TECHNICAL REPORT

Water Balance of the 1993 Midwest Flood

by

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1. Introduction

Throughout the spring and summer months of 1993, extended rainfall throughout much of the Midwestern United States caused record flooding that inundated much of the Upper Mississippi River Basin (UMRB). Precipitation in May was more then twice the normal over an area that extended from southeastern South Dakota across Iowa to eastern Kansas. From early June to the end of July, high amounts of precipitation persisted over the upper Midwest (Wahl, et al., 1993). USGS records indicated that at 45 streamflow gauging stations, the peak discharge recorded during 1993 had recurrence intervals of greater than 100 years. However, because of the natural and man-made changes in the flood region, some sites had less-than-record peak discharges (Parret, et al., 1993). The storage of large volumes of water in reservoirs significantly reduced the peak flow and flood damages downstream from the dams (Southard, 1993).

Following the 1993 Midwest flood, President Clinton established the Scientific Assessment and Strategy Team (SAST) on November 24, 1993, to study the effects of the flood and to make recommendations about future flood preparedness. The SAST joined the Interagency Floodplain Management Review Committee (FMRC) on January 10, 1994 (FMRC, 1994). As part of this effort, the SAST project identified a need for a daily water balance of the flooded area to determine how much water fell and how quickly it moved through the landscape.

There were two significant policy issues resulting from the flood: (1) how did the flood volume and velocity of flow increase by land use changes associated with agricultural development in the Midwest, including extensive drainage of wetlands; and (2) what plan should be adopted for restoration of failed levee systems. The first of these questions is hydrologic, the second, hydraulic. The hydraulic issues were addressed by the SAST project and related efforts by modeling the motion of water through the main tributaries of the Mississippi and Missouri Rivers where the major levee failures occurred.

The hydrologic questions were not so readily addressed because of the huge region affected by the flood, some 700,000 km^2 in area. Flood hydrology models are normally applied to regions 100 to 1,000 times smaller than this area. Thus, the need for the present study arose – to model the movement of water through the landscape of the SAST study area by constructing a daily water balance in a series of subwatersheds in the flooded area.

A USGS WEB site designated for SAST is located at: http://edcwww2.cr.usgs.gov/sast-home.html . Figure 1.1 shows the location and the extent of the SAST study area. This region covers all of the UMRB above St. Louis and that portion of the Missouri Basin whose drainage enters the Missouri River by watershed

(Missouri, Platte, Kansas, Osage, and Gasconade Rivers). The contribution of the remainder of the Missouri Basin was accounted for by using gauged data from tributary flows at the border of the study region.

The goal of this project was to calculate the daily water balance for the SAST region for 1993. A Geographic Information System (GIS) was used to determine the balance. GIS offers a technology to formulate more objective and consistent methods to synthesize collected data and to assess water quality and quantity over large areas (Maidment, 1996). The spatial resolution of the SAST region was defined by the location of discharge gauging stations as well as the completeness and quality of the discharge record. The preliminary analysis was performed using daily discharge values recorded at 261 USGS stations from 01/01/1993 to 09/30/1993. The final water balance was estimated for 132 watersheds defined by the stations that have a complete discharge record for all days of 1993. The cumulative storage values were then spatially averaged over 4, 6, and 8 digit hydrologic units (HUC) to provide an alternative way of viewing the water balance.

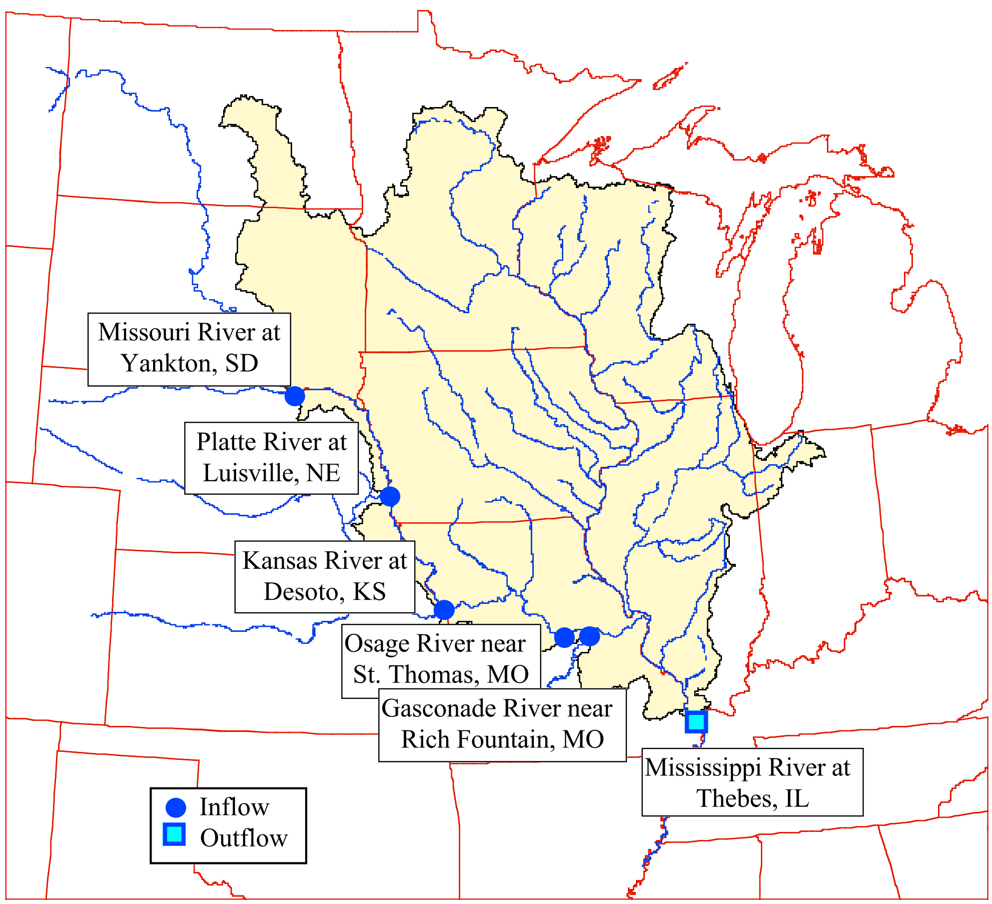


Figure 1.1 Location and extent of the SAST region.

The following temporal resolutions were utilized: (1) daily average values of precipitation depth, (2) daily average values of streamflow discharge, and (3) monthly values of evaporation taken as constant for each day of the month. Detailed information about the data used in this research is discussed in the following sections.

2. Data and Computer Software Description

The data used in this study are divided into two categories. The first category contains data used to calculate the water balance:

- Precipitation record
- Discharge record
- Evaporation data

The other category is composed of the data describing the land surface:

- Digital Elevation Model
- Digital map of rivers, RF1
- Digital map of Hydrologic Units.

Arc/Info® and ArcView®, registered trademarks of Environmental Systems Research Institute, Inc., Redlands, California, constitute the primary GIS software. The data and the software are described in the following sections.

2.1 Precipitation data

Climate station locations and daily precipitation depth for 17,000 National Climatic Data Center (NCDC) stations are available from a CD-ROM set published by Hydrosphere Data Products, Inc. (Hydrosphere, 1994). For the purposes of this research, the 1993 daily precipitation depth measured at 1078 stations in the SAST region and within a 50 km buffer outside of the region were exported from Hydrosphere's CD-ROMs in ASCII (text) format.

2.2 Discharge record

The gauging station locations, drainage areas, and the daily river discharge for 31,000 USGS gauging stations are available on a CD-ROM set also published by Hydrosphere Data Products, Inc. (Hydrosphere, 1994). These data originate from the USGS WATSTORE system (daily and peak values). Daily flow rate measured at 261 USGS stations during the 1993 and 1994 water years were exported from the CD-ROMs. These stations had complete records for the water years.

2.3 Evaporation data

Monthly potential evaporation depth values for the SAST region by climate division, in ASCII format (file : `/pub/SAST/cde93.dat`), were downloaded from the USGS anonymous FTP (file transfer protocol) site: `ftp://srv1rvares.er.usgs.gov`. The map of National Oceanic and Atmospheric Administration (NOAA) climate divisions (each state is divided into nine climate zones) was obtained from the National Climatic Data Center. An Arc/Info coverage of these climate divisions is available via the Internet at http://nsdi.usgs.gov/nsdi/wais/water/climate_div.HTML.

2.4 Digital Elevation Model

Elevation data form the terrain model upon which basic hydrologic processes are represented. In this research, a Digital Elevation Model (DEM) is used not only to determine the water flow paths, but also to divide the study region into gauged zones, to determine the "flow" topology between the zones, and to delineate the stream network. The 500 m (15 second) DEM is utilized in this research. It was created by resampling 1-Degree DEM files and was released by the USGS on CD-ROM (Rea and Cederstrand, 1995).

A Digital Elevation Model (DEM) consists of a 2-D array of ground positions at regularly spaced intervals. One-Degree DEM files (3x3 arc-second data spacing) are available for the entire U.S. The majority of the 1-Degree DEMs were produced by the Defense Mapping Agency (DMA) either from cartographic sources (1:24,000 scale through 1:250,000 scale maps) or from photographic sources. Some of these DEMs were created by regridding 7.5-minute and 30-minute DEMs. The compressed (and uncompressed) DEM files are available via the Internet at ftp://edcftp.cr.usgs.gov/pub/data/DEM/250/. Users can also select DEMs by clicking on a map of the U.S. at the following Internet site: http://edcwww.cr.usgs.gov/glis/hyper/guide/1_dgr_demfig/index1m.html .

2.5 Digital map of rivers, RF1

A Reach File 1 (RF1) is a representation of streams in the conterminous United States at a scale of approximately 1:500,000. The original file was prepared by the U.S. Environmental Protection Agency. In 1994 it was translated from a mainframe computer into Arc/Info, and it is available in the Arc/Info export format via the Internet site: http://nsdi.usgs.gov/nsdi/wais/water/rf1.HTML . Because of the size of the entire RF1 data set (its Arc/Info export file occupies 57 MB), it is also available in 18 separate files, each covering a 2-digit hydrologic unit code or water resources region.

In this research, the RF1 was used to adjust the DEM in order to ensure that the major streams delineated from the DEM were compatible with the RF1 streams. A detailed description of the DEM adjustment process is presented in Section 4.4.1.

2.6 Hydrologic Units

Hydrologic Unit Codes are a hierarchical watershed system developed by the USGS that divides the U.S. and the Caribbean into 21 major regions (2-digit HUC), 222 subregions (4-digit HUC), 352 accounting units (6-digit HUC), and 2,150 cataloging units (8-digit HUC). This system delineates river basins having drainage areas usually greater than 700 mi^2. Digital maps of the HUCs are available in the Arc/Info export file format via the Internet: http//nsdi.usgs.gov/nsdi/wais/water/huc2m.HTML .

In this research, the digital maps of HUCs were used to correct the boundaries of the watersheds as they were delineated from the DEM (this procedure is discussed in Section 4.4.2) and to calculate averages over the HUC regions of spatially distributed - daily cumulative water storage values.

2.7 GIS software

Arc/Info and ArcView constitute the GIS software used in this research. Arc/Info is a spatial analysis system which represents spatial data in separate layers and provides operators for manipulating these data. The software is available for workstations and PCs. Arc/Info contains three basic spatial primitives for vector data: points, lines or arcs, and polygons. The software also supports three derived data structures: grids (a rectangular mesh of points), triangulated irregular networks (a set of points connected by triangles), and networks (a set of connected arcs with assigned flow properties). Each spatial primitive (point, line, and polygon) can have an associated record in the database called an Info file. The fields of this record contain user-specified descriptive attributes, such as area, length, category, name, etc. The one-to-one correspondence between spatial features (point, line or polygon) and data records (Info) is the basis of the Arc/Info data model.

Besides the Arc/Info core system, two Arc/Info processors are extensively used in this research: GRID and TABLES. GRID manipulates maps in raster grid format, while TABLES is used to handle the data stored in the following four attribute tables:

1) point attribute table (PAT) an Info table of a point coverage
2) arc attribute table (AAT), an Info table of an arc coverage
3) polygon attribute table (PAT), an Info table of a polygon coverage
4) value attribute table (VAT), an Info table associated with a grid.

The Arc/Info macro language (AML) enables the automation of complex or repeated tasks, and it was used extensively in this study.

ArcView is a GIS software package completely operated from a graphical user interface. Although it can perform only simple spatial operations on maps in vector format, it has very powerful and convenient tools to manage attribute tables. Avenue, an object oriented script language within ArcView, lets the user build complex GIS applications. ArcView is available for workstations and for personal computers (ESRI, 1995). ArcView version 2.1 was used in this research.

3. Methodology

In this section a description of the core methodology used for the water balance calculation is presented. Section 3.1 explains the division of the SAST region into modeling units which have been named gauged zones, and Section 3.2 contains mathematical descriptions of the water balance. A detailed description of the methodology used to construct a GIS database of water balance components, as well as a discussion of GIS techniques used to calculate the balance are presented together with procedures in Section 4.

3.1 Gauged zones

The SAST region is divided into gauged zones defined by the location of USGS gauging stations. A first order gauged zone is determined by one gauging station, the zone outlet. Higher order zones are defined by one or more stations through which river water flows into a zone, and one station which is the zone outlet. Figure 3.1 shows an example of the gauged zones.

