crop *bc* in the Land Resource Region *rl* in the base year ($R_{bc,rl}^0$), and the price elasticity of supply for crops (ε_{pc}). Crop production is represented at the Land Resource Region *rl* level and is therefore more disaggregated than the level at which livestock production is represented. Net returns per production activity are obtained from shadow prices on calibration constraints.

The slopes for the crop PMP functions are derived from $\beta_{b,r} = \sum_{p \in p2b} ((P_p^0 / X_{b,rl}^0)$ * (1/ ε_{pc}) *($X_{bc,rl}^0$ / $\sum_{ba} X_{bc,rl}^0$) * $\text{YLD}_{p,rl}$) , where $p \in p2b$ maps livestock product *p* to livestock production activity *b* and $\text{YLD}_{p,rl}$ equals average yield for crop *p* in Land Resource Region *rl*. The intercept is then obtained from $\alpha_{b,rl}$ = $R_{bc,rl}^0$ - $\beta_{b,rl}$ * $X_{bc,rl}^0$.

The 10th term, $\sum_{xcropp(b,g,h,y,t,rl,r)} X_{xcropp} [\sum_{ft} S_{b,t,ft,rl,r} \left(w_{b,g,h,y,t,ft,rl,r}^n + w_{b,g,h,y,t,ft,rl,r}^\sigma \right)]$, is the sum of the fertilizer costs for crop production activities, where $S_{b,t,ft,rl,r}$ is the convexity variable that indicates the proportion of a particular fertilizer application activity *ft* used by crop production activity $X_{xcropp(b,g,h,y,t,rl,r)}$. The expression contained within the parentheses represents the cost of each of the fertilizer activities *ft* associated with the crop production activity $X_{xcropp(b,g,h,y,t,rl,r)}$, where

$w^{n}_{b,g,h,y,t,ft,rl,r}$ represents fertilizer cost and $w^{\sigma}_{b,g,h,y,t,ft,rl,r}$ represents the risk premium associated with using a particular fertilizer application rate.

The 11[th] term in the objective function, $\sum_{xcropp(b,g,h,y,t,rl,r)} X_{xcropp} w^{vc}_{xcropp}$, is the sum of the production costs, excluding fertilizer, for the primary crop production activities, where w^{vc}_{xcropp} represents the sum of all the cost of the inputs, excluding quasi-fixed and fertilizer inputs used by the production activity. The implicit assumption underlying this specification is that the prices of these inputs are constant.

Similarly, the 12th term, $\sum_{xlvstp(b,g,h,y,t,r,r)} X_{xlvstp} w^{vc}_{xlvstp}$, represents the total costs of the primary livestock production activities.

