A.3. MODEL APPENDIX

A.3.1. MODEL SOURCE CODE

A.3.2. DIMENSIONS AND VARIABLES OF THE MODEL

A.3. MODEL APPENDIX

A.3.1. MODEL SOURCE CODE

```
/*************************************************************
*
*    model.cpp
*
*      Carrying Capacity Study
*
*        Xerca Doctoral Thesis; 1996-99
*        Director: Mike Mesarovic
*        With the help of: Ali, Gundo, Sree,...
*
*      Last version: August 23; 1999
*
*************************************************************/

#include "stdafx.h"
#include <stdio.h>
#include "crcp9899.hh"

long model(long firstYear, long year, FILE *fpl)
{
 int j,k,r;
 static float  spop[reg],spops[reg],spops_agg,scrcp[reg],
                                swtwdt[reg],sagland[reg],saglandir[reg],
                                syldpir[reg],syldpnir[reg];


          /*****************************
          *
          * POPULATION 1st LEVEL MODEL
          *
          *****************************/

          if (year > firstYear)
         {
                  for (r=0; r<reg; r++) {

                           /* Compute total population of the region (population in millions) */

                           pops[r]=spops[r]*(1+rpopm[r]*rpop[r]/100.);
                  }
         }
```

```
        for (r=0; r<reg; r++) {
                /* Compute total population density (land in 10^3he) */
                popsds[r]=pops[r]/(land[r]/1000.);
                /* Compute total population density (output: people/km2) */
                popsdskm2[r]=100*pops[r]/(land[r]/1000.);
        }
                /* Aggregation population region aggregate */
        pops_agg=0.;
        land_agg=0.;
        for (r=1; r<7; r++) {
                pops_agg = pops_agg + pops[r];
                land_agg = land_agg + land[r];
        }
                /* Aggregation population rate */
                rpop_agg = 100.*(pops_agg - spops_agg)/spops_agg;
                /* Aggregation population density */
                popsds_agg = pops_agg/(land_agg/1000.);

/*****************************
*
* POPULATION 2n LEVEL MODEL
*
*****************************/

if (year > firstYear)
{
        for (r=0; r<reg; r++) {
                /* Compute population rate */
                crbrtr[r]=crbrt[r]*crbrtm[r];
```

```
                crdthr[r]=crdth[r]*crdthm[r];
                rpopo[r]=(crbrtr[r]-crdthr[r])/10;

                /* Compute total population of the region */
                pop[r]=spop[r]*(1.+(rpopo[r])/100.);
        }
}
        for (r=0; r<reg; r++) {
                /* Compute total population density (land in 10^3he) */
                popds[r]=pop[r]/(land[r]/1000.);
        }
                /* Compute variables aggregate */
                brt_agg = 0.;
                dth_agg = 0.;
                pop_agg = 0.;
        for (r=1; r<7; r++) {
                brt[r] = crbrtr[r]*pop[r]/1000.;
                dth[r] = crdthr[r]*pop[r]/1000.;
                brt_agg = brt_agg + brt[r];
                dth_agg = dth_agg + dth[r];
                pop_agg = pop_agg + pop[r];
        }
                crbrt_agg = brt_agg*1000./pop_agg;
                crdth_agg = dth_agg*1000/pop_agg;
                rpopo_agg = (crbrt_agg - crdth_agg)/10.;
                popds_agg = pop_agg/(land_agg/1000.);
```

```
/***********************************
*
*  CARRYING CAPACITY 1st LEVEL MODEL
*
*  from population 1st level model
*
***********************************/

if (year > firstYear)
{
        for (r=0; r<reg; r++) {

                /* Compute carrying capacity of the region */

                crcp[r]=scrcp[r]*(1+rcrcpm[r]*rcrcp[r]/100.);
        }
}

        for (r=0; r<reg; r++) {

                /* Compute carrying capacity deficit */

                crcpsdf[r]=crcp[r]-popsds[r];

                /* Compute carrying capacity index */

                incrcps[r]=crcp[r]/popsds[r];

                        if (incrcps[r] > 1)