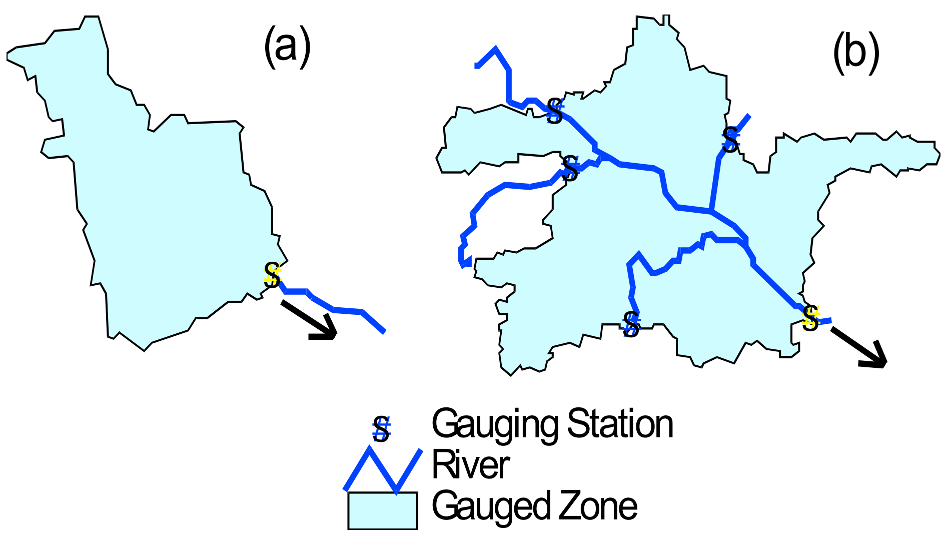


Figure 3.1 Example of gauged zones; (a) first order zone - one outlet no inflow points, (b) zone with multiple inflow points.

For each gauged zone, the water storage (depth) is calculated. This value is then used to calculate the storage in each 4, 6, and 8-digit HUC.

3.2 Mathematical description

The water balance for each gauged zone is described by the following equation:

$$\frac{dV_i}{dt} = I_i - O_i \tag{3.1}$$

where: V is the volume of water stored in the i-th gauged zone; t is the time index, i is the zone index, I is the rate of inflow that enters zone i, and O is the rate of outflow from the i-th zone.

The water balance is calculated for each day of the year 1993, i.e. $\Delta t = 1$ day. Two sources of inflow are considered: precipitation and river inflow, and two types of outflow are assumed: evaporation and river outflow. Thus, Equation (3.1) can be integrated through a time interval Δt:

$$\Delta y_i = P_i - E_i + \frac{\Delta t}{A_i}\left[\sum Q_{in,i} - Q_{out,i}\right] \tag{3.2}$$

where: Δy is the change in storage in zone i; P is the average precipitation depth in zone i over time step Δt; E is the evaporation; ΣQ_{in} is the total river inflow into zone i; Q_{out} is the river outflow from zone i; and A is i-th zone area.

The cumulative water storage for each day of 1993 is calculated by summation of the incremental storages Δy:

$$S_{i,d} = \sum_{k=1}^{d} \Delta y_{i,k} \tag{3.3}$$

where: $S_{i,d}$ is the storage in the gauged zone i, on the day d of the year 1993; i is a gauged zone index; d is a day of the year 1993; and k is a day index.

The water storage on December 31, 1993 is assumed to be the same as the water storage on January 1, 1993. Two methods of water balance correction are utilized in this research. In the first method, an average coefficient ($\alpha = 0.775$) is used to correct the evaporation depth in all gauged zones. The following equation is applied to approximate the water storage:

$$S_{i,d} = \sum_{k=1}^{d} \left(P_i - \alpha E_i + \Sigma Q_{in,i} - Q_{out,i}\right) \tag{3.4}$$

where α is the evaporation correction factor. Here, this factor is estimated considering the SAST region as one big gauged zone. Corrections are then made according to the following equation:

$$\hat{S}_{i,d} = S_{i,d} - \frac{d}{365} S_{i,365} \tag{3.5}$$

where *d* is the day of 1993 (1 for January 1, 365 for December 31). The value of storage calculated for the last day of 1993, $S_{i,365}$ is the amount of water by which the water balance did not close.

In the other method of water balance calculation, the evaporation correction factor is calculated for each individual gaged zone . The following equation describes this method:

$$\hat{S}_{i,d} = \sum_{k=1}^{d} \left(P_i - \alpha_i E_i + \Sigma Q_{in,i} - Q_{out,i} \right) \tag{3.6}$$

The storage in the 4 -, 6 -, and 8-digit HUCs is calculated by averaging the storages estimated in gauged zones within the HUC areas.

4. Procedures

4.1 GIS database of daily precipitation

The precipitation and streamflow daily values were extracted from Hydrosphere CD-ROMs. The following sections describe the creation of the precipitation database only, since the procedures for building the streamflow database were similar to those for the precipitation database.

The GIS database of precipitation records is created in five steps:

1) The data are extracted from Hydrosphere CD-ROMs in ASCII format
2) The ASCII files are imported into an Arc/Info database format (INFO file);
3) An ASCII file containing station ID, latitude, and longitude is created;
4) A point coverage of stations is built
5) The INFO file that contains the station description and the precipitation record is merged (joined) with the PAT (point attribute table) of the stations coverage.

4.1.1 Extracting data from the Hydrosphere CD-ROM

The following steps were performed to select and extract daily precipitation depth for all days of 1993. Two selection criteria were used: state name and latitude/longitude. The steps required to select and extract the daily precipitation depth for all days of 1993 are listed below:

```
Menu
Select  State
        Latitude/Longitude
Mark    All Stations
Export  Export marked stations
        Precipitation total [in]
        Format: delimited
        Data for year 1993, add ->
```

The names of the states and the latitude and longitude that were utilized in the data extraction process are listed in Table 4.1.

Table 4.1 Selection of the climate stations from the Hydrosphere CD-ROMs.

State.	Abr.	FIPS	Latitude		Longitude	
			Min	Max	Min	Max
North Dakota	ND	38	45:00	49:00	96:00	101:00
South Dakota	SD	46	42:00	-	96:00	100:30
Nebraska	NE	31	39:00	-	95:00	99:30
Kansas	KS	20	38:00	-	94:00	97:00
Minnesota	MN	27	43:00	49:00	91:00	-
Iowa	IA	19	40:00	-	90:00	-
Missouri	MO	29	36:00	-	89:00	-
Wisconsin	WI	55	42:00	-	87:00	-
Illinois	IL	17	36:00	-	87:00	-
Michigan	MI	26	41:00	-	85:10	-
Indiana	IN	18	40:00	-	85:10	-
Kentucky	KY	21	36:00	-	88:00	-

A total of 1509 records were extracted. An example of one record for the station GALESBURG is presented below. It must be noted, that all values for a given station are stored in one line.

File 4.1 Precipitation file: example of precipitation data extracted from the Hydrosphere CD-ROM, a record for Galesburg, IL, 1993:

```
3320,GALESBURG,17,3,6,1948,10,1994,47,98.421,KNOX,770.000,4057,09023,9,0
,IN,PRCP,1993,JAN,2.130,0.073,0.640,0.000,0.000,0.000,0.230,0.460,0.300,
0.000,0.000,0.100,0.000,0.160,9998.000,9998.000,0.220,0.010,0.000,0.000,
0.000,0.000,0.000,0.000,0.640,0.010,0.000,0.000,0.000,0.000,0.000,0.000,
0.000,0.000,0.000,FEB,1.330,0.055,0.400,0.000,0.000,0.000,0.000,0.000,0.
000,0.000,0.000,0.000,0.000,9998.000,0.000,0.390,0.050,0.030,0.000,0.100
,9998.000,0.000,0.000,0.000,0.400,0.110,9998.000,0.000,9998.000,0.250,0.
000,0.000,9999.000,9999.000,9999.000,MAR,3.390,0.126,1.210,0.000,0.000,0
.000,0.280,0.680,0.010,0.000,0.000,0.000,0.000,0.090,0.040,9998.000,9998
.000,0.000,0.000,0.160,0.130,0.000,0.050,0.110,9998.000,0.420,1.210,0.02
0,0.020,9998.000,0.000,0.000,0.000,0.000,0.170,APR,4.490,0.166,0.940,0.0
00,0.290,0.020,0.000,0.000,0.000,9998.000,0.000,0.380,0.260,0.000,0.000,
0.000,0.000,0.450,0.940,0.750,0.160,9998.000,0.000,0.690,0.190,0.000,0.0
00,0.000,0.000,0.000,0.000,9998.000,0.220,0.140,9999.000,MAY,2.940,0.098
,0.860,0.000,0.060,0.040,0.130,0.350,0.230,0.000,0.170,0.000,0.000,0.000
,0.030,0.320,0.000,0.000,9998.000,0.020,0.000,0.000,0.000,0.000,0.000,0.
000,0.860,0.090,0.000,0.000,0.000,0.060,0.110,0.010,0.460,JUN,5.630,0.20
1,1.580,0.000,0.000,0.580,0.130,0.120,0.670,0.000,9998.000,0.230,0.300,0
.000,0.000,0.010,0.000,0.000,0.000,0.000,0.000,0.160,0.100,0.730,0.000,0
.000,0.000,0.000,1.580,0.000,0.000,9998.000,0.180,0.840,9999.000,JUL,12.
120,0.433,6.130,0.000,0.530,0.090,0.040,0.000,0.000,0.260,0.000,0.240,0.
000,0.350,0.150,0.120,0.000,0.480,9998.000,0.010,0.420,0.230,9998.000,0.
000,0.000,0.060,2.440,6.130,0.420,9998.000,0.000,0.150,0.000,0.000,0.000
,AUG,9.730,0.347,3.070,0.000,0.360,0.000,0.000,0.060,0.000,0.170,0.000,0
.000,0.000,3.070,9998.000,0.240,0.110,0.000,0.430,1.760,0.560,0.000,1.00
0,0.000,0.000,0.000,0.760,9998.000,0.000,0.000,0.000,9998.000,0.300,0.00
0,0.910,SEP,4.580,0.170,1.530,0.000,9998.000,0.300,0.290,0.000,0.000,0.7
20,0.000,0.050,0.000,0.000,0.000,0.000,0.000,1.530,0.340,0.010,0.000,0.0
00,0.010,0.010,0.030,9998.000,9998.000,0.000,0.000,1.240,0.050,0.000,0.0
```

```
00,0.000,9999.000,OCT,0.990,0.033,0.360,0.000,0.000,0.000,0.000,0.000,0.
000,0.000,0.000,0.000,0.360,9998.000,0.000,0.000,0.000,0.000,0.000,0.260
,0.310,0.000,0.050,0.000,0.010,0.000,0.000,0.000,0.000,0.000,0.000,0.000
,0.000,0.000,0.000,NOV,1.580,0.066,0.580,0.000,0.000,0.000,0.050,9998.00
0,9998.000,9998.000,9998.000,0.000,0.000,0.000,0.000,0.000,0.580,0.010,0
.220,0.000,0.050,9998.000,0.000,0.000,0.000,0.000,0.000,0.070,0.350,0.22
0,9998.000,0.030,0.000,0.000,9999.000,DEC,1.500,0.060,0.320,0.000,0.000,
0.310,0.000,0.320,0.000,0.040,0.000,0.000,0.000,9998.000,0.000,0.000,999
8.000,0.320,0.130,9998.000,0.020,0.180,0.060,9998.000,0.000,9998.000,999
8.000,0.000,0.070,0.050,0.000,0.000,0.000,0.000,0.000,ANN,50.410,0.154,6
.130,0.000,9999.000,9999.000,9999.000,9999.000,9999.000,9999.000,9999.00
0,9999.000,9999.000,9999.000,9999.000,9999.000,9999.000,9999.000,9999.00
0,9999.000,9999.000,9999.000,9999.000,9999.000,9999.000,9999.000,9999.00
0,9999.000,9999.000,9999.000,9999.000,9999.000,9999.000,9999.000,9999.00
0
```

The data from each state were exported into one file and then all files were combined into one file (concatenated) by the UNIX command `cat`:

```
cat  ia.txt il.txt in.txt ks.txt ky.txt mi.txt mn.txt mo.txt nd.txt
ne.txt sd.txt wi.txt  > total.txt
```

The GNU programming utility `gawk` was used to replace all values that equal 9999 (a missing observation) with -1, and all values that equal 9998 (a trace amount of precipitation) with 0.001. This meant that the trace precipitation was assumed to be 0.001 inches. `Gawk` was used because the original `awk` program had problems with such long lines:

```
gawk '{gsub(/9999/,"-1"); print}' abcin > abcout
```

4.1.2 Converting precipitation data into Arc/Info format

The Arc/Info INFO file of precipitation data was created utilizing the Arc/Info module TABLES and ArcView GIS. Before importing data from an ASCII file, TABLES requires a definition of all items (name, width, precision, type etc.). To import the ASCII file using ArcView, the first line of the ASCII data must contain the names of all items. A header line was created in a text editor and then added to the ASCII precipitation database by the UNIX `cat` command.

File 4.2 Header file: example of the header line for precipitation data:

id,stname,state,division,startm,startyr,endm,endyr,reccnt,percent,county,datum,latitude,longitude,mcritday,
mcritmth,units,parameter,year,jan,jan_tot,jan_mean,jan_max,jan_min,p930101,p930102,p930103,p930104
,p930105,p930106,p930107,p930108,p930109,p930110,p930111,p930112,p930113,p930114,p930115,p9
30116,p930117,p930118,p930119,p930120,p930121,p930122,p930123,p930124,p930125,p930126,p930
127,p930128,p930129,p930130,p930131,feb,feb_tot,feb_mean,feb_max,feb_min,p930201,p930202,p9302
03,p930204,p930205,...

. . .