The 13[th] term, $\sum_{ir}\sum_{r} w^{crp}_{ir,r} CRAC_{ir,r}$, is the sum of rental payments for CRP land, while the final two terms, $\sum_{ir}\sum_{r}\alpha^{crp}_{ir,r} CRAC_{ir,r} - \frac{1}{2}\sum_{ir}\sum_{r}\beta^{crp}_{ir,r} CRAC^{2}_{ir,r}$ represent the sum of the areas under the CRP supply functions. The parameters of the CRP supply functions are derived from the supply of each input *ir* placed in the CRP in each Farm Production Region *r* in the base year ($CRAC^{0}_{ir,r}$), the net return to CRP activities in each region in the base year ($R^{0}_{ir,r}$), and the price elasticity of input supply ($\varepsilon_{ir,r}$). Slopes and intercepts are obtained by using the similar formulas to the formulas used to derive them for the other supply functions. In GAMS code, the objective function is depicted as:

```
UOBJ.. CPS =E=  SUM(P,  ALPHA(P,"DOM")    *     DOMESUSE(P)
                  + 0.5 * BETA( P,"DOM")    * SQR(DOMESUSE(P)))
                + SUM(P$PRES(P), ALPHA(P,"RESD") * RESIDUSE(P))
                - SUM(P$PRES(P), ALPHA(P,"RESS") * RESIDSUP(P))
                + SUM(P,  ALPHA(P,"EXP")    *     EXPORTUSE(P)
                  + 0.5 * BETA( P,"EXP")    * SQR(EXPORTUSE(P)))
*                   NOTE: ALPHA(P,"EEP") WAS INCREASED ABOVE BY AVE BNS LVL
                + SUM(P,  ALPHA(P,"EEP")    *     EEPUSE(P)
                  + 0.5 * BETA( P,"EEP")    * SQR(EEPUSE(P)))
                + SUM(P,  ALPHA(P,"SCE")    *     STKUSEC(P)
                  + 0.5 * BETA( P,"SCE")    * SQR(STKUSEC(P)))
                + SUM(P,  ALPHA(P,"SGE")    *     STKUSEG(P)
                  + 0.5 * BETA( P,"SGE")    * SQR(STKUSEG(P)))
* <<            + SUM(P,  ALPHA(P,"SGA")    *     STKACCG(P))
                - SUM(P, (ALPHA(P,"IMP")    * IMPORTSUP(P)) $ (ALPHA(P,"IMP") GT 0)
                  + 0.5 * BETA( P,"IMP")    * SQR(MAX(0, (IMPORTSUP(P) - DIF(P,"IMP")))))
                - SUM(P, (ALPHA(P,"PRDN")   * PRDNSUP(P)) $ (ALPHA(P,"PRDN") GT 0)
                  + 0.5 * BETA( P,"PRDN")   * SQR(MAX(0, (PRDNSUP(P) - DIF(P,"PRDN")))))

                - SUM(C, YACT(C) * (PPC("PROCCOST",C) + SCR(C,"NET RETURN")))

                - SUM((R,IR),
                        INPTRSUPFP(R,IR)  * PMINI(R,IR) $ PMINI(R,IR))
                - SUM((R,IR), ALPHAI(R,IR)  *     INPUTRSUP(R,IR)
                  + 0.5 *     BETAI( R,IR)  * SQR(INPUTRSUP(R,IR)))
                - SUM((R,IR),
                        INPUTRFSUP(R,IR)  * INPUTR(R,IR,"PFXP"))

                - SUM((B,H,R),
                     ( ALPHAP(B,"NP",H,R)  *  SUM(XLVSTP(B,"NP",H,Y,T,U,R), XACT(XLVSTP))
                  + 0.5 * BETAP( B,"NP",H,R)* SQR(SUM(XLVSTP(B,"NP",H,Y,T,U,R), XACT(XLVSTP)))
                     ) $ (XI4(B,"NP",H,R) GT 0)
                    )$RTYPE
```

```
                - ( SUM(XCROPP(BC,G,H,Y,T2,RL,R),   XACT(XCROPP)
                        * SUM(FT, SXACT(BC,T2,FT,RL,R) *
                          ( PCRNIT(BC,G,H,Y,T2,FT,RL,R, "NCOST")
*                           +PCRNIT(BC,G,H,Y,T2,FT,RL,R, "GRNPMT")
                           +PCRNIT(BC,G,H,Y,T2,FT,RL,R, "RSKADJ")
                           )
                             )
                      )
                  )  $((ENVIR=1)$(VNITF=1))

                - ( SUM(XALL,   XACT(XALL)   * PCR(XALL,      "VCOST")) ) $(ENVIR=1)
                - ( SUM(XALL,   XACT(XALL)   * PCR(XALL,      "NICOST")) )$(STDCROP=1)

                - SUM(XALNDC, XACT(XALNDC) * PCR(XALNDC,"NET RETURN"))    $(ENVIR=1)
                - SUM(XALNDC, XACT(XALNDC) * PCR(XALNDC,"NET RETURN"))    $(STDCROP=1)

                - SUM(XALBLV, XACT(XALBLV) * PCR(XALBLV,"NET RETURN"))    $(ENVIR=1)
                - SUM(XALBLV, XACT(XALBLV) * PCR(XALBLV,"NET RETURN"))    $(STDCROP=1)

$BATINCLUDE MODULE.CTL ACPROG apACUOBJ.GMS
*
*$BATINCLUDE MODULE.CTL VNITF vnUOBJ.GMS

                - SUM(YCROP(B,H,R),
                            ALPHAX(B,H,R)     * PMPAC(B,H,R)
                  +  0.5 * SUM((BA)$YCROPX(B,H,R,BA),
                             PMPAC(B,H,R)     * BETAX(B,H,R,BA) * PMPAC(BA,H,R))
                     )$RTYPE

                - SUM(YCROP(B,H,R),
                          ( ALPHAA(YCROP)       *     PMPAC(YCROP)
                  +  0.5 *     BETAA(YCROP)       * SQR(PMPAC(YCROP)))
                     )$RTYPE

                - SUM(YCROP2(B,H,RL,R),
                          ( ALPHA2(YCROP2)       *     PMPAC2(YCROP2)
                  +  0.5 *     BETA2(YCROP2)       * SQR(PMPAC2(YCROP2)))
                     )$RTYPE

                 - SUM((B,RL)$SACPLRR(B,RL),
                          ( ALPHA3(B,RL)       *     ACLRR(B,RL))$ (ALPHA3(B,RL) GT 0)
                  +  0.5 *     BETA3(B,RL)       * SQR(MAX(0, (ACLRR(B,RL) - PMPDIF(B,RL))))
                     )$RTYPE

                - SUM(XCROPP(B,G,H,Y,T,U,R),
                          ( ALPHAZ(XCROPP)       *     XACT(XCROPP)
                  +  0.5 *     BETAZ(XCROPP)       * SQR(XACT(XCROPP)))
                     )$RTYPE

$BATINCLUDE MODULE.CTL ACPROG apPBUOBJ.GMS
$BATINCLUDE MODULE.CTL ACPROG apDPUOBJ.GMS

                + SUM(XCROPP(   B,G,H,Y,T,U,R), XACT(XCROPP) * PCR(XCROPP,"MKRETADJ"))
$BATINCLUDE MODULE.CTL ACPROG apMKUOBJ.GMS

*               - 0.5 * CAR * SUM(R$R10(R), SUM(BA$VENT(BA,R), SUM(B$VENT(B,R),
*                             XACT(B,R) * VCV(B,BA,R)) * XACT(BA,R)))

                + SUM((R,IR),
                      CRPLND(R,IR,"%1") * ACRESDY("TOTAL","HST","CRPR","A","%1",R)
                                                   $ACRESDY("TOTAL","HST","CRPR","A","%1",R)

                  +   (      ALPHAC(IR,"%1",R)   *     CRPLND(R,IR,"%1")
                  +    0.5 * BETAC( IR,"%1",R)   * SQR(CRPLND(R,IR,"%1"))
                      ) $   ACRESDY("TOTAL","HST","CRPR","A","%1",R)
                     )
```

```
- SUM(RL$GPPBASE(RL), (PFCPR(RL) + CRPPR(RL)) * GPPAC(RL))
;
```

