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$EOLCOM //
$TITLE Afghan Water Rights Priority Model
$OFFSYMXREF OFFSYMLIST OffLISTING OFFUPPER

OPTION LIMROW=000, LIMCOL = 0;

$ONTEXT

EOLCOM // tells GAMS to ignore anything in the line's text after the symbol //
OFFLISTING deletes all program lines and just includes GAMS listing
Set LIMROW = 0 to eliminate all equations in the GAMS listing
Set LIMROW = 100 or more to show all equations in listing. Helps trap  errors

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* ---------------------------------------------------------------------------------------
*  Model 4 Simple Farm management
*  Adds a SET (r) for water-sharing rule based on priority allocation of water as parameter
*  water sharing rule requires introducing a priority SET (j)
*  Also solves several models automatically inside a series of loops
* ---------------------------------------------------------------------------------------

$OFFTEXT

*************************************   Section 1 **********************************
*                                      Sets                                         *
```

```
*******************************************************************************************

SETS

i    province

/
  1-Mousil
  2-Basra
/

k    crop

/  1-wheat
   2-cotton
/

s   hydrologic water supply scenario

/
normal
dry
/

j  water right priority: same number # of elements as # of provinces - 1 priority per province

/       j1*j2
/

r water allocation rule label: allows evaluating many water shortage sharing rules
/
us_priority     upstream   priority                    //rule 1
prop_sharing    proportional sharing of shortages      //rule 2
/

set rji(r,j,i) mapping set: assigns water use priorities to province - separate mapping for each proposed rule

/ us_priority  . (j1.1-Mousil, j2.2-Basra)
  prop_sharing . j1. (1-Mousil,   2-Basra)
/

display rji;
```

```
************************************  Section 2
**************************************************************************
*                                         Data
*
**************************************************************************************************************************
****

table  Bc(i,k)    crop water demand(ET) (1000s cubic meters per Ha = 10ths of meters depth)

                 1-wheat          2-cotton
 1-mousil          11.9             18.0
 2-Basra           13.5             21.4

*Bc(k) =  0.5 * Bc(k)

table    Yield_p(i,k)   Crop Yield tons per Ha (proportional to ET)

               1-wheat         2-Cotton
1-Mousil        1.39             2.32
2-Basra         1.57             2.75


* economic data


parameter   Price_p(k)        Crop Prices ($ US per ton)

/1-Wheat        225
 2-Cotton       906
/

table Cost_p(i, k)     Crop Production Costs excluding water ($ US per Ha)

                1-wheat   2-cotton
1-Mousil          200      1286
2-Basra           207      1345

;

* data from Dr. Saud Amer 2012
```

```
Table land_p(i,k)   observed land in prodn year 2006 (1000 Ha)

                1-wheat        2-cotton
1-mousil          47.4           0.45
2-basra           16.9           0.00
;

Parameter Net_revenue_p(i,k)  calculated net revenue per unit land ($ US per HA)
;

Net_revenue_p(i,k) = Price_p(k) * Yield_p(i,k) - Cost_p(i,k);

parameter Wat_supply_p(s)      total water available (million cubic meters per year)
;

Wat_supply_p('normal') = sum((i,k), land_p(i,k) * Bc(i,k));   // calculates observed water use
Wat_supply_p('dry')    = 0.5 * wat_supply_p('normal');        // dry: half of observed water use

parameter right_p(i)  total water assigned by province in full supply conditions (paper water)
;

right_p(i)  =  sum(k, Bc(i,k) * land_p(i,k));  // sums over crops: ith province's historical (2006) water use under
full supply

* code below loops over each priority (j) then maps each priority to corresponding province i
* code is thanks to Pete Stacy at GAMS Development Corporation Feb 1 2012

parameter   tot_assigned(r,s) cumulative water assigned to province (i) including higher priorities;
            tot_assigned(r,s)  = 0;  // starts at 0 - prepares to loop

parameter
  tot_pap_right_by_prior(r,  j) cumulative paper right at jth priority for all provinces including ties
  remain_supply_by_prior(r,s,j) residual supply    at jth priority after supplying higher priorities
  wet_wat_use           (r,s,i) wet (not paper) water use assigned to ith province - limited by total basin supply
;

Loop(r,                                                                    // loop over sharing rule (r)
 Loop(j,                                                                   // loop over priority (j)

   tot_pap_right_by_prior(r,j) = sum[i$rji(r, j, i), right_p(i)] ;         // total paper rights by (j) priority by
provinces includes ties
   remain_supply_by_prior(r,s,j) =
```

```
       min[(wat_supply_p(s) - tot_assigned(r,s)), tot_pap_right_by_prior(r,j)]; // remaining supply by (j) priority
after protecting higher priorities
   Loop(i$rji(r,j,i),
       wet_wat_use(r,s,i) = (right_p(i)/tot_pap_right_by_prior(r,j))
       * remain_supply_by_prior(r,s,j) + eps;                                  // wet water assigned to (i) province
    tot_assigned(r,s) = tot_assigned(r,s) + wet_wat_use(r,s,i) ;               // cumulative water (check) assigned to
last province getting water - should match total supply