...p931217,p931218,p931219,p931220,p931221,p931222,p931223,p931224,p931225,p931226,p
931227,p931228,p931229,p931230,p931231,ann,ann_tot,ann_mean,ann_max,ann_min,p931301,p931302,

p931303,p931304,p931305,p931306,p931307,p931308,p931309,p931310,p931311,p931312,p931313,p931314,p931315,p931316,p931317,p931318,p931319,p931320,p931321,p931322,p931323,p931324,p931325,p931326,p931327,p931328,p931329,p931330,p931331

where: p930101 ... p931231 indicate days of the year 1993 in format `pyymmdd` (p - states with precipitation record, yy - year, mm - month of the year, and dd - day of the month). In the example shown above, the value mm = 13 (as in p93*13*01) indicates average annual values for 1993. The other names (id, stname, state, division, etc.) are used after Hydrosphere's notation (Hydrosphere, 1994).

The file was opened by ArcView and then saved as an Arc/Info INFO file. Since this INFO file had to be joined with the PAT (Point Attribute Table) of the climate stations point coverage, an item that contains unique station ID for the U.S. was added using Arc/Info command `additem` (Line 1, Listing 4.1). The ID was created in TABLES by multiplying the station FIPS code (item `state`) by 1,000,000 and adding the published station ID (item `id`) to the result.

Listing 4.1 Adding an item that contains station ID

```
1: additem totalinf totalinf st_id 12 12 I
2: Tables:
3: select totalinf
4: calculate st_id = state * 100000 + id
```

4.1.3 Location of stations (latitude and longitude)

The data exported from the Hydrosphere CD-ROMs (Hydrosphere, 1994) contains a description of the climate stations including latitude and longitude. Since the coordinates are in degrees and minutes they need to be converted into decimal degrees. Listing 2.2 shows an example of the ASCII file that contains station ID, latitude, and longitude (in decimal seconds). Note that the station `id` is calculated from the state FIPS number and the NCDC number, i.e.

`st_id = state * 100000 + id` (21 is the FIPS code for Kentucky)

Listing 4.2 Example of a file containing station IDs and coordinates

```
2100402,-320280,132780
2101727,-320820,132360
2103223,-317760,133260
2103295,-316800,132840
2104967,-319800,133080
2105150,-317040,134400
2105233,-319080,132420
2105235,-319200,132660
2105694,-317940,131820
2106110,-319560,133440
```

```
2106117,-318960,133560
END
```

4.1.4 Point coverage of the climate stations

Listing 4.3 shows the Arc/Info dialog used to create a point coverage (`precip`) from the lat/long coordinates stored in the ASCII file `xy.csv`.

Listing 4.3 Creating a point coverage of climate stations from latitude/longitude coordinates

```
Arc: generate xxxgeo
Generate: input xy.csv
Generate: points
Generate: q
Arc: build xxxgeo point
```

To make the point coverage compatible with other maps used in this study, the map was projected into the Albers projection as follows (Listing 4.4). The projection parameters used are standard ones for USGS maps except that the Albers projection rather than the Lambert Conformal Conic projection was used to preserve correct surface area throughout the study region.

Listing 4.4 Projecting the point coverage of NCDC climate stations from the Geographic "projection" into Albers projection coordinates

```
Arc: project cover xxxgeo xxx
Input
Projection geographic
units ds
Parameters
output
Projection ALBERS
Zunits NO
Units METERS
 Spheroid GRS1980
 Xshift 0.0000000000
 Yshift 0.0000000000
 Parameters
 29 30 0.000 /* 1st standard parallel
 45 30 0.000 /* 2nd standard parallel
 -96 0 0.000 /* central meridian
 23 0 0.000 /* latitude of projection's origin
 0.00000 /* false easting (meters)
 0.00000 /* false northing (meters)
 end
```

4.1.5 The daily precipitation database

A GIS database contains both spatial and descriptive information. To create the GIS database of daily precipitation record the precipitation INFO file was joined with the PAT of the climate stations coverage. This was performed in Arc/Info using the `joinitem` command which requires the creation of a common item name between joined data files. The join item `st_id` was added in Arc/Info (using the `additem` command, line 1, Listing 4.5) and in TABLES the values from item `xxx-id` were copied into item `st_id` (line 4, Listing 4.5). Note that in this procedure, station ID (`st_id`) is not an NCDC ID, but has been calculated by multiplying a state's FIPS * 10000 + NCDC's station ID.

Listing 4.5 Joining the PAT of point coverage with the Info file of precipitation depth

```
1:additem xxx.pat xxx.pat st_id 12 12 I
2:Tables:
3:select xxx.pat
4:calculate st_id = xxx-id
5:q
6:Usage: JOINITEM <in_info_file> <join_info_file> <out_info_file>
   <relate_item> <start_item> {LINEAR | ORDERED | LINK}
7:joinitem xxx.pat totalinf xxx.pat st_id
```

where: `xx.pat` is the point attribute table of the climate station coverage and `totalinf` is the Info file with the precipitation record. Figure 4.1 shows the map of 1509 climate stations that was extracted from the Hydrosphere CD-ROM.

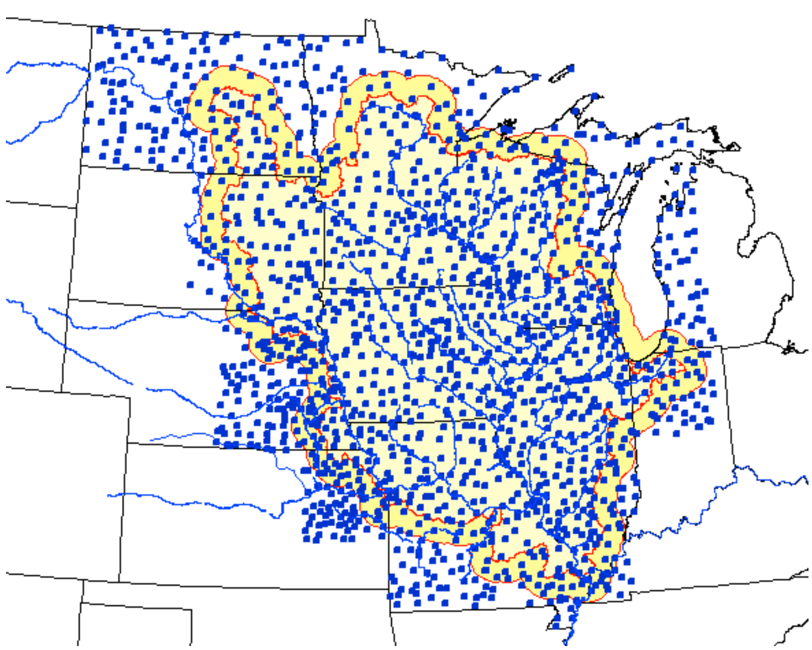


Figure 4.1 Precipitation stations extracted from the Hydrosphere CD-ROM.

To reduce the size of the digital map, only the stations that are inside the SAST region and within a 50 km buffer outside the SAST region were selected for further analysis. Listing 4.6 presents the application of the Arc/Info `clip` command. Coverage `buffer50` is a map of the SAST study area with a 50 km buffer zone. The name of the new point coverage of the precipitation stations is `prec50`. Figure 4.2 presents 1078 NCDC stations selected for spatial redistribution of precipitation depth in the SAST region

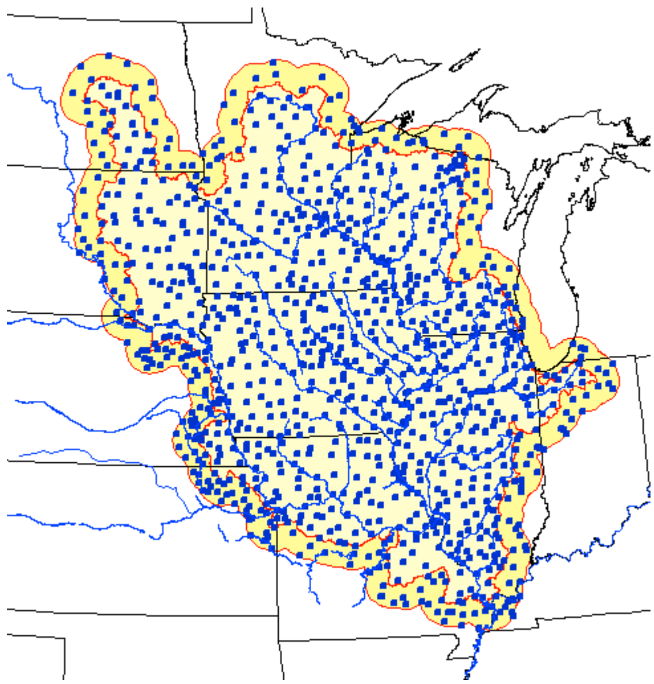


Figure 4.2 Selected NCDC stations within the SAST region and a 50 km-wide buffer zone.

Listing 4.6 Selecting stations within SAST extended by a 50 km buffer zone.

```
Usage: CLIP <in_cover> <clip_cover> <out_cover> {POLY | LINE | POINT
   | NET | LINK | RAW} {fuzzy_tolerance}
clip xxx ~/flood/data/buffer50 prec50 point
```

Listing 4.7 shows a few items from the point attribute table of `prec50` coverage:

Listing 4.7 Selected items of `prec50.pat`.

COLUMN	ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC	ALTERNATE NAME	INDEXED?
1	AREA	4	12	F	3		-
5	PERIMETER	4	12	F	3		-
9	CODEC50#	4	5	B	-		-
13	CODEC50-ID	4	5	B	-		-
17	ST_ID	12	12	I	-		-
29	ID	4	4	I	-		-
33	STNAME	23	23	C	-		-
56	STATE	2	2	I	-		-
58	DIVISION	2	2	I	-		-
60	STARTM	2	2	I	-		-
62	STARTYR	4	4	I	-		-
66	ENDM	2	2	I	-		-
68	ENDYR	4	4	I	-		-
72	RECCNT	3	3	I	-		-
75	PERCENT	6	6	N	3		-
81	COUNTY	17	17	C	-		-
98	DATUM	8	8	N	3		-
106	LATITUDE	4	4	I	-		-
110	LONGITUDE	5	5	I	-		-
115	MCRITDAY	1	1	N	-		-
116	MCRITMTH	1	1	N	-		-
117	UNITS	2	2	C	-		-
119	PARAMETER	4	4	C	-		-
123	YEAR	4	4	I	-		-
127	JAN	3	3	C	-		-
130	JAN_TOT	8	8	N	3		-
138	JAN_MEAN	8	8	N	3		-
146	JAN_MAX	8	8	N	3		-
154	JAN_MIN	8	8	N	3		-
162	P930101	8	8	N	3		-
170	P930102	8	8	N	3		-
178	P930103	8	8	N	3		-
186	P930104	8	8	N	3		-
194	P930105	8	8	N	3		-
202	P930106	8	8	N	3		-
210	P930107	8	8	N	3		-

4.2 Spatial distribution of precipitation depth

A grid of distributed precipitation depth has been created for each day's precipitation directly from the gauge precipitation station map. The inverse distance weighting procedure (IDW) has been applied. To make the calculations shorter and to save disk space, a 4000 x 4000 m cell size was assumed for the precipitation grid.

Listing 4.8 Creating grids of daily precipitation depth

```
/* -------------------------------------------------------------------------
/* PRECIPITATION REDISTRIBUTION
/* -------------------------------------------------------------------------
/*    input
&s data = $HOME/flood/precip/poinmap/prec50 /* point coverage
&s wgrid = $HOME/flood/dem/buf50g /grid window sample
grid
&r rainsast 5 1 12 31 ~/flood/dem/buf50g 4000 ~/flood/precip/poinmap/prec50 YES
```

```
/* &run rainsast 4 1 4 31 %wgrid% 4000 %data% YES
q
&return /* return from this AML
/* ------------------------------------------------------------------------
```

The procedure `rainsast.aml` performs all calculations. It sets the cell size to a user-supplied value (in this example, the value is 4000), sets the size of the new grid to the size of `buf50g` (a grid that serves as a standard for the size of new grids), and calculates a new grid. This process is shown in Listing 4.9.

Listing 4.9 Creating the precipitation grid by the inverse distance weighting method

```
setcell 4000
setwindow buf50g
p930408 = idw ( prec50 , p930408 )
```

Since the procedure described above must be executed for each day of 1993, it has been included into the Arc Macro Language (AML) `&DO` command that repeats calculations for each day of the specified time period, i.e., from day 1 of month `%fm%` to day 31 of month `%tm%`. An example of the `&DO` block is presented in Listing 4.10.

Listing 4.10 Application of the `&DO` command to repeat action for each day and each month of 1993

```
&DO mt = %fm% &to %tm%
&if %mt% lt 10 &then
&sv nitem1 = [subst %nitem0% m %mt% ]
&else
&sv nitem1 = [subst %nitem0% 0m %mt% ]
&DO dy = 1 &to 31
&s ab = [calc %mt% = %fm%] AND [calc %dy% lt %fd%]
&s bb = [calc %mt% = %tm%] AND [calc %dy% gt %td%]
&s cc = %ab% OR %bb%
&IF NOT %cc% &THEN
&do
&if %dy% lt 10 &then
&sv nitem = [subst %nitem1% d %dy% ]
&else
&sv nitem = [subst %nitem1% 0d %dy% ]
&type %nitem%
/* check if the item exists
&s iexists = [iteminfo %xdat% -point %nitem% -exists]

&if %iexists% &then
&do
&sv selec = res %nitem% %klm% 0
&type selecting stations %selec% [date -vfull]

arc reselect %xdat% xxxxx1 point
%selec%
~
```

```
n
n
arc build xxxxx1 point
%nitem% = int ( %cfac% * idw ( xxxxx1, %nitem% ) )
kill xxxxx1 all
&end
&end
&end
&end
```

To include all available measurements of precipitation depth in the spatial redistribution process, all stations that have a measurement for the processing day have been used. For each day, station selection was performed (Arc/Info command `reselect`) and then the grids of spatial distribution of precipitation depth were calculated (IDW procedure):

Listing 4.11 Example of the AML that selects precipitation stations that have a complete record on June 8, 1993 and creates a grid of precipitation depth (adopted from `RAINSAST.AML`)

```
arc reselect prec50 xxxxx1 point
res p930608 ge 0
~
n
n
arc build xxxxx1 point
p930608 = int (25400 * idw ( xxxxx1, p930608 ) )
kill xxxxx1 all
```

In Listing 4.11, the number 25,400 is the unit conversion factor (1 inch = 25.4 mm). Millimeters are multiplied by 1,000 to preserve accuracy when converted to integers. To get the results back to mm, the grids need to be divided by 1,000. Figure 4.3 shows an example of the precipitation grid (precipitation spatially distributed for 07/19/93).