                        {

                                incrcps[r]=1;
                        }

                /* Compute population capacity */

                popcp[r]=crcp[r]*land[r]/1000.;

                /* Compute population deficit */

                popsdf[r]=pops[r]-popcp[r];
        }

                /* Compute variables aggregate */

                popcp_agg = 0.;

                for (r=1; r<7; r++) {
```

```
                popcp_agg = popcp_agg + popcp[r];
        }

                popsdf_agg = pops_agg - popcp_agg;

                crcp_agg = popcp_agg/(land_agg/1000.);

                crcpsdf_agg = crcp_agg - popsds_agg;

                incrcps_agg = crcp_agg/popsds_agg;

                if (incrcps_agg > 1)
                {

                        incrcps_agg=1;
                }


/*****************************************************
*
*  WATER RESOURCES, AVAILABIBLITY AND CAPABILITY
*  MODEL
*
*  from population 1st level model
*
*****************************************************/


                /* Compute FIRST water scarcity index (water in cubic Kilometers) */

        for (r=0; r<reg; r++) {

                inwtscs[r] = 1000*wtrsrn[r]/pops[r];
        }

                /* Compute FIRST water scarcity index for X region */

                inwtscs[9] = 1000*wtrsrn[9]/pops_agg;

                /* Compute SECOND water scarcity index */

        for (r=0; r<reg; r++) {

                inwtscn[r] = 1000.*pops[r]/wtrsrn[r];
        }

                inwtscn[9] = 1000.*pops_agg/wtrsrn[9];
```

```
                /* Compute THIRD water scarcity index */

        for (r=0; r<reg; r++){

                inwtwdtac[r] = 100.*wtwdtac[r]/wtrsrn[r];
        }

                inwtwdtac[9] = 100.*wtwdtac[9]/wtrsrn[9];

                /* Compute capability evolution of water withdrawal */

if (year > firstYear)
{
        for (r=0; r<reg; r++) {

                wtwdt[r] = swtwdt[r]*(1.+ rwtwdt[r]*rwtwdtm[r]/100.);
        }
}

                /* Compute per capita index water withdrawal total */

        for (r=0; r<reg; r++) {

                inwtwdtpc[r]= 1000*wtwdt[r]/pops[r];
        }

                inwtwdtpc[9]= 1000*wtwdt[9]/pops_agg;


/**********************************
*
*  CARRYING CAPACITY 2n LEVEL MODEL
*
*  AGRICULTURAL LAND AND WATER MODEL
*
*  from population 1st level model
*
**********************************/

if (year > firstYear)
{


                /*  Compute agricultural land */

        for (r=0; r<reg; r++) {

                agland[r] = sagland[r]*(1.+raglandm[r]*ragland[r]/100.);
        }
```

```
                /*  Compute population density related with agricultural hectares  */

        for (r=0; r<reg; r++) {

                popdsaghe[r]=(agland[r]/1000.)/pops[r];
        }

                /*      Compute agricultural irrigated land */

        for (r=0; r<reg; r++) {

                aglandir[r]=saglandir[r]*(1.+raglandirm[r]*raglandir[r]/100.);
        }
}

                /*  Compute water used in irrigation (water in cubic Kilometers)*/

        for (r=0; r<reg; r++) {

                irwtus [r] = kcrintir[r]*kirwthc[r]*aglandir[r];
        }

                /*      Compute agricultural non-irrigated land */

        for (r=0; r<reg; r++) {

                aglandnir[r]=agland[r]-aglandir[r];
         }

                /* Compute yield production non-irrigated (Kg/He)*/

 if (year > firstYear)
{
        for (r=0; r<reg; r++) {

                yldpnir[r] = syldpnir[r]*(1.+ryldpnirm[r]*ryldpnir[r]/100.);
        }
}

                /* Compute yield production irrigated          */

 if (year > firstYear)
{
        for (r=0; r<reg; r++) {

                yldpir[r] = syldpir[r]*(1.+ryldpirm[r]*ryldpir[r]/100.);
        }
}
```

```
        /*  Compute daily kilocalorie supply per capita and day */

for (r=0; r<reg; r++) {

        dailys[r]= klostag[r]*(aglandir[r]*kcrintir[r]*yldpir[r]*calyld[r]+