CPS (consumer and producer surplus) is defined to be the sum of the areas under domestic, export, and commercial stock demand functions, minus the sum of areas under import, regional (variable and fixed price) input, national input, and other cost supply functions, plus the expected value of deficiency payments. The area under domestic demand functions, for example, is computed by the terms: SUM(P, ALPHA(P,"DOM")*DOMESUSE(P) + 0.5*BETA(P,"DOM")*SQR(DOMESUSE(P))). In simpler algebra, this is: (intercept * price + 0.5 * slope * (price*price)). Some of the expressions in `UOBJ` are complicated by the DIF and DIFI terms and formulation, which are necessary to exclude negative surplus values. The GAMS code used to represent the objective function differs from the algebraic formulation mainly in that it includes portions of code that permit alternative representations of the supply response for crop production and make supply of CRP land and the CRP rental rate exogenous (i.e., fixed). Control variables are used to determine which parts of the objective function are active. For example, the control variables `ENVIR`, `STDCROP`, and `VNITF` are used to control the supply response formulation for crops. When `STDCROP = 1` and `ENVIR = 0`, then crop production in REAP is represented with single production activities for each crop down to the Farm Production Region level. This formulation of the model uses the standard PMP functions to represent crop acreage response. When `STDCROP = 0` and `ENVIR = 1,` then crop production in REAP is represented with multiple rotations and tillage practices for a single crop down to the Land Resource Region. This formulation uses the nested set of CET functions in combination with the standard PMP crop function to represent crop acreage response. If `VNITF = 1,` then nitrogen fertilizer application rates are determined endogenously, whereas when `VNITF = 0,` then nitrogen fertilizer application rates per production activity are fixed. Permitting variable nitrogen fertilizer application rates per production activity is only available when ENVIR = 1.

Commodity Balance

The commodity balance constraints require that the supply of a commodity from all its sources is greater than or equal to the demand for it in all its uses. This ensures that no more of a commodity is consumed than is available for consumption. In equilibrium, this constraint will be binding, or the product will not be produced at all. Sources of `P` include the amount produced from all production activities `B` producing `P` across all government programs, `G`; production methods, `H`; system types, `Y`; tillage practices, `T;` in regions `RL,` and `R` or from all processing activities `C` or unspecified domestic source plus the amount supplied by imports and from beginning stocks. Uses of a commodity `P` include domestic use (seed and industrial uses), commercial and government stocks, and exports. This is represented algebraically by the constraint:

$$
\begin{aligned}
&\sum\nolimits_{xcropp\,(b,g,h,y,t,rl,r)} s_{p,xcropp} \Big(\sum_{ft} pp^{n}_{p,b,g,h,y,t,ft,rl,r}\, S_{b,t,ft,rl,r}\Big) X_{xcropp} \\
&+ \sum\nolimits_{xlvstp\,(b,g,h,y,t,r,r)} pp_{p,xlvstp}\, X_{xlvstp} + \sum_{c} ppc_{p,c} Y_c \\
&+ \sum_{m\in S} Z_{m,p} - \sum_{m\notin S} Z_{m,p} \ge 0, \qquad\qquad p = 1,\dots, P;
\end{aligned}
$$

where $\sum\nolimits_{xcropp(b,g,h,y,t,rl,r)} s_{p,xcropp}\big(\sum_{ft} pp^{n}_{p,b,g,h,y,t,ft,rl,r} S_{b,t,ft,rl,r}\big) X_{xcropp}$ represents the amount of commodity p produced by all primary crop production activities, $\sum\nolimits_{xlvstp(b,g,h,y,t,r,r)} pp_{p,xlvstp} X_{xlvstp}$ represents the net amount of p produced by all livestock production activities, $\sum_{c} ppc_{p,c} Y_c$ represents the net amount of p produced (or used) by the processing activities, $\sum_{m\in S} Z_{m,p}$ is the amount of commodity p supplied from supply markets (import and beginning stock markets) m , and $\sum_{m\in D} Z_{m,p}$ represents the amount of commodity p used in demand markets (domestic, export, and ending stocks). In GAMS code, this is depicted as:

```
PRODBAL(P).. (SUM(XCROPP, XACT(XCROPP) * PP(P,XCROPP) * XSP7(P,XCROPP)) )$(VNITF=0)  {Fix Fert }
                + ( SUM(XCROPP(B,G,H,Y,T,RL,R),  XACT(XCROPP) * SUM(FT, SXACT(B,T,FT,RL,R)
                  * PNIT(P,B,G,H,Y,T,FT,RL,R))* XSP7(P,XCROPP))           $(VNITF=1)  {Var Fert }
                + SUM(XLVSTP,    XACT(XLVSTP) * PP(P,XLVSTP))                         {LVSTK}
*              + SUM(XFRUTP,    XACT(XFRUTP) * PP(P,XFRUTP))                         {FRUIT}
                + SUM(XOLU,      XACT(XOLU  ) * PP(P,XOLU  ))                         {OLUSE}
$BATINCLUDE MODULE.CTL ACPROG apPRDBAL.GMS
                + SUM(C,     YACT(C)     * PPC(P,C)) {PROCESSING}
                + IMPORTSUP(P)   $ PI(P)
                + PRDNSUP(P)     $ PF(P)
                - DOMESUSE(P)    $ PD(P)
                - EXPORTUSE(P)   $ PE(P)
                - EEPUSE(P)      $ PEEP(P)
                - STKUSEC(P)     $ PSCE(P)
                - STKUSEG(P)     $ PSGE(P)
                - RESIDUSE(P)    $ PRES(P)
                + RESIDSUP(P)    $ PRES(P)
            =G=
                - STKCOMB(P)
                - STKGOVB(P)
                + STKGOVD(P)
                + STKGOVX(P)
                + RESIDUAL(P)               <<ZERO IN CALIBRATE, FIXED IN VERIFY AND BEYOND RUNS
                ;
```