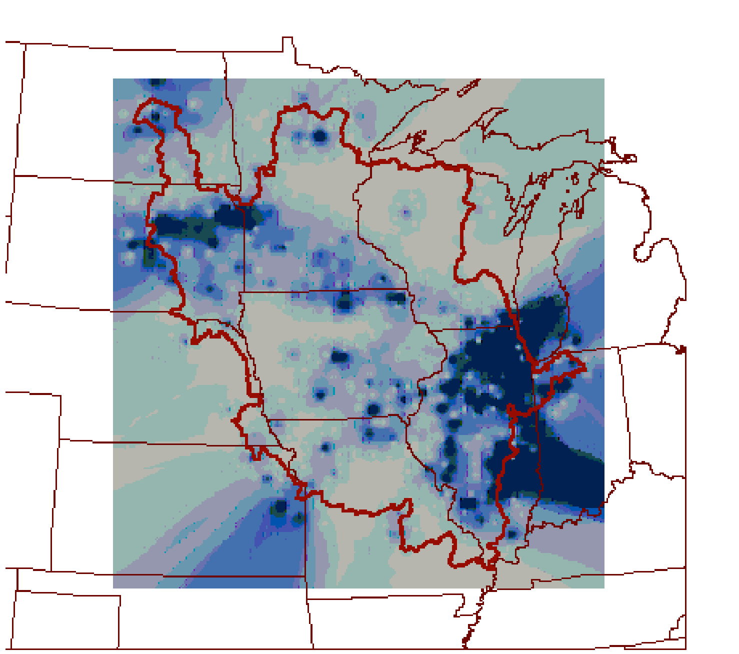


Figure 4.3 Precipitation depth in the SAST region interpolated for July 19, 1993.

4.3 Grids of monthly evaporation

4.3.1 Potential evaporation data

Grids of monthly evaporation were constructed using the potential evaporation data downloaded from the anonymous ftp site: srv1rvares.er.usgs.gov/pub/SAST/ cde93.dat. This data file was converted into a comma delimited format, the column `units` was added, and the file was renamed `ev1.txt`.

The Arc/Info coverage of the U.S. divided into climate divisions was downloaded from http://nsdi.usgs.gov/nsdi/wais/water/climate_div.HTML . The divisions applied for the SAST evaporation estimates are identified by a different color than the other US climate divisions (Figure 4.4).

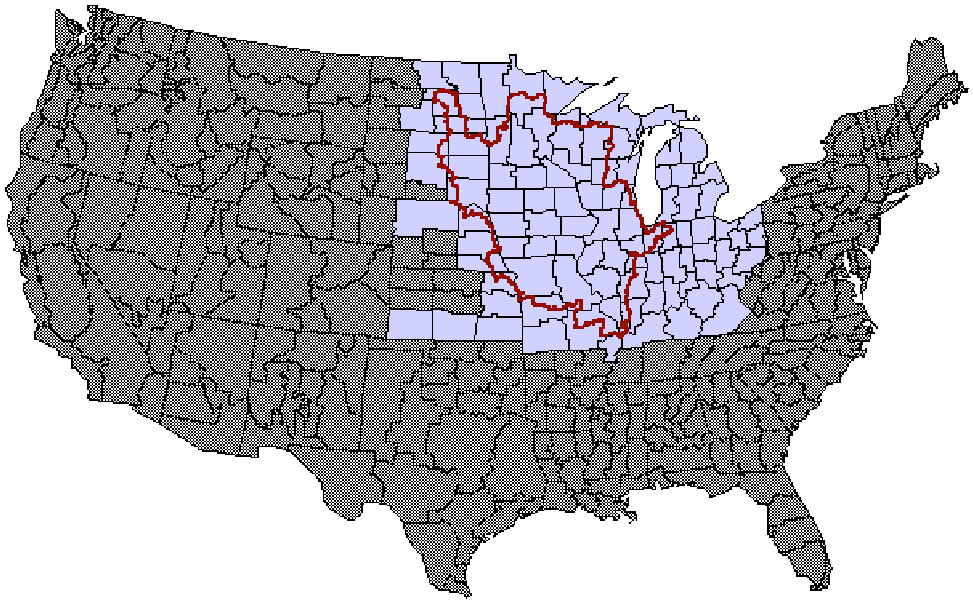


Figure 4.4 Climate divisions - coverage `clim_div`.

Two items were added to the attribute table `clim_div.pat`: `link_id` (string, four characters) and `atext` (string, two characters). Then, in TABLES, the climate division zone identification code was calculated:

```
calculate [atext] = [Div#]
calculate [link_id] = [St] + [atext]
```

where: `[St]` contains two letters identifying the state (e.g. IA for Iowa).

In this study, the climate division has been identified by two letters that specify the state and a number that defines the division within the state. For example, climate division 3 in Washington state has the identification code WA3. The data from file `cde93.dat` were incorporated into the polygon attribute table of the climate divisions coverage using the following steps:

1. Import data in text format into ArcView
2. Calculate the division identification codes
3. Link resulting table with `clim_div.pat`
4. Save the results in the attribute table, `clim_div.pat`

The climate divisions for which data were included in the file `cde93.dat` have been selected in the following way:

Listing 4.12 Selection of the SAST climate divisions

```
Arc: reselect ev2 ev4 poly
  Reselecting POLYGON features from EV2 to create EV4
Enter a logical expression. (Enter a blank line when finished)
>: res year eq 1993
>:
Do you wish to re-enter expression (Y/N)? n
Do you wish to enter another expression (Y/N)? n
  89 features out of 360 selected.
  Reselecting polygons...
Number of Polygons (Input,Output) = 360 91
Number of Arcs (Input,Output) = 1139 305
  Creating EV4.pat...
  Creating EV4.aat...
216 unique nodes built for /EXPORT/HOME2/PAWEL/FLOOD/EVAPOR/EV4
```

Figure 4.5 shows the climate divisions selected for evaporation analysis in the SAST region:

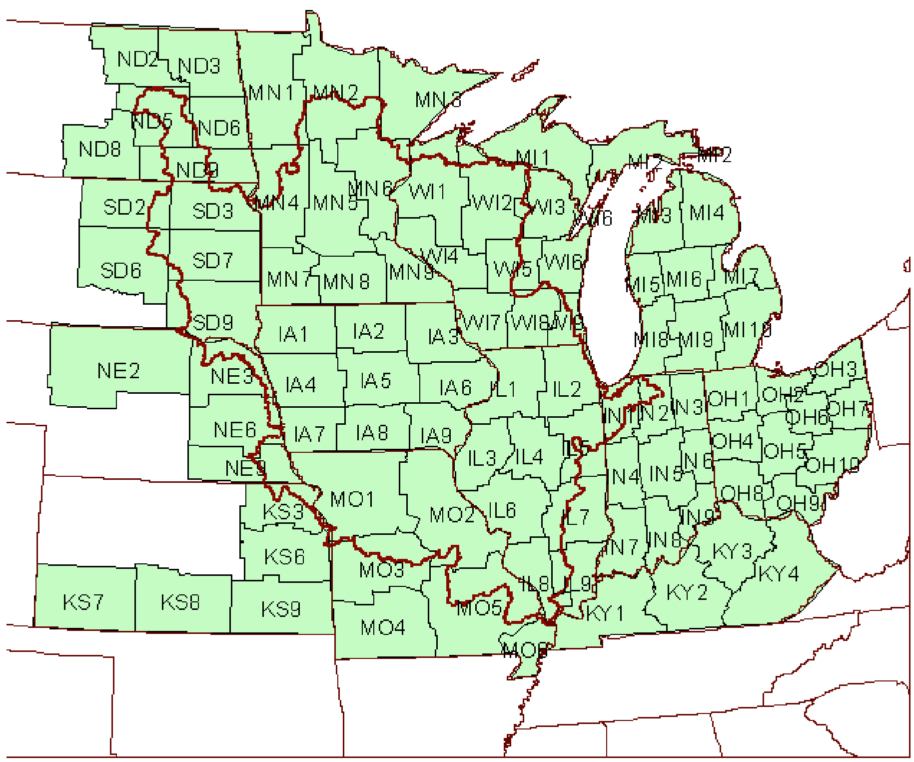


Figure 4.5 Climate divisions applied to SAST water balance estimation.

Since file `cde93.dat` did not contain data for all divisions that comprise the SAST region, the values for the following divisions were calculated from the evaporation published for neighboring divisions:

```
-----------------------------------------------------------
State Division [St] [St#] [Div#]
```

Kansas	North East	KS	14	3	
	East Central		14	6	
N. Dakota	Central	ND	32	5	
	North Central		32	2	(within 50 km buffer)
	South Central		32	8	(within 50 km buffer)
S. Dakota	North Central	SD	39	2	
Nebraska	North Central	NE	25	2	(within 50 km buffer)

Figure 4.6 shows map of the evaporation estimated for July 1993 by climate division (data from the file `cde93.dat`, units: inches)

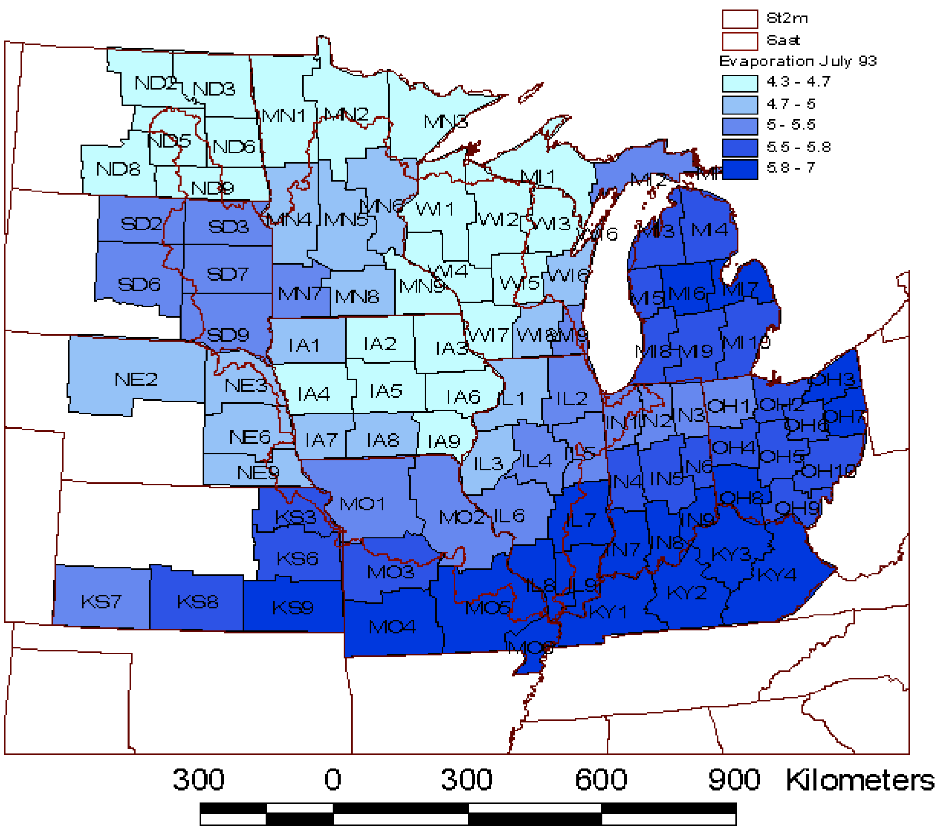


Figure 4.6 Evaporation in July 1993 (in inches; data from the USGS file `cde93.dat`).

4.3.2 Grids of the potential evaporation in the SAST region

For each month of 1993 a grid of evaporation data was created. The structure of these grids, i.e. the cell size and the grid extent, are the same as the structure of the precipitation grids (4 km x 4 km). Listing 4.13 shows the GRID dialog for converting the polygon coverage of evaporation into 12 grids.

Listing 4.13 Converting the vector map of the potential evaporation (`ev4`) into a grid.

```
setcell ../precip/gridprc/p930101
setwindow ../precip/gridprc/p930101
e930100 = int (25400 * polygrid (ev4 , jan ) )
e930200 = int (25400 * polygrid (ev4 , feb ) )
e930300 = int (25400 * polygrid (ev4 , mar ) )
e930400 = int (25400 * polygrid (ev4 , apr ) )
e930500 = int (25400 * polygrid (ev4 , may ) )
e930600 = int (25400 * polygrid (ev4 , jun ) )
e930700 = int (25400 * polygrid (ev4 , jul ) )
e930800 = int (25400 * polygrid (ev4 , aug ) )
e930900 = int (25400 * polygrid (ev4 , sep ) )
e931000 = int (25400 * polygrid (ev4 , oct ) )
e931100 = int (25400 * polygrid (ev4 , nov ) )
e931200 = int (25400 * polygrid (ev4 , dec ) )
e931300 = int (25400 * polygrid (ev4 , ann ) )
```

In Listing 4.13, the multiplication factor 25,400 converts the units in inches to micrometers (10^{-6} m). Micrometers were used to preserve the precision of values after they were converted into integers. Using integer grids saves a great deal of hard disk memory as compared to storing floating point grids.