        aglandnir[r]*kcrintnir[r]*yldpnir[r]*calyld[r])/(pops[r]*365.*1000.);
}

        /*  Compute daily Index */

for (r=0; r<reg; r++) {

        indailys[r]=dailys[r]/dailyfao[r];
}

        /*  Compute population capacity in agreement to grain production total
        equivalent and FAO Daily */

for (r=0; r<reg; r++) {

        popcpag[r] = klostag[r]*(aglandir[r]*kcrintir[r]*yldpir[r]*calyld[r]+
        aglandnir[r]*kcrintnir[r]*yldpnir[r]*calyld[r])/(dailyfao[r]*
        365.*1000.);
}

        /*  Compute index carrying capacity 2n level */

for (r=0; r<reg; r++) {

        incrcp[r]=popcpag[r]/pops[r];

        if (incrcp[r] > 1)
                {
                        incrcp[r]=1;
                }
}

        /*  Compute population capacity in agreement to grain non irrigated
        production total equivalent and FAO Daily */

for (r=0; r<reg; r++) {

        popcpagnir[r] =
        klostag[r]*(aglandnir[r]*kcrintnir[r]*yldpnir[r]*calyld[r])/
        (dailyfao[r]*365.*1000.);
}
```

```
        /*  Compute index carrying capacity non irrigated 2n level */

for (r=0; r<reg; r++) {

        incrcpnir[r]=popcpagnir[r]/pops[r];

        if (incrcpnir[r] > 1)
                {
                        incrcpnir[r]=1;
                }
}

        /*  Compute population capacity in agreement to grain irrigated
        production total equivalent and FAO Daily */

for (r=0; r<reg; r++) {

        popcpagir[r] = klostag[r]*(aglandir[r]*kcrintir[r]*yldpir[r]*calyld[r])/
        (dailyfao[r]*365.*1000.);
}

        /*  Compute index carrying capacity irrigated 2n level */

for (r=0; r<reg; r++) {

        incrcpir[r]=popcpagir[r]/pops[r];

        if (incrcpir[r] > 1)
                {
                        incrcpir[r]=1;
                }
}

        /*  Compute variables aggregate */

        agland_agg = 0.;

        aglandir_agg = 0.;

        aglandnir_agg = 0.;

        irwtus_agg = 0.;

        popcpag_agg = 0.;

        popcpagnir_agg = 0.;

        popcpagir_agg = 0.;
```

```
for (r=1; r<7; r++) {
        agland_agg = agland_agg + agland[r];
        aglandir_agg = aglandir_agg +aglandir [r];
        aglandnir_agg = aglandnir_agg + aglandnir [r];
        irwtus_agg = irwtus_agg + irwtus [r];
        popcpag_agg = popcpag_agg + popcpag[r];
        popcpagnir_agg = popcpagnir_agg + popcpagnir[r];
        popcpagir_agg = popcpagir_agg + popcpagir[r];
}
irwtus_agg = kcrintir[9] * kirwthc [9] * aglandir_agg;
popdsaghe_agg = (agland_agg/1000.)/pops_agg;
incrcp_agg = popcpag_agg/pops_agg;
incrcpnir_agg = popcpagnir_agg/pops_agg;
incrcpir_agg = popcpagir_agg/pops_agg;
if (incrcp_agg > 1)
        {
                incrcp_agg =1;
        }
if (incrcpnir_agg > 1)
        {
                incrcpnir_agg =1;
        }
if (incrcpir_agg > 1)
        {
                incrcpir_agg =1;
        }
```

```
        /*******************
        *
        *  BACKUP VARIABLES
        *
        ********************/


                for (r=0; r<reg; r++) {

                        /* Backup total population 1st level model variable */

                        spops[r]=pops[r];

                        /* Backup total aggregation population 1st level model variable */

                        spops_agg=pops_agg;

                        /* Backup total population 2n level model variable */

                        spop[r]=pop[r];

                        /* Backup carrying capacity variable */

                        scrcp[r]=crcp[r];

                        /* Backup water withdrawal total */

                        swtwdt[r]=wtwdt[r];

                        /* Backup agricultural model variables */

                        sagland[r]=agland[r];

                        saglandir[r]=aglandir[r];

                        syldpir[r]=yldpir[r];

                        syldpnir[r]=yldpnir[r];
                }
        return 1;
}
```