Fertilizer Application Convexity Constraints

The fertilizer application constraints permit the relationship between yield and fertilizer application rates per unit per production activities to be approximated by a small set of discreet fertilizer application activities. This set of convexity constraints allows fertilizer application rates per unit of a production activity to vary independently of the application rate used for other production activities. The set can be easily extended to cover other inputs if desired.

The constraint on fertilizer application rates is represented algebraically by:

$$\sum_{ft} S_{b,t,ft,rl,r} - 1 = 0, \qquad b = 1,...,B;\ t = 1,...,T;\ rl = 1,...,RL;\ r = 1,...,R;$$

where $0 \le S_{b,t,ft,rl,r} \bullet\le 1$, and $\sum_{ft} S_{b,t,ft,rl,r}$ represents the sum of the proportions of a fertilizer application rate used per cropping system *b,t* and must equal one. In GAMS code, this is written:

```
CNVXBAL(B,T2,RL,R)$CNVX(B,T2,RL,R)..
                  SUM(HCROPPFT(B,T2,FT,RL,R), SXACT(B,T2,FT,RL,R))
            =E=   1;
```

Input Supply Balance

The supplies of all inputs, except quasi-fixed inputs (cropland and pasture), are assumed to be perfectly elastic. This means that there is no need to explicitly represent supply balance for these inputs since it is assumed that there will always be sufficient supply to meet demand.

The supplies of quasi-fixed inputs are divided into two separate pools: livestock (pasture and AUMs) and crop (cropland). The supply of livestock land is specified by using a simple linear inverse supply function in each of the 10 Farm Production Regions. AUM is used in the Pacific, Mountain, and the Northern and Southern Plains regions to represent the carrying capacity of the land.

The pool of cropland in each Farm Production Region is further split into crop, rotation, and tillage-specific pools for each of the 45 Land Resource Regions by soil erosion category (HEL/NHEL). Cropland supply is represented with a simple inverse supply function for each Farm Production Region. Allocation of land to crops is represented with a system of simple linear, PMP calibrated, supply functions. In each Land Resource Region, the distribution of crop-specific land to rotations and tillage type is represented with a set of nested constant elasticity of transformation functions.

In essence, the structure of the model assumes that farmers engage in a multistage decision process whereby they first determine the amount of land to allocate to crops and livestock. In the next stage, farmers determine how much livestock land to allocate to each species and how much of the cropland to each crop. Then, for each crop, farmers decide how much land to allocate to each rotation, and they determine the tillage practice they will use for each rotation.

Regional Crop Rotation Acres Balance

The regional crop rotation acres balance ensures that land allocated to a particular crop rotation *b* is equal to the use of land by all the tillage practice activities *t* associated with that rotation in region *rl*. The balance is represented by the function:

$$\alpha_{b,rl}\left(\sum\nolimits_{xcropp(b,g,h,y,t,r,rl)}\delta_{b,t,rl}\left(X_{xcropp}\right)^{-\rho_{b,rl}}\right)^{-\left(\frac{1}{\rho_{b,rl}}\right)} - RAC_{b,rl} = 0, \quad b = 1,\ldots,B;\ rl = 1,\ldots,RL;$$

where

$$\rho_{b,rl} = (1-\sigma_{b,rl})/\sigma_{b,rl}$$

$$\delta_{b,t,rl} = \frac{R^{0}_{xcropp} * (X^{0}_{xcropp})^{1+\rho_{b,rl}}}{\sum\limits_{ta} R^{0}_{xcropp} * (X^{0}_{xcropp})^{1+\rho_{b,rl}}}$$

and

$$\alpha_{b,rl} = X^{0}_{xcropp} / (\sum_{ta}\delta_{b,ta,rl} * X^{0\ -\rho_{b,rl}}_{xcropp})^{-1/\rho_{b,rl}}$$