4.4 Dividing the SAST region into gauged zones

The process of dividing a region into gauged zones (zones that are defined by the location of the USGS gauging stations) was a complex one. It can be divided into several sub-processes that are described in the following sections.

4.4.1 Creating a map of the flow direction and delineation of the stream network

The grid that describes the cell-to-cell flow (flowdirection) is crucial for all hydrologic analyses that are performed in a rasterized environment. Procedures such as stream and watershed boundary delineation, dividing a basin into modeling units, stream slope calculation, estimation of flow path length, and connection of hydrologic units, are examples of operations that cannot be performed without the map of flow direction. Moreover, the accuracy of all derived information depends on the precision of the flow direction grid. Therefore, an effort was made to improve the map that represents the flow paths. The RF1 digital 1:500 000 map of the U.S. rivers was selected as a basis for the spatial framework of the entire flow system. The following explanations support the application of a map of existing rivers to correct the flow system determined from the DEM:

- Since the location of a stream that is delineated from elevation data depends on the cell size, the stream networks determined from the DEMs of different resolutions are not compatible. Thus, the gauging stations linked to one gridded river system will not be in agreement with the other river systems derived from DEM grids of different cell sizes.
- The stream system constitutes the best framework for the spatial flow. It took hundreds and thousands of years for a river bed to develop into its current form. Since the river practically does not change, other information such as gauging station locations is related to the location of a stream reach.
- In flat regions, the streams delineated from the DEM tend to be straight lines, whereas, in reality the rivers have a tendency to meander. This causes an overestimation of the stream slope and an underestimation of the river length.
- RF1 represents the true river system, whereas, the stream network delineated from the map of elevations just approximates the same system.

The process of DEM adjustment was based on the conversion of the RF1 into the raster grid form and then increasing the elevation of all DEM cells that do not represent gridded RF1 cells by an arbitrary value (e.g., 10,000 m). This operation forced Arc/Info GRID to create a map of flow direction that was compatible with the flow system represented by the original vector map of rivers (RF1). The method of enhancing the flow system delineation has the following disadvantages:

- Since the elevations of the DEM are changed, the modified DEM can not be used for tasks other than the estimation of flow direction.
- The stream network has to be represented by a single line. A double line description of rivers can be utilized if the distance between the lines is smaller than the cell size.
- All existing loops have to be removed or opened to eliminate ambiguous flow paths.
- All lakes have to be converted into line representations or into polygons.
- The cell width applied in the adjustment process should be smaller than half of the distance between any streams in RF1. This is done to avoid connections of stream networks from different basins that may occur when converting from vector format to raster format.

If the river network does not fulfill the requirements listed above, some post-conversion editing of the gridded RF1 is necessary.

The following GRID commands were applied to specify the cell size and the map extent of the rasterized RF1:

```
setcell stdem
setwindow stdem
```

where `stdem` is the DEM.

The portion of the RF1 map that represents rivers in the SAST region was converted into grid format by applying the `linegrid` command:

```
strf1 = linegrid ( rf1 )
```

To ensure that the flow paths delineated from the DEM are in line with the RF1 river network, the terrain map was adjusted. Elevations of all cells that do not represent the real stream network were raised by 10,000 m:

```
stdem2 = con ( isnull ( strf1 ), stdem + 10000 , stdem)
```

The depressions were removed to ensure that the whole region contributes to runoff, and the flow direction grid `stfdr` was constructed:

```
fill stdem2 stfill2 stfdr
```

Rivers were delineated under the assumption that the runoff from a drainage area of 100 km^2 produces a stream. A region of 400 cells of 500 m cell resolution (1 cell = 0.25 km^2) constitutes an area of 100 km^2. (The system of rivers was used only to determine the proper location of the gauging stations necessary for delineation of the gauged zones).The value "1" was assigned to all cells that had an accumulated upstream number of cells greater than 400 "flowing" into them:

```
stfac = flowaccumulation ( stfdr)
ststr = con ( crfac > 400 , 1, 0)
```

The map of the flow system (`stfdr`) and the map of the river system (`stdtr`) were used to locate the USGS gauging stations on the river network.

4.4.2 Creating a base map of the gauged zones

A watershed is explicitly defined by its outlet point. A gauged zone is explicitly defined by the watershed outlet point (outflow from the zone) and the upstream gauging stations (inflow points). Thus, the precision of the location of gauging stations on the river is crucial for proper drainage area delineation.

A map of gauging stations was edited to minimize the error between the drainage area published by the USGS and the drainage area determined from the DEM. The drainage area of selected zones was adjusted by:

1. Moving the stations downstream or upstream by 2-3 cells (to include or exclude a river tributary from the delineated watershed);
2. Building flow barriers to correct the flow path
   a) separating streams connected at the beginning
   b) separating streams connected in the middle;

3. Locating stations on streams which changed position after the elevation grid was edited.

Dummy stations were introduced to exclude some portions of the delineated regions that, according to the HUC maps, do not belong to the SAST territory. A dummy station is a fictitious station representing the outlet of the drainage area that should not drain into the SAST region. Since GRID assigns the value of the watershed outlet cell to all cells that compose the watershed, the elimination of improperly delineated portions of the SAST region was performed by removing all zones with an ID equal to the ID of the dummy stations. The locations of dummy stations are presented in Figures 4.7-4.9, while their descriptions are as follows:

- Stations 998, 997, and 996 were used to exclude areas north of the SAST region (Figure 4.7)
- Stations 992 and 995 were utilized to correct eastern SAST boundaries (Figure 4.8)
- Station 785000 excluded the West part of the Missouri River (located 1 cell upstream of station 6467500)
- Station 222222 excluded the Platte River (located 1 cell upstream of Station 6805500)
- Station 154882 excluded the Kansas River (located 1 cell upstream of station 6892350)
- Station 37555 excluded the Osage River (located 1 cell upstream of station 6926500)
- Station 8236 excluded the Gasconade River (located 1 cell upstream of station 6934000)

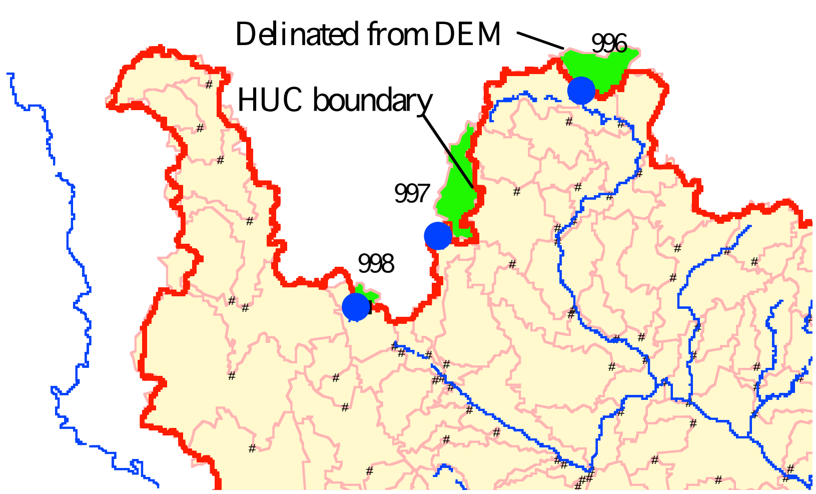


Figure 4.7 Location of the dummy stations 998, 997, and 996 which were applied to correct the northern SAST boundaries.

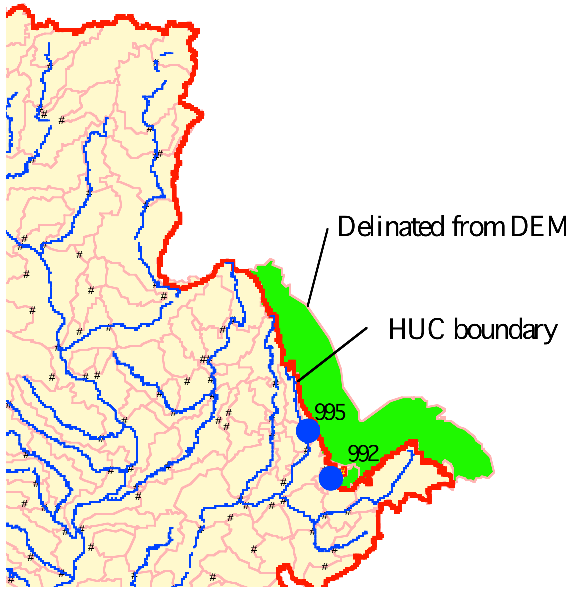


Figure 4.8 Location of the dummy stations 995 and 992 that were applied to correct the eastern SAST boundaries.

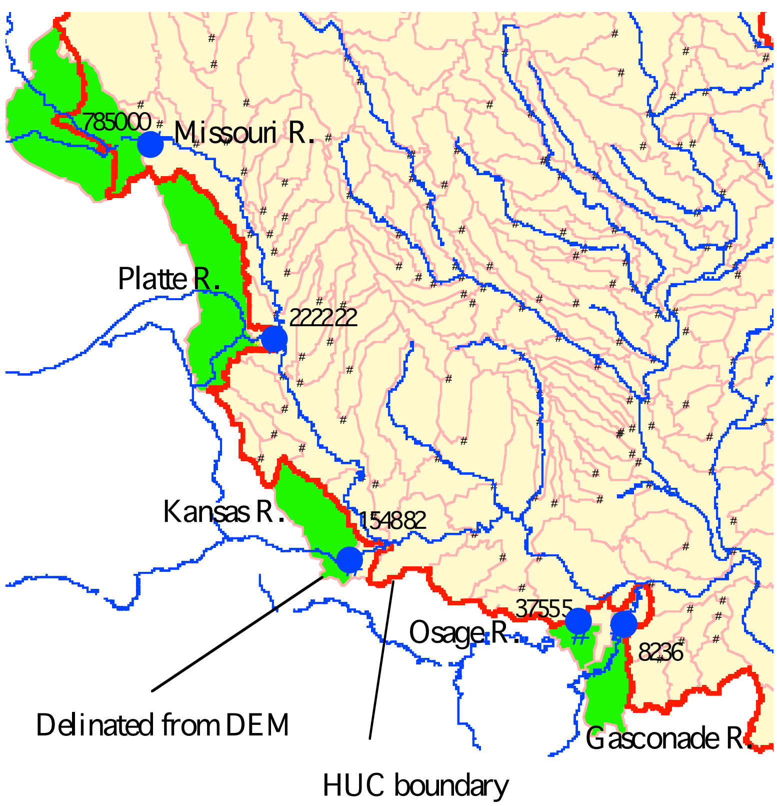


Figure 4.9 Location of selected stations to eliminate the drainage area west of the SAST study area. Stations "cut" the following rivers: Missouri , Platte , Kansas, Osage, and Gasconade.

Despite a significant difference between the USGS drainage area and the area estimated by DEM analysis, one of the gauged zones (zone ID = 6479438), located in the northern lake region was not corrected due to the lack of consistent information about flow paths (lack of RF1 rivers and questionable HUC boundaries). The drainage area error for this zone was about 50%: the USGS reports the drainage area to be 2,608 km^2, whereas the drainage area delineated from the DEM is 1,554 km^2. This error propagated to downstream zones, i.e., the value of the drainage areas of downstream zones: 6479525 and 6480000 were affected.

Ninety percent of stations had delineated drainage areas close to the USGS estimates, and the differences were smaller than 5%. Listing 4.14 shows the final steps of gauged zone delineation. In the first line, the cells that represent gauges are separated from the cells that represent streams, and the cells that represent the stream network (major flow paths) are eliminated. The `con` (condition) command is a selection command. If the cell value in the `ed5v6` grid is greater than one, the cell is copied to the grid `out56`, otherwise `NODATA` is assigned to the respective cell. This process copies all cells that represent stations, including dummy stations, from the grid `ed5v6` to the grid `out56`. The grid `ed5v6` is a grid that contains delineated stream networks (cell value = 1), dummy stations (cell values 900 - 999), cells that cut drainage areas west of the SAST area (cell value < 1,000,000), and cells that represent the gauging stations (cell value = station ID).

In line 2 of Listing 4.14 below, the watersheds are delineated (including watersheds that have outlets represented by the dummy cells). The grid `st5fdr` contains the indicators of flow direction. In line 3 only the watersheds that are related to the USGS stations are selected and copied to the grid `zones56` (the dummy watersheds are eliminated).

Listing 4.14 Selected steps of the division of SAST into water balance units (gauged zones).

```
1: out56 = con (ed5v6 > 1, ed5v6 )
2: tot56wsh = watershed ( st5fdr , out56 )
3: zones56 = con ( tot56wsh > 1000000, tot56wsh)
```

The grid `Zones56` was used to calculate the average evaporation, average precipitation depth and the water balance for 9 months of 1993 (from January to September). Figure 4.10 shows the gauged zones, the location of the USGS gauging stations, and the major flow paths that link the stations.