A.3.2. DIMENSIONS AND VARIABLES OF THE MODEL

Dimension			
Regions	**reg**		
subscript	Regions	Sudan	sudan
subscript	Regions	Ethiopia	ethiopia
subscript	Regions	Somalia	somalia
subscript	Regions	Kenya	kenya
subscript	Regions	Uganda	uganda
subscript	Regions	Rwanda	rwanda
subscript	Regions	Burundi	burundi
subscript	Regions	Tanzania	tanzania
subscript	Regions	Africa	africa
subscript	Regions	SubRegion	subregaf

Variable			
Long name	**Short name**	**Sector**	**dimension**
Agricultural Land	agland	agriout	Regions
Agricultural Land Aggregate	agland_agg	agriout	
Agricultural Land Irrigated	aglandir	agriout	Regions
Agricultural Land Irrigated Rate	raglandir	agriinp	Regions
Agricultural Land Irrigated Rate Multiplier	raglandirm	agriscn	Regions
Agricultural Land Irrigation Aggregate	aglandir_agg	agriout	
Agricultural Land Non Irrigation Aggregate	aglandnir_agg	agriout	
Agricultural Land Non rrigated	aglandnir	agriout	Regions
Agricultural Land Rate	ragland	agriinp	Regions
Agricultural Land Rate Multiplier	raglandm	agriscn	Regions
Agricultural Lost Coefficient	klostag	agriinp	Regions
Calorie Yield	calyld	calinp	Regions
Carrying Capacity	crcp	crcpout	Regions
Carrying Capacity Aggregate	crcp_agg	crcpout	
Carrying Capacity Deficit 1st	crcpsdf	crcpout	Regions
Carrying Capacity Deficit 1st Aggregate	crcpsdf_agg	crcpout	
Carrying Capacity Index	incrcp	crcpout	Regions
Carrying Capacity Index Aggregate from Irrigated	incrcpir_agg	crcpout	
Carrying Capacity Index 1st	incrcps	crcpout	Regions
Carrying Capacity Index 1st Aggregate	incrcps_agg	crcpout	
Carrying Capacity Index Aggregate	incrcp_agg	crcpout	
Carrying Capacity Index Aggregate from Non Irrigated	incrcpnir_agg	crcpout	
Carrying Capacity Index from Irrigated	incrcpir	crcpout	Regions