The function is nonlinear, implying that the marginal rate of transformation between land used in one tillage activity of a particular type of rotation and land used for other tillage practices used with the same rotation is declining. The parameters for these equations are derived from the quantity of each crop production activity in the base year X^{0}_{xcropp}, the net return to each production activity, R^{0}_{xcropp}, and an elasticity of transformation $\sigma_{b,rl}$ for each crop rotation *b* in each Land Resource Region *rl*. Net returns per crop production activity are obtained from shadow prices on calibration constraints. In GAMS code, this can be written as:

```
CETT(BA,RL)               $RCROP4(BA,RL)..
                           AT(BA,RL) * SUM(T2$DELTAT(BA,T2,RL), DELTAT(BA,T2,RL)
                           * SUM(XCROPP(BA,G,H,Y,T2,RL,UR)$ROTSHR(BA,T2,RL),
                                     XACT(BA,G,H,Y,T2,RL,UR))$(XACTD(BA,T2,RL) > 0)
                           **(-RHOT(BA,RL)) )**(-1/RHOT(BA,RL))
$BATINCLUDE MODULE.CTL ACPROG apCET1.GMS
                       =E= RAC(BA,RL);
```

Dollar control statements are used to make sure that these equations are generated only for those rotations with positive acreage in a region and include only those production activities with a positive amount of acreage.

Regional Crop Acreage Balance

The regional crop acreage balance constraint ensures that supply of land allocated to crop *b* in Land Resource Region *rl* is equal to the land used by the crop rotations *ba* to produce that crop. This balance is represented by the function:

$$\alpha_{b,rl}\left(\sum_{ba}\delta_{ba,rl}s_{b,ba,rl}RAC_{ba,rl}^{-\rho_{b,rl}}\right)^{-\left(\frac{1}{\rho_{b,rl}}\right)} - X_{b,rl} = 0, \qquad b \in bc, b = 1,...,B;\ rl = 1,...,RL;$$

where

$$\delta_{ba,rl} = \frac{R_{ba,rl}^{0} * RAC_{ba,rl}^{0\ \ 1+\rho_{b,rl}} * (\sum_{b}\lambda_b X_{b,rl}^{-\rho_{b,rl}})^{(-1/\rho_{b,rl}-1)} * s_{b,ba,rl})^{-1}}{\sum_{ba}R_{ba,rl}^{0} * RAC_{ba,rl}^{0\ \ 1+\rho_{ba,rl}} * (\sum_{b}\lambda_b X_{b,rl}^{-\rho_{b,rl}})^{(-1/\rho_{b,rl}-1)} * s_{b,ba,rl})^{-1}}, \quad b, ba = 1,\ldots,B; \quad rl = 1,\ldots,RL$$

$$\alpha_{b,rl} = \sum_{b} X_{b,rl} / (\sum_{ba}\delta_{b,rl}s_{b,ba,rl}RAC_{ba,rl}^{\ -\rho_{b,rl}})^{-1/\rho_{b,rl}}$$

$s_{b,ba,rl}$ is the crop enterprise ***b*** share of one unit of rotation ***ba*** acres in region ***rl***.

The function is nonlinear and implies that there is a declining rate of transformation between land used in one crop rotation and land used to produce the same crop as part of another rotation. The parameters for these equations are derived from the quantity of each rotation acre supplied in the base year $RAC_{ba,rl}^{0}$, the net return to each crop rotation activity, $R_{ba,rl}^{0}$, the weighted sum of crop b acreages, $(\sum_{b}\lambda_b X_{b,rl}^{-\rho_{b,rl}})^{(-1/\rho_{b,rl}-1)}$, and an elasticity of transformation $\sigma_{b,rl}^{r}$ for each crop *b* in each Land Resource Region *rl*. Net returns per crop rotation activity are obtained from shadow prices on the model's calibration constraints. The transformation elasticities used in the calculation of the parameters of these functions are derived by using an iterative procedure that selects the set of transformation elasticities that generate the same crop supply response as obtained from FAPSIM (Price, 2004). In GAMS code, this is written as:

```
CETR(B,RL)              $ACLRRL(B,RL,"CK4")..
                        A(B,RL)*SUM(BA$DELTA(BA,RL), DELTA(BA,RL) * BSBROT(B,BA,RL)
                        * RAC(BA,RL)**(-RHO(B,RL))
                                   )**(-1/RHO(B,RL))
                    =E= ACLRR(B,RL);
```

Again, the dollar control statements are used to restrict the equations generated and rotations represented in the equations to those for which positive crop and rotation acreage exists.