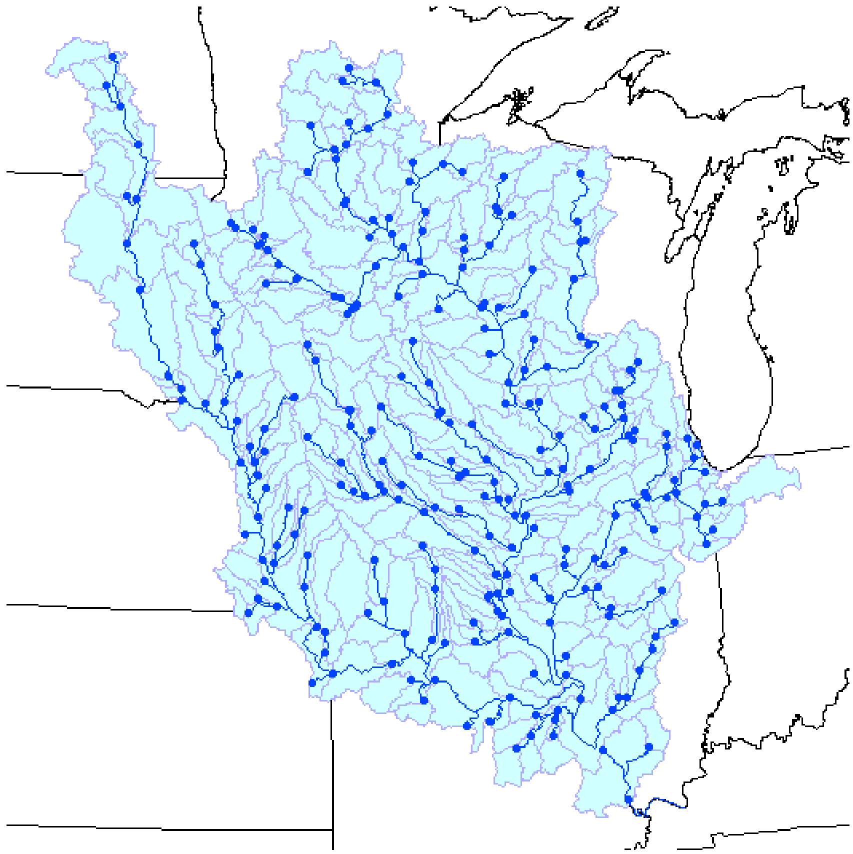


Figure 4.10 SAST divided into 256 gauged zones, USGS gauging stations selected for water balance calculations, and the station flow links.

4.5 Connectivity of gauged zones

To estimate the flow balance, the sum of inflows into the gauged zone must be calculated. The stations immediately upstream of a zone outlet station, can be identified if the position or order of each station on the flow path is known. The Arc/Info AML `nextwsh.aml` creates an INFO file with two items, one stores the gauged zone ID and the other item contains the ID of the next zone on the flow path, i.e. the downstream zone. The listing of `nextwsh.aml` is shown in Appendix B2 and a portion is shown in Listing 4.15. The major part of this AML assigns a watershed outlet cell in grid `out56`, a value from the cell located in the watershed grid `zones56`, that is directed by the flow direction grid (`st5fdr`). In line 1, Listing 4.15, a value of zero is assigned to all cells that have nodata, and grid `xwsh` is created. This step is necessary to ensure that the next watershed to the last zone on the flow path is indicated by the ID equal to zero (there are no zones downstream of the last unit). Lines 2-9 create the grid `zonenxt` which is similar to the grid of watershed outlets `out56`; it contains the same cells but their values represent the ID of the downstream unit. Figure 4.11 shows the flow system of zones, stations, and flow links in Iowa.

Listing 4.15 Identification of the downstream zone

```
xwsh = con ( isnull ( zones56 ), 0, zones56 )
zonenxt = con ( out56 > 0, con (st5fdr == 1, xwsh(1,0),
~
con (st5fdr == 2, xwsh(1,1), ~
con (st5fdr == 4, xwsh(0,1), ~
con (st5fdr == 8, xwsh(-1,1), ~
con (st5fdr == 16, xwsh(-1,0), ~
con (st5fdr == 32, xwsh(-1,-1), ~
con (st5fdr == 64, xwsh(0,-1), ~
con (st5fdr == 128, xwsh(1,-1), -1)))))))))
```

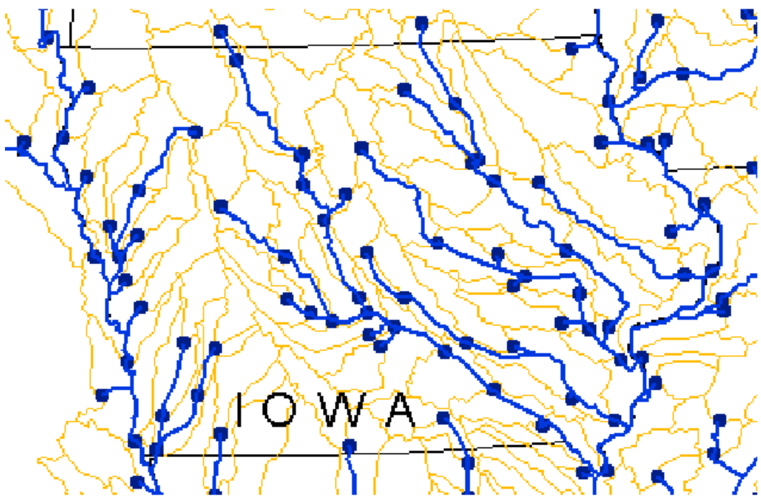


Figure 4.11 Flow system in Iowa used for water balance estimation in the SAST region.

4.6 Zonal Water Balance

Once the SAST region was subdivided into zones, the average precipitation and average evaporation for each gauged zone could be estimated. section 4.6.1 explains the process of calculating the average precipitation depth for each gauged zone and for each day of 1993 and then storing the averages in an Info file. Section 4.6.2 presents a similar methodology to the one described in section 4.6.1, but applied to calculate the average zonal evaporation depth for 12 months of 1993. The estimation of the water balance in gauged zones is presented in section 4.6.3.

4.6.1 Average precipitation depth

Two Arc/Info macros were developed to create an Info file that stored the gauged zones' precipitation depth values. The first AML (Listing 4.16) merely executes the other macro, `rmap56.aml,` for each month of the 1993. The following parameters were supplied to `rmap46.aml`:

`p_path = $home/flood/precip/gridprc/` (path to the folder in which the daily precipitation grids are stored)
`zone = zones56` (grid that defines the zones; 56 is the map-set version number);
`id = unit_id` (name of an item that stores station/zone ID);
`rmap56` (name of the AML that calculates the zonal average and stores the results in the INFO files `prc1, prc2, prc3,... prc12`)
`1 1 1 31` (start month, start day, end month, end day)
`10` (cell values are multiplied by 10 before they are converted into integer values to increase the precision of calculations);
`p` (prefix used to create precipitation item names).

Listing 4.16 Calculation of the average zonal precipitation (execution of `rmap56.aml`).

```
&messages &off
&s p_path = $home/flood/precip/gridprc/
&s zone = zones56
&s id unit_id
/*
&type start jan [date -vfull]
&r rmap56 1 1 1 31 %p_path% %zone% prc1 %id% 10 p
&r rmap56 2 1 2 28 %p_path% %zone% prc2 %id% 10 p
&r rmap56 3 1 3 31 %p_path% %zone% prc3 %id% 10 p
&r rmap56 4 1 4 30 %p_path% %zone% prc4 %id% 10 p
&r rmap56 5 1 5 31 %p_path% %zone% prc5 %id% 10 p
&r rmap56 6 1 6 30 %p_path% %zone% prc6 %id% 10 p
&r rmap56 7 1 7 31 %p_path% %zone% prc7 %id% 10 p
&r rmap56 8 1 8 31 %p_path% %zone% prc8 %id% 10 p
&r rmap56 9 1 9 30 %p_path% %zone% prc9 %id% 10 p
&r rmap56 10 1 10 31 %p_path% %zone% prc10 %id% 10 p
&r rmap56 11 1 11 30 %p_path% %zone% prc11 %id% 10 p
&r rmap56 12 1 12 31 %p_path% %zone% prc12 %id% 10 p
&type end of dec [date -vfull]
&messages &on
q
q
```

```
23: &return
```

The macro `rmap56.aml`, listed in Appendix B3, uses the GRID command `zonalmean` to calculate the average values. Before the precipitation depth is written to the INFO table, it is divided by 1000 to get results back in millimeters. Program `rmap56.aml` is a customized version of `raininfo.aml`. Figure 4.12 presents an example of the estimated precipitation depth in the SAST gauged zones for July 19, 1993.

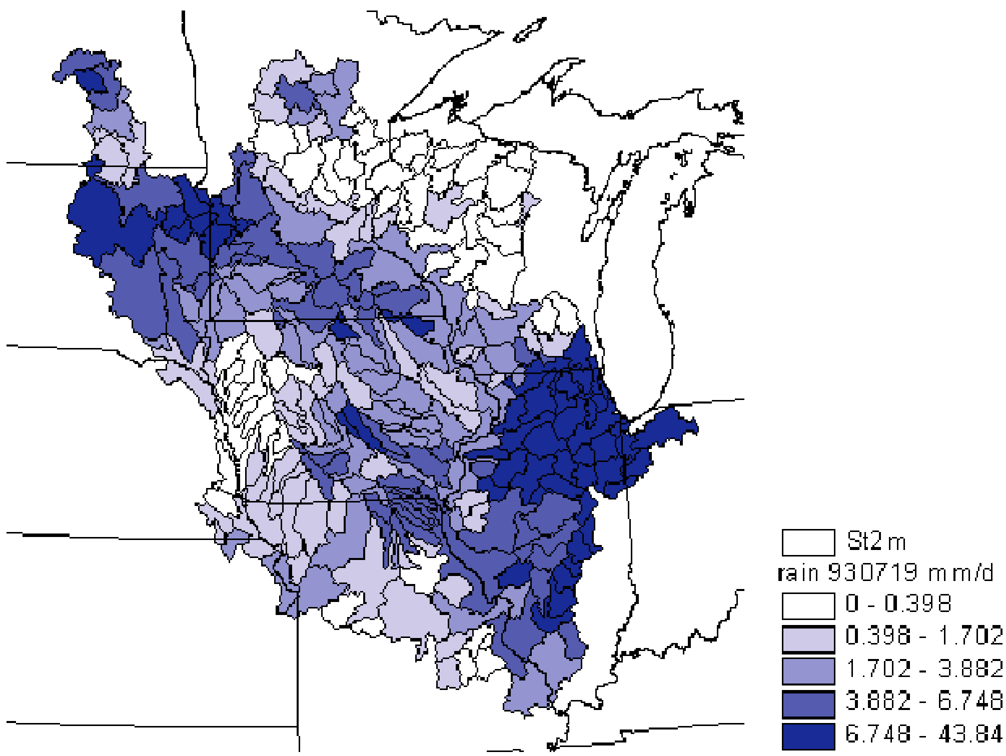


Figure 4.12 Estimated precipitation depth in the SAST gauged zones for July 19, 1993.

It is possible to calculate the zonal average for the whole year utilizing the following input parameters for the `rmap56.aml` macro:

```
&r rmap56 1 1 12 31 %p_path% %zone% prc93 %id% 10 p
```

but if the calculations are split into monthly intervals, the process is more controllable, e.g., if the process crashes during computer execution, only calculations for one month (31 days) need to be repeated.

4.6.2 Average evaporation

A similar method to the one described above, was applied to create the Info file of the monthly evaporation. The macro `emap56.aml` is just a modification of `rmap56.aml`. It must be noted that the evaporation is in depth units per month [mm/month], not in [mm/day] as is the precipitation.

The following parameters were used in `emap56.aml`:

`fm = 1` (first month, 1 = January)
`tm = 13` (annual depth, not utilized in this study)
`zone = zones56` (grid that defines the gauged zones)
`outinf = evap.dat` (INFO table with zonal evaporation depth)
`id_itm = unit_id` (item that contains zone ID)
`prc = 10` (used to increase the precision of manipulating the integer values)
`prx = e` (prefix used to create an evaporation item name)

4.6.3 Water Balance

Due to the Arc/Info restrictions on the size of an Info file, the calculations had to be divided into monthly time steps. The macro bal1.aml is one of 12 macros that perform the following tasks:

- creates ASCII files containing data required for the water balance calculations
- execute a program that calculates the balance
- imports the program results (balance)
- stores the results in an INFO file.

The macros `bal1.aml .. bal12.aml` require 6 parameters. For example, the following parameters were defined to calculate the balance for January, 1993:

`flw = d56eqp1.dat` Info file that contains: zone ID, ID of the downstream zone (flow connectivity), zone area in km^2, flow rate, evaporation (mm/day), and precipitation (mm/d) for January
`fm = 1` (from month)
`fd = 1` (from day)
`tm = 1` (to month)
`td = 31` (to day)
`out = bal1` output INFO file

`data56` = an INFO file that contains zone ID numbers ("base or prototype" INFO file that is copied to create a file in which the results are stored `copyinfo data56 %out%`)

The GIS-time series created using with these AMLs uses metric units and the international date format (year-month-day) to name the items in Info tables. An exception is the flow rate data which are in cubic feet per second (cfs).