Carrying Capacity Index from Non Irrigated	incrcpnir	crcpout	Regions
Carrying Capacity Rate	rcrcp	crcpinp	Regions
Carrying Capacity Rate Multiplier	rcrcpm	crcpscn	Regions
Coeficcient cropping intensity irrigated	kcrintir	agriinp	Regions
Coeficcient cropping intensity non irrigated	kcrintnir	agriinp	Regions
Crude Birht Rate Aggregate	crbrt_agg	popout	
Crude Birth Rate	crbrt	popinp	Regions
Crude Birth Rate - Real	crbrtr	popout	Regions
Crude Birth Rate Multiplier	crbrtm	popinp	Regions
Crude Death Rate	crdth	popinp	Regions
Crude Death Rate - Real	crdthr	popout	Regions
Crude Death Rate Aggregate	crdth_agg	popout	
Crude Death Rate Multiplier	crdthm	popinp	Regions
Daily 1st	dailys	calout	Regions
Daily FAO	dailyfao	calinp	Regions
Daily Index 1st	indailys	calout	Regions
Irrigation Water Per Hectare Coefficient	kirwthc	agrinp	Regions
Irrigation Water Used	irwtus	agriout	Regions
Irrigation Water Used Aggregate	irwtus_agg	agriout	
Land	land	agriinp	Regions
Land Aggregate	land_agg	agriout	
Number of Birth	brt	popout	Regions
Number of Birth Aggregate	brt_agg	popout	
Number of Death	dth	popout	Regions
Number of Death Aggregate	dth_agg	popout	
Population Capacity	popcp	crcpout	Regions
Population Capacity Aggregate	popcp_agg	crcpout	
Population Capacity Aggregate Agree Agricultural Model	popcpag_agg	crcpout	
Population Capacity Aggregate Agricultural Irrigated	popcpagir_agg	crcpout	
Population Capacity Aggregate Agricultural Non Irigated	popcpagnir_ agg	crcpout	
Population Capacity Agree Agricultural Irrigated	popcpagir	crcpout	Regions
Population Capacity Agree Agricultural Model	popcpag	crcpout	Regions
Population Capacity Agree Agricultural Non Irrigated	popcpagnir	crcpout	Regions
Population Deficit	popdf	crcpout	Regions
Population Deficit 1st	popsdf	crcpout	Regions
Population Deficit 1st Aggregate	popsdf_agg	crcpout	
Population Deficit Aggregate	popdf_agg	crcpout	
Population Deficit Rate Output	rpopdfo	crcpout	Regions
Population Deficit Rate Output 1st	rpopsdfo	crcpout	Regions
Population Density	popds	popout	Regions
Population Density 1st	popsds	popout	Regions

Population Density 1st Aggregate	popsds_agg	popout	
Population Density 1st km2	popsdskm2	popout	Regions
Population Density Aggregate	popds_agg	popout	
Population Density Related Agricultural Land	popdsaghe	agriout	Regions
Population Density Related Agricultural Land Aggregate	Popdsaghe _agg	agriout	
Population Rate	rpop	popinp	Regions
Population Rate Aggregate 1st	rpop_agg	popout	
Population Rate Multiplier	rpopm	popscn	Regions
Population Rate Output	rpopo	popout	Regions
Population Rate Output Aggregate	rpopo_agg	popout	
Population Total	pop	popout	Regions
Population Total 1st	pops	popout	Regions
Population Total 1st Aggregate 1st	pops_agg	popout	
Population Total Aggregate	pop_agg	popout	
Water Barrier	wtbr	waterinp	Regions
Water Barrier 2	wtbr2	waterinp	Regions
Water Resources Annual Renewable	wtrsrn	waterinp	Regions
Water Scarcity	wtsc	waterinp	Regions
Water Scarcity 2	wtsc2	waterinp	Regions
Water Scarcity Index 1st	inwtscs	waterout	Regions
Water Scarcity Index 2n	inwtscn	waterout	Regions
Water Stress	wtst	waterinp	Regions
Water Stress 2	wtst2	waterinp	Regions
Water Withdrawal Total	wtwdt	waterout	Regions
Water Withdrawal Total Actual	wtwdtac	waterinp	Regions
Water Withdrawal Total Actual Index	inwtwdtac	waterout	Regions
Water Withdrawal Total Aggregate	wtwdt_agg	waterout	Regions
Water Withdrawal Total Index Per Capita	inwtwdtpc	waterout	Regions
Water Withdrawal Total Rate	rwtwdt	waterinp	Regions
Water Withdrawal Total Rate Aggregate	rwtwdt_agg	waterout	Regions
Water Withdrawal Total Rate Multiplier	rwtwdtm	waterscn	Regions
Yield Production Irrigated	yldpir	agriout	Regions
Yield Production Irrigated Rate	ryldpir	agriinp	Regions
Yield Production Irrigated Rate Multiplier	ryldpirm	agriscn	Regions
Yield Production Non Irrigate	yldpnir	agriout	Regions
Yield Production Non Irrigate Rate	ryldpnir	agriinp	Regions
Yield Production Non Irrigate Rate Multiplier	ryldpnirm	agriscn	Regions