Regional Input Balance

The regional input balance equations ensure that no more of a quasi-fixed input *ir* is used in region *r* than can be supplied and list all sources of supply and all sources of use for any such input (production activity, government program category, method of production, system of production, strata of production, and region). This includes all cropland put into the Conservation Reserve Program.

$$\sum_{xcropp(b,g,h,y,t,rl,r)} pp_{ir,xcropp} X_{xcropp} + \sum_{xlvstp(b,g,h,y,t,r,r)} pp_{ir,xlvstp} X_{xlvstp}$$
$$+CRAC_{ir,r} - VI_{ir,r} \leq 0; \qquad ir = 1,\ldots,I;\ r = 1,\ldots,R;$$

In GAMS code this is written as:

```
INPUTRBALF(R,IR)$(INPUTR(R,IR,"QBASE") OR INPUTR(R,IR,"PFXP"))
               ..  SUM(XCROPP(B,G,H,Y,T,U,R),    XACTS(XCROPP)   * PP(IR,XCROPP))  {PIP+NPR}
                  + SUM(XLVSTP(B,G,H,Y,T,U,R),    XACT(XLVSTP)    * PP(IR,XLVSTP))  {LIVESTK}
                  + SUM(XFRUTP(B,G,H,Y,T,U,R),    XACT(XFRUTP)    * PP(IR,XFRUTP))  {FRUT+VEG}
$BATINCLUDE MODULE.CTL ACPROG apINPBAL.GMS
                  +  CRPLND(R,IR,"%1")                                     {+ CRP}
                    $ (ACRESDY("TOTAL","HST","CRP","A","%1",R) GT 0)

            =L=   INPUTRSUP( R,IR)  $ MFI(  R,IR)                          {CONVERTED TO MFI QUAL}
                +(INPTRSUPFP(R,IR)  $ MFI(  R,IR)) $ PMINI(R,IR)           {CONVERTED TO MFI QUAL}
                + INPUTRFSUP(R,IR)  $ ((INPUTR(R,IR,"PFXP") GT 0) AND
                                       (INPUTR(R,IR,"ELAS") LE 0))
                  ;
```

In REAP, the nonlinear regional input supply curves are represented in two linear segments. The first portion—over which input price is constant—is represented by `INPTRSUPFP(R,IR)`. After input use exceeds `INPTRSUPFP(R,IR)`, input supply is represented with an upward sloping linear curve.

Nonnegativity Constraints

$Z_{m,p}$, Y_c , $VI_{ir,r}$, $FI_{ir,r}$, $X_{b,rl}$, $RAC_{b,rl}$, $X_{b,g,h,y,t,rl,r}$, $S_{b,t,ft,rl,r}$, $CRAC_{ir,r} \geq 0$

Nonnegativity constraints in GAMS are implied when the POSITIVE VARIABLE command is used when the variables are declared.

Bounds and Starting Values

Variable bounds are specified by placing an .UP, .LO, or .FX after the primary variable name. For example, INPUTRUSE.UP(R, IR) is used to specify upper bounds placed upon regional input activity levels—this bounds regional input supply. Input supply functions may be bounded with limits on the physical availability of the resource. Input supply and commodity demand functions are generally bounded with arbitrary limits, not meant to restrict the model solution, but to improve optimizer efficiency by restricting the domain over which the optimizer must search.

```
INPUTRUSE.UP(R,IR)$INPUTR(R,IR,"QBASE") = INPUTR(R,IR,"QBASE")*3;
INPUTRUSE.UP(R,IR)$SFI(R,IR) = INPUTRUSE.UP(R,IR) / SFI(R,IR);

DOMESUSE.UP(P)     = 2*DEMSUP(P,"DOM","QBASE")$DEMSUP(P,"DOM","QBASE");
DOMESUSE.UP(P)$SF(P,"DOM") = DOMESUSE.UP(P) / SF(P,"DOM");
EXPORTUSE.UP(P)    = 2*DEMSUP(P,"EXP","QBASE")$DEMSUP(P,"EXP","QBASE");
EXPORTUSE.UP(P)$SF(P,"EXP") = EXPORTUSE.UP(P) / SF(P,"EXP");
STOCKUSE.UP(P)     = 2*DEMSUP(P,"STKE","QBASE")$DEMSUP(P,"STKE","QBASE");
STOCKUSE.UP(P)$SF(P,"STKE") = STOCKUSE.UP(P) / SF(P,"STKE");
```

Starting values are specified by placing .L after the primary variable name. XACT.L(B,R), for example, specifies initial values for primary commodity production activities. The base activity level values, PP("BASELEVL",B,R), are specified as initial values to give the optimizer a good starting point; the REAP optimization is begun from the initial values rather than, say, a previous saved basis.

The remaining starting values are specified as part of the PMP formulation. A calibration run is first performed with the PMP type activities locked onto the PMP base activity levels. The XACT.FX(B,R) specification is used to fix the PMP activities at the desired levels:

```
XACT.L(B,R)        = PP("BASELEVL",B,R);
XACT.FX(B,R)$PMP(B,R) = PMP(B,R);
```