The water balance is calculated by the `b4v1` program and its modified versions written in the C language. The AML macro described above exports ASCII data required by `b4v1`, executes `b4v1`, and creates an Info file in which it stores the results of `b4v1` calculations. This program uses the following unit conversion factor: 2.4466 (1 cfs = 2446.6 m^3/d, 1 m^3 = 10^9 mm^3, 1 km^2 =10^{12} mm^2), The following two lines which calculate the balance, are excerpted from the `b4v1` program:

```
x1 = 2.4466 * (gsqo[i] - gsin[i] ) / unar[i];
bal[i] = unpr[i] - unev[i] - x1;
```

where:

`gsqo[i]` = outflow from zone i [cfs]
`gsin[i]` = sum of inflows into zone i [cfs]
`unar[i]` = zone area [km^2]
`bal[i]` = water balance [mm/d]
`unpr[i]` = average precipitation depth [mm/d] (daily values)
`unev[i]` = average evaporation [mm/d] (derived from monthly values)

5. Results

A preliminary analysis was performed for 9 months of 1993 from January to September. This analysis showed, that the cumulative storage had a decreasing tendency, leading to a large water deficit in September. This deficit occurred because the evaporation data used represented potential evaporation. The results of these calculations are presented in Section 5.1. To obtain a more realistic pattern of storage, a new data set was created and the analysis was repeated for the entire 12 months of 1993 under the assumption that the storage in each gauged zone would be similar at the beginning and at the end of 1993. The results are presented in Section 5.2. Finally, the gauged zones were refined by removing stations with questionable measurement precision, to eliminate strange month-to-month storage fluctuations. More information on this subject, as well as the water balance estimates using HUCs, is discussed in Section 5.3.

5.1 Preliminary analysis

The original goal of this project was to calculate water storage for the period from January 1 to September 30, 1993. The preliminary calculations of water storage were performed for the SAST region considered as one gauged zone. Five rivers flow into the "SAST zone" through the following USGS stations:

6926500 Osage River near St. Thomas, MO
6934000 Gasconade River near Rich Fountain, MO
6467500 Missouri River at Yankton, SD
6805500 Platte River at Louisville, NE
6892350 Kansas River at Desoto, KS

The outflow from the SAST region is measured at station 7022000 located on the Mississippi River at Thebes, IL.

The water storage results, as well as the 30-day moving average, are shown in Figure 5.1. There is a visible decreasing trend. Also the moving average locally increases in June, and locally decreases in July. Figure 5.2 presents cumulative storage estimated for the SAST region.

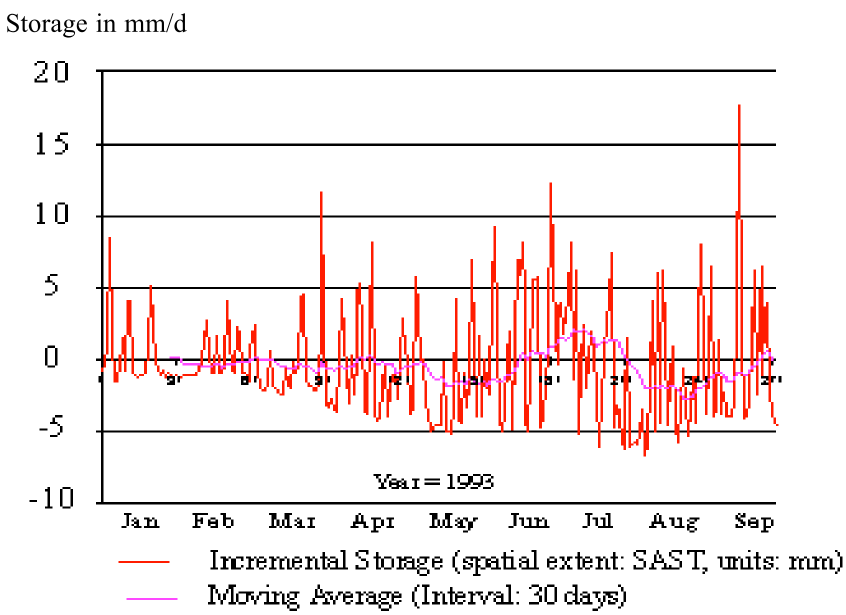


Figure 5.1 Incremental storage [mm/day] in the SAST region for 01/01/93-30/09/93.

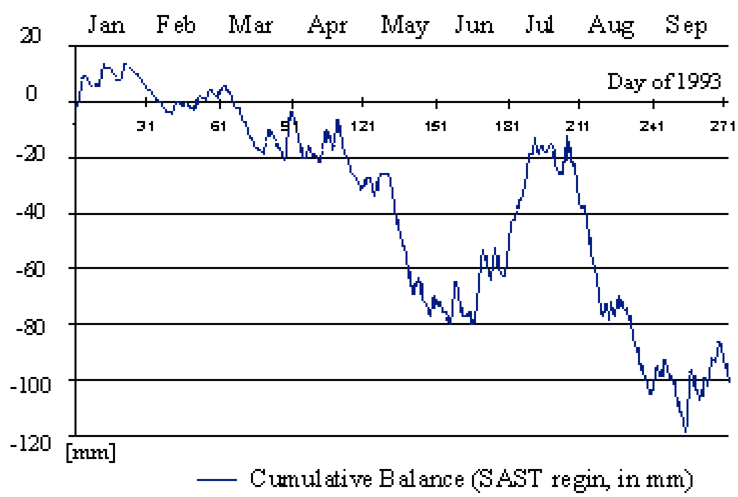


Figure 5.2 Cumulative storage [mm] in the SAST region for 01/01/93 - 30/09/93.

A systematic negative balance, i.e. more water escapes from the region (evaporation, outflow) than enters (inflow, precipitation), indicates that the water balance is not correct. It is unlikely, that the precipitation or the flow record exhibits such a "decreasing" behavior. The evaporation data most likely introduced this error.

The evaporation losses are overestimated in this calculation. Figure 5.3 shows the cumulative water balance after the amount of water that leaves the system (evaporation + outflow) was decreased by about 14 [mm/month].

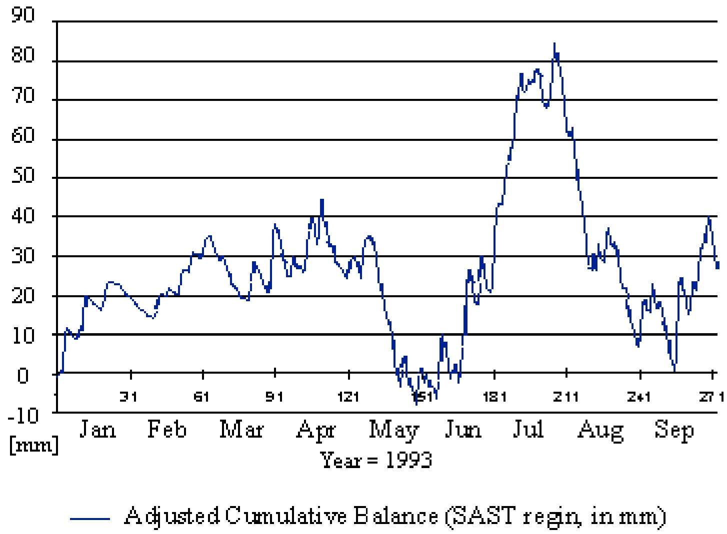


Figure 5.3 Adjusted Cumulative storage [mm] in the SAST region for 01/01/93 - 30/09/9 (water losses depth has been decreased by about 0.47 mm/day).

The closure of the water balance for the year 1993 was achieved by reducing the evaporation depth. It is suspected that the monthly values used in the research are approximate, since evaporation measurements are scarce (only 7 climate stations located within the SAST region boundaries with a complete record of evaporation were found in Hydrosphere's CD-ROM database).

For each day of 1993, from January 1 to December 31, cumulative precipitation depth in the SAST region, cumulative inflow into the SAST region, cumulative outflow from the region (the Mississippi River discharge at Thebes), and cumulative evaporation depth were calculated. Then, an evaporation adjustment coefficient was calculated using the following formula:

$$\alpha = \frac{\sum_{i=1}^{365} Q_{in,i} + \sum_{i=1}^{365} P_i - \sum_{i=1}^{365} Q_{out,i}}{\sum_{i=1}^{365} E_i} = \frac{645.4}{810.6} = 0.796[mm] \qquad (5.1)$$

where:

α = evaporation adjustment coefficient = 0.796;

$\Sigma Q_{out,i}$ = surface outflow = 594.5 [mm/yr];

$\Sigma Q_{in,i}$ = surface inflow = 121.8 [mm/yr];

ΣP_i = precipitation depth = 1118.2 [mm/yr];
ΣE_i = evaporation depth = 810.6 [mm/yr].

Figure 5.4 shows cumulative values of the water balance components.

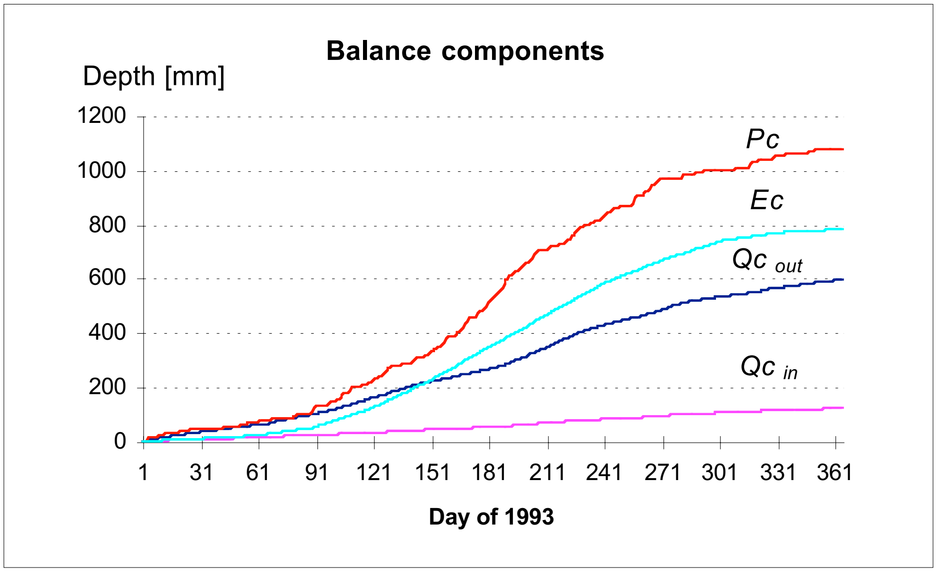


Figure 5.4 Cumulative values of the water balance components (units: mm per number of days that passed from January 1); Qc_{out} - surface outflow (Mississippi R. discharge at Thebes); Qc_{in} - surface inflow (sum of dicharges of Osage R., Gasconade R., Missouri R., Platte R., and Kansas R.); *Pc* - precipitation depth; *Ec* - evaporation.

Figure 5.5 compares cumulative $\sum_{i=1}^{n} Q_{in,i} + \sum_{i=1}^{n} P_i - \sum_{i=1}^{n} Q_{out,i}$ with different fractions of the cumulative evaporation $\beta \sum_{i=1}^{n} E_i$ (β =1, 0.796 and 0.9):

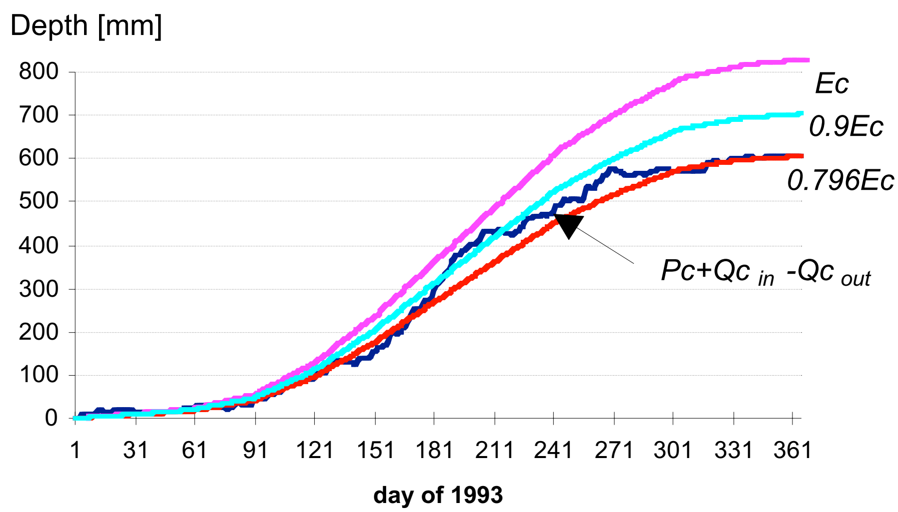


Figure 5.5 Comparison of $Pc + Qc_{in}$ - Qc_{out} with evaporation depth Ec.

The total water balance for the SAST region is shown in Figure 5.6 with the adjusted potential evaporation (79.6%) being utilized in the balance calculations. A rapid increase in the water stored from the end of May to the beginning of August is evident. The storage increased by more than 100 mm over a period of two months. The negative storage during May relative to that at the beginning of January is associated with melting of the snow pack.

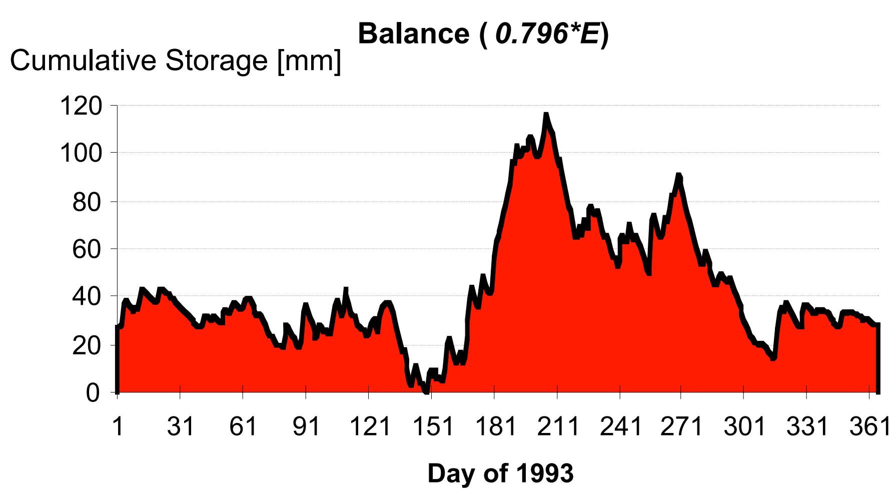


Figure 5.6 Water storage in the SAST region in 1993 [mm].