   );                                                                          // end province loop
  );                                                                           // end priority loop
);                                                                             // end rule loop

parameter tot_wat_use(r,s)  total water use defined;
tot_wat_use  (r,s) = sum(i, wet_wat_use(r,s,i)) + eps;  // checks total use assigned against supply

*********** end of water allocation system ******************

**** begin looping over water sharing rule and water supply scenario below
* rr, ss, are subset of original sets... allows fast scenario analysis below

set rr(r);   // water sharing rule
set ss(s);   // water supply scenario

rr(r)=no;    // switches subset off for now
ss(s)=no;    // switches subset off for now

*****************************  SECTION 3 ********************************************
*                              Variables                                            *
*********************************************************************************

positive variables

hectares_v    (r,i,k,s)   land in production by rule-province-crop-scen    (1000 Ha - marginal is $US per Ha)
T_hectares_v  (r,i,  s)   total land in prodn by rule-province-scen        (1000 Ha - marginal is $US per Ha)
uses_crop_v   (r,i,k,s)   total water use by rule-province-crop-scen      (million m^3 - marginal is $US per 1000 m^3)
uses_v        (r,i,  s)   total water use by rule-province-scen           (million m^3 - marginal is $US per 1000 m^3)

variables

ag_ben_k_v    (r,i,k,s)   total farm income by rule-province-crop-scen    ($US 1000s - no marginals shown)
ag_ben_v      (r,    s)   total farm income by rule-scen                  ($US 1000s - no marginals shown)
```

```
Tot_b_v           total farm income re-calc for each rule-scen (objective) ($US 1000s - no marginals shown)

*******************************   Section 4  ****************************************
*                                 Equations                                           *
*************************************************************************************

Equations

// Equations DECLARED

T_hectares_e   (r,i,  s)    total land in production by province-scen  (1000 Ha - marginal is $US per Ha)
Uses_crop_e    (r,i,k,s)    total water use by crop-province-scean     (million m^3 - marginal is $US per 1000 m^3)
uses_e         (r,i,  s)    total water use by scen                    (million m^3 - marginal is $US per 1000 m^3)

ag_ben_k_e     (r,i,k,s)    total farm income by crop-province-scen    ($US 1000s - no marginals shown)
ag_ben_e       (r,    s)    total farm income by scen                  ($US 1000s - no marginals shown)

Tot_b_e                     total farm income by element of loop       ($US 1000s - no marginals shown)

;

// Equations defined (using above names with algebraic formulas)

// Equations below defined over rule (rr) and scenario (ss) using subset rr and ss

T_hectares_e   (rr,i,  ss)..  T_hectares_v(rr,i,  ss)   =e=  sum(k,   hectares_v  (rr,i,k,ss));
Uses_crop_e    (rr,i,k,ss)..  uses_crop_v (rr,i,k,ss)   =e=  Bc(i,k) *  hectares_v(rr,i,k,ss);
uses_e         (rr,i,  ss)..  uses_v      (rr,i,  ss)   =e=  sum(k,    uses_crop_v(rr,i,k,ss));

ag_ben_k_e     (rr,i,k,ss)..  ag_ben_k_v  (rr,i,k,ss)   =e=  net_revenue_p(i,k) * hectares_v(rr,i,k,ss);
ag_ben_e       (rr,    ss)..  ag_ben_v    (rr,    ss)   =e=  sum((i,k), ag_ben_k_v(rr,i,k,ss));

Tot_b_e                   ..  Tot_b_v                  =e=  sum((rr,ss), ag_ben_v(rr,ss));   // sums total benefits
over indices for sensitivity analysis

*************** Section 5 ***********************************************************
*  Labels and defines models                                                          *
*  Each model has one objective function                                              *
*************************************************************************************

model TE_04 /all/ ;
```

```
*********************************  Section 6   ***************************************
*                                  BOUNDS                                             *
*  Bounding shows a positive shadow price for each limiting resource                  *
*************************************************************************************

uses_v.up    (r,i,  s) = wet_wat_use(r,s,i  );  // upper bound limits available water to observed water use
hectares_v.up(r,i,k,s) =      land_p(    i,k);  // can produce no more land by crop than under full water supply

*hectares_v.lo('1-mousil','1-wheat') =  10;     // food security requirement
*uses_crop_v.lo('wheat')  = 1;                  // another way of enforcing food security

*************** Section 7 ***************************************************************
*               SOLVE THE MODEL                                                         *
*************************************************************************************

  loop(r,
    loop(s,

      ss(s) = yes;
      rr(r) = yes;

      Solve TE_04 using nlp maximizing Tot_b_v;  // multiple solves inside loop avoids writing solve several times

* closes loops below over r,s (rule for sharing shortages, water supply scenario)

    rr(r) = no;
    ss(s) = no;

    );
  );

// THE END
```