Two additional sets of variables and equations are used in REAP to ensure that the CET functions for the tillage and rotation strata are always defined when evaluated by the solver. (This is needed because many other solvers evaluate exponents by transforming them into logarithms; consequently, if a value of zero is returned, the model will stop and give an error message indicating that an illegal operation was performed.)

```
EQUATIONS          CETTEVAL          CET TILLAGE PRACTIVE EVALUATION DOMAIN CONSTRAINT
POSITIVE VARIABLE  CETTEVALV(B,T,U)  CET TILLAGE PRACTICE DOMAIN VARIABLE

CETTEVAL(BA,T2,U)                $ROTSHR(BA,T2,U)..
                                      SUM(XCROPP(BA,G,H,Y ,T2,U,UR), XACT(XCROPP))
                                  =E= CETTEVALV(BA,T2,U);

CETTEVALV.L(BA,T2,U)              $XACTD(BA,T2,U)
                                = XACTD(BA,T2,U);
CETTEVALV.UP(BA,T2,U)             $XACTD(BA,T2,U)
                                = CETTEVALV.L(BA,T2,U) * 100;
CETTEVALV.LO(BA,T2,U)             $XACTD(BA,T2,U)
                                 = CETTEVALV.L(BA,T2,U) * .01;

EQUATIONS          CETREVAL     CET ROTATION EVALUATION DOMAIN CONSTRAINT
POSITIVE VARIABLE  CETREVALV(BA,U)    CET ROTATION DOMAIN VARIABLE

CETREVAL(BA,RL)       $RAC.L(BA,RL)..
                        RAC(BA,RL) =E= CETREVALV(BA,RL);
CETREVALV.L(BA,RL)     $RAC.L(BA,RL)
                       = RAC.L(BA,RL);
CETREVALV.UP(BA,RL)    $CETREVALV.L(BA,RL)
                       = CETREVALV.L(BA,RL) * 10;
CETREVALV.LO(BA,RL)    $CETREVALV.L(BA,RL)
                       = CETREVALV.L(BA,RL) * .01;
```

Solving the Model

MODEL Statement Specification

The MODEL statement is used to define a GAMS model as some combination of the equations that have been declared. REAP1 is the first calibration run model, consisting of all equation blocks initially specified for the first calibration run: the objective function, the product balance equations, the regional variable-price input balance, the regional fixed-input balance, the supply response equations, and the government program equations (plus several optional dry/irrigation and acreage limit controls not used in current REAP formulations). REAPS8 is the final, validated REAP formulation, after calibration of all supply response and constant elasticity share functions. The BATINCLUDE statements shown below allow equations to be added to the model definition for REAPS8 if options for including those modules have been turned on. In the **MODEL** statement for REAPS8 the variable nitrogen application rate module has been turned on (VNITF = 1), causing the convexity constraint equations to be added to the model definition for REAPS8.

```
$STITLE REAP MODEL SPECIFICATION:  ROWS AND OBJECTIVE FUNCTION, CALIBRATION RUN
* -------------------------------------------------------------------------------

*                               DECLARE THE MODEL EQUATIONS
  EQUATIONS
     OBJECTIVE FUNCTION
             UOBJ       REAP OBJECTIVE FUNCTION

*    COMMODITY AND INPUT BALANCE
             PRODBAL    COMMODITY PRODUCT BALANCE EQUATION
             INPUTRBALF REGIONAL INPUT BALANCE EQUATION
             INPUTRFBAL REGIONAL FIX PRICE INPUT BALANCE EQUATION
             CETT       CONSTANT ELASTICITY OF TRANSFORMATION AMONG TILLAGE TYPES
             CETR       CONSTANT ELASTICITY OF TRANSFORMATION AMONG ROTATIONS
             CNVXBAL    VARIABLE N FERT APPLICATION CONVEXITY CONSTRAINTS
             GPPBASEAC  GOVERNMENT PROGRAM PAYMENT BASE SODBUSTER PROVISIONS

 MODELS
       REAP1 FLEXIBLE MODEL FORUMLATION /
                          UOBJ,      PRODBAL,   INPUTRBALF, INPUTRFBAL, GPCON
                          ACEQ2
                          /;

      REAP8 STRATA FIXED MODEL FORUMLATION /
                          UOBJ,      PRODBAL,   INPUTRBALF
                          CETR,      CETREVAL,  CETT,       CETTEVAL
BATINCLUDE D:\REAPGAMS\A1A0\CET\MODULE.CTL
BATINCLUDE D:\REAPGAMS\A1A0\CET\MODULE.CTL
BATINCLUDE D:\REAPGAMS\A1A0\NITR\VNMODEL1.GMS
  *<vnMODEL1.GMS>
  *bVNITF
                           CNVXBAL
  *eVNITF

                               /;
```

SOLVE Statement Specification

The SOLVE statement calls for solution of a particular model. The following SOLVE statement asks for solution of model REAPS8 by maximizing variable CPS:

```
SOLVE REAPS8 USING DNLP MAXIMIZING CPS.
```

The SOLVE statement essentially causes GAMS to generate the model in a form in which it can be passed to and solved by an optimizer or other solution procedure. Discontinuous nonlinear programming (DNLP) is the solution method specified. REAP requires DNLP because of the two expressions in the objective function that contain the MAX function, for example: (MAX(0,(IMPORTSUP(P)-DIF(P,"IMP")))). This formulation causes a discontinuity in the objective function, at which point the function gradients for these variables are be undefined.

Model Solution

Some useful solution and diagnostic information is printed into the LST output file for every model run, indicating first whether an optimal solution was found.

```
                S O L V E      S U M M A R Y
MODEL   REAP8               OBJECTIVE  CPS
      TYPE    DNLP                DIRECTION  MAXIMIZE
      SOLVER  MINOS5              FROM LINE  58062

  **** SOLVER STATUS     1 NORMAL COMPLETION
 **** MODEL STATUS      2 LOCALLY OPTIMAL
 **** OBJECTIVE VALUE           769542.4849

  RESOURCE USAGE, LIMIT       1656.960    10000.000
  ITERATION COUNT, LIMIT      3500        20000
  EVALUATION ERRORS              0            0

M I N O S    5.3    (NOV 1990)         VER: 225-386-02
      = = = = =

B. A. MURTAGH, UNIVERSITY OF NEW SOUTH WALES
        AND
      P. E. GILL,  W. MURRAY,  M. A. SAUNDERS AND M. H. WRIGHT
      SYSTEMS OPTIMIZATION LABORATORY, STANFORD UNIVERSITY.

  OPTIONS FILE
  ------------
       BEGIN GAMS/MINOS  OPTIONS
       * MINOS5.OP6 USED IN A0C2 DIRECTORY FOR VFY RUN AFTER CTF
        HESSIAN DIMENSION      1050
        SUPERBASICS LIMIT      1050
        COMPLETION          PARTIAL
        LOG FREQUENCY            20
        SOLUTION                 NO
        PRINT LEVEL               1
        ROW TOLERANCE           1.0E-7
        MINOR ITERATIONS        1000
        MAJOR ITERATIONS        40
        MAJOR DAMPING PARAMETER  .2
        MINOR DAMPING PARAMETER  .2
        PENALTY PARAMETER        .5
       END GAMS/MINOS OPTIONS

WORK SPACE ALLOCATED           --    7.52 MB

EXIT -- OPTIMAL SOLUTION FOUND

MAJOR ITNS, LIMIT            13      40
  FUNOBJ, FUNCON CALLS       5294    5302
  SUPERBASICS                 580
  INTERPRETER USAGE        346.59
  NORM RG / NORM PI     1.969E-07
```

```
  NO. OF ITERATIONS                3500     OBJECTIVE VALUE      7.6954248487E+05
  NO. OF MAJOR ITERATIONS            13     LINEAR OBJECTIVE    -4.9270982959E+04
  PENALTY PARAMETER            0.000000     NONLINEAR OBJECTIVE  8.1881346783E+05
  NO. OF CALLS TO FUNOBJ           5294     NO. OF CALLS TO FUNCON           5302
  NO. OF SUPERBASICS                580     NORM OF REDUCED GRADIENT    5.363E-04
  NO. OF BASIC NONLINEARS          1086     NORM RG / NORM PI           2.119E-07
  NO. OF DEGENERATE STEPS             0     PERCENTAGE                       0.00
  NORM OF X                   4.174E+02     NORM OF PI                  2.531E+03
  NORM OF X  (UNSCALED)       1.084E+03     NORM OF PI (UNSCALED)       2.724E+03
  CONSTRAINT VIOLATION        7.906E-12     NORMALIZED                  7.288E-15

STATUS         OPTIMAL SOLN          ITERATION 3500     SUPERBASICS  580

  SOLUTION FILE SAVED ON FILE  20
  MAJOR ITNS, LIMIT           13      40
  FUNOBJ, FUNCON CALLS       5294    5302
  SUPERBASICS                580
  INTERPRETER USAGE        346.59
  NORM RG / NORM PI     1.969E-07
```

Output Reports

In the LST output file generated, GAMS will report the solution and marginal values for model variables and equations. In addition, two standard sets of reports are generated by REAP. The first report, called "A1A0RPT00.GMS," is found in the A1A0LIB directory (table 8). This bulletin is generated automatically every time REAP solves successfully and is found at the end of the GAMS listing. A1A0RPT00 calculates such things as changes in acreage planted, commodity supply and uses, commodity prices, farm income, and environmental indicators. The tables in A1A0RPT00 are in standard GAMS format and are used primarily in the evaluation of model results.

In addition, a second report of about 40 to 60 pages of model results can be generated for distribution. This summary report is generated by running ARPT20.GMS, that is located in the AREPORT directory (table 9). The report includes explanations of commodity, input, and environmental indicators, plus tables reporting supply and use, acreage, income, other economic indicators, and physical and economic environmental indicators. Detailed tables focusing on additional topics are often produced for specific scenario analysis. A fragment of the output generated by ARPT20 for a carbon sequestration analysis is shown in example 13. This fragment lists some of the tables that are generated by ARPT20. An example of the tables from this report is shown in table 9.

Example 13—ARPT20 fragment

```
        REAP REGIONAL AGRICULTURAL MODEL -- CARBON SEQUESTRATION  ALTERNATIVES             PAGE 2
    SCP1100S 2010 0201bsl AER SCP RUNS ALL C=0 P=100 D=0 FP=1 NDISC=1 A1A093V TCM15bV    03/04/02

                             CONTENTS

                   TABLE                                                     PAGE
                   ---------------------------------------------------       ----
                   PRIMARY COMMODITY AND PRODUCT LISTS                          2
                   SECONDARY (PROCESSED) PRODUCTS LISTS                         4
                   PRODUCTION INPUTS                                            5
                   ENVIRONMENTAL INDICATORS                                     6
                   ALTERNATIVE CROP ROTATIONS                                   7
                   TABLE 1:  GOVERNMENT PROGRAM ASSUMPTIONS                     8
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                   TABLE 3:  PROCESSED PRODUCT SUPPLY AND USE                  10
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```