The water balance in each gauged zone was calculated using the adjusted evaporation values. Figure 5.7 presents cumulative storage in gauged zones along the Mississippi River. It can be noticed that in some of the gauged zones the cumulative storage at the end of September is still very high, questioning the balance closure at the end of the year, e.g. the four most downstream Mississippi River units: 5474500, 5587450, 7010000, and 7022000. Therefore new hydrologic data were prepared for the all of 1993.

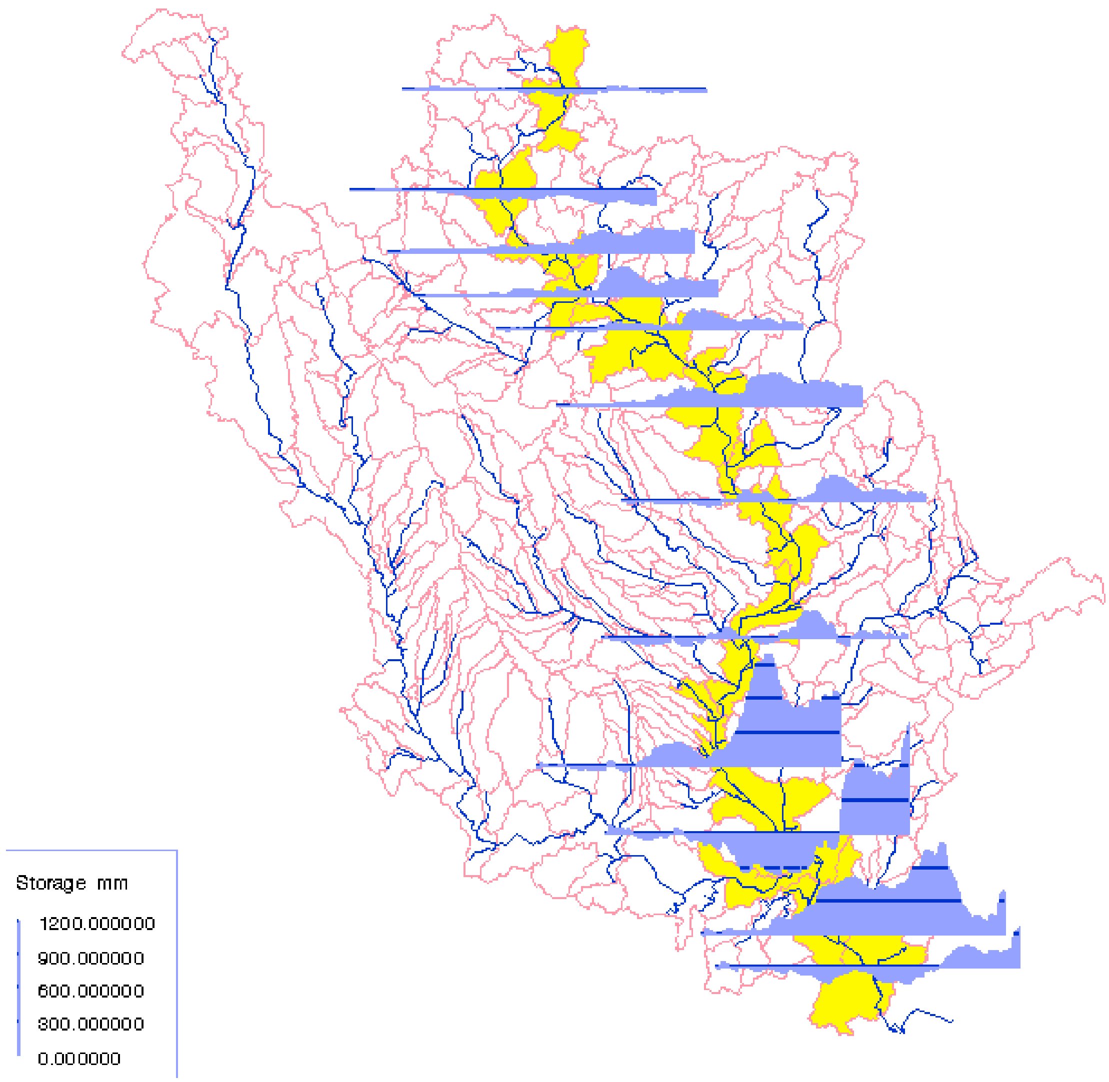


Figure 5.7 Example of the water storage in gauged zones along the Mississippi River (January 93 - September 93).

5.2 Water Balance Calibration

5.2.1 Annual water balance closure

For each gauged zone the water balance was calculated utilizing equation (3.4) with the evaporation correction factor α equal to 0.796:

$$S_{i,d} = \sum_{k=1}^{d}\left(P_i - 0.796E_i + \Sigma Q_{in,i} - Q_{out,i}\right) \qquad (5.2)$$

The results of these calculations are stored in the folder /bal66b/ which is described in more detail in Appendix C2 (the name of this variant of water balance calculation is "bal66b"). The cumulative storages estimated on December 31, 1993, $S_{i,365}$, are the differences between the beginning-of-year and end-of-year storages in the *i*-th zone. These errors of the annual water balance closure for gauged zones are shown in Figure 5.8. They vary from -96.3 [cm] to +134.3 [cm]. For 164 zones, i.e. 64% of the SAST region area, the water balance closure error was smaller than 10 [cm], whereas for 213 zones (81% of total area) the closure error was less than 20 [cm].

For some zones that are located along the large rivers such as the Missouri River (zones 6601200, 6610000, 6807000, 6818000, 6909000, 6893000, 6895500, 6934500, 7010000, and 7020500) the closure error exhibits fluctuations between negative values (water deficit in the annual balance) and positive values (surplus in the annual water balance). This occurs because the volume of water added by each increment of drainage area going down the river is small when compared to the volumes of water already in the river. Small errors occur in the estimation of inflow and outflow. When the outflow is subtracted from the inflow to produce the storage change, the small difference between two large numbers contains the error in the large numbers.

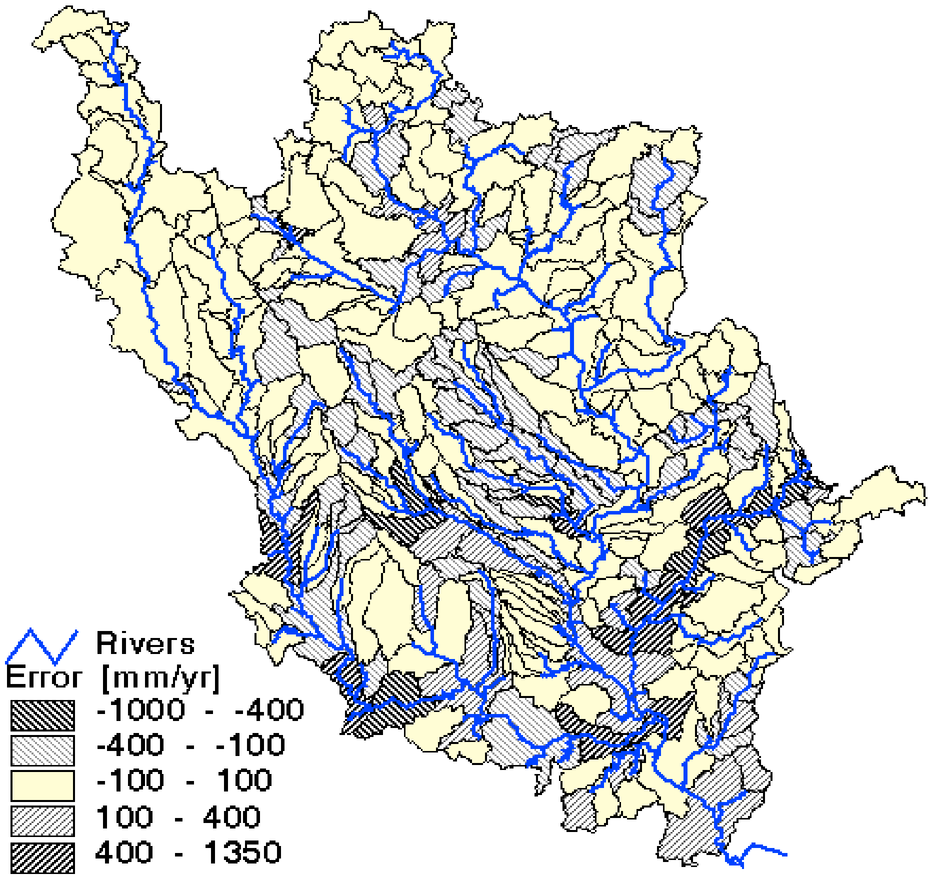


Figure 5.8 The difference between the storage level on Jan 01, 1993 and estimated storage on Dec 31, 1993.

Figure 5.9a shows cumulative storage (in mm) for the previously mentioned zones of the Missouri River and Figure 5.9b presents the same storage but represented as a volume of water (in km^3). Further analysis is required to clarify the oscillations of the water balance surpluses/deficits along the rivers.

The attribute table of the coverage `b66b` stored in folder `/bal66b/` contains cumulative storage for each day of 1993 and for each gauged zone (ver. 66) that was corrected to obtain zero-level storage at the end of the year (each daily balance was adjusted by the amount of $\frac{error_i}{365}$. The error is stored in the PAT of the coverage `./b66b/b66ber)`. In an attempt to reduce these fluctuations, some incremental areas were combined along the Mississippi and Missouri Rivers.

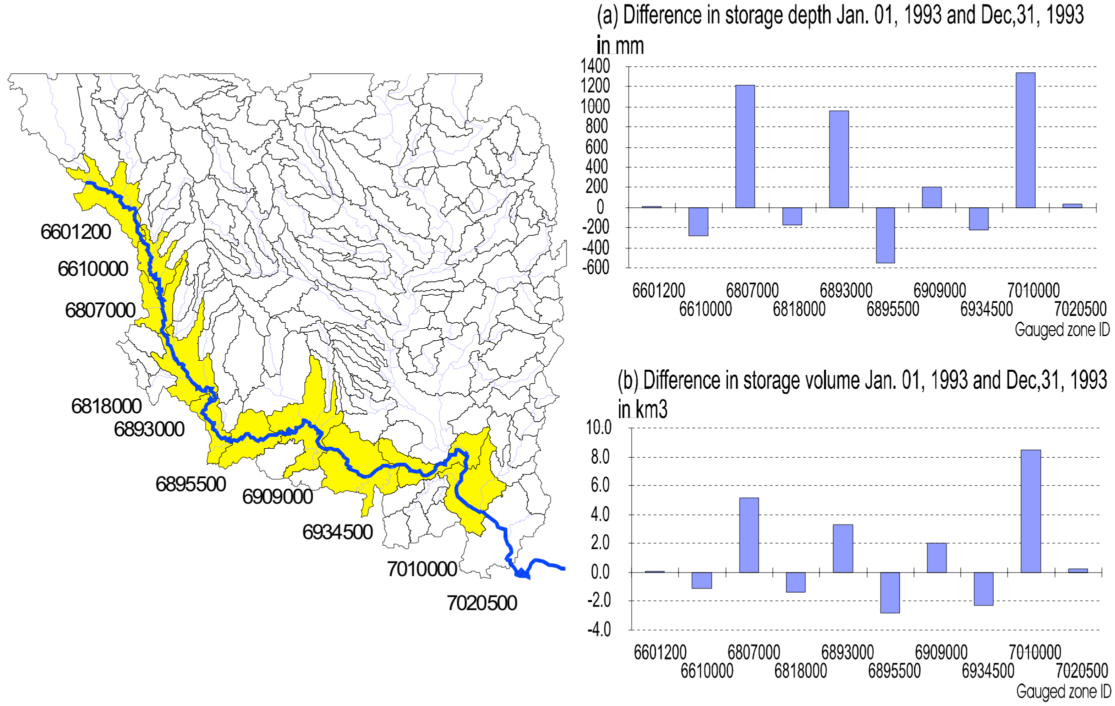


Figure 5.9 The difference between the (a) the storage depth and (b) the storage volume on Jan 01, 1993 and estimated storage on Dec 31, 1993 in gauged zones along the Missouri River.

5.2.2 Corrected water balance

The ensure that the water storage is the same at the beginning and at the end of 1993, the value of evaporation was multiplied by a coefficient, estimated for each gauged zone. This correction method was applied in the spatial layouts (variant `bal66ec` - all gauged zones, var. `bal67ec` - reduced set of gauged zones, and var. `bal68ec` - final set of gauged zones). The process is described by the following equation (Eq. 3.6):

$$\hat{S}_{i,d} = \sum_{k=1}^{d} \left(P_i - \alpha_i E_i + \Sigma Q_{in,i} - Q_{out,i}\right) \tag{3.6}$$

The coefficient α_i was estimated for each gauged zone using the Arc/Info TABLES subprogram.

5.2.3 Reduced number of gauged zones

The number of zones was reduced from 256 in variant `b66` to 132 in variant `b68` by reducing number of gauging stations from 261 to 137. The following factors were considered when the zones were merged by eliminating USGS gauging stations:

1) Magnitude of the evaporation correction factor, α
2) Magnitude of the error in annual water balance closure
3) Pattern of the monthly water storage in neighboring zones
4) Quality of the discharge record

The first two factors were discussed in Section 5.2.1 and Section 5.2.2. Regarding the third factor, the patterns of the temporal changes of water storage in gauged zones located close to each other on the flow path were expected to be similar. The monthly water storage shown in Figure 5.10 indicates that the neighborhood units may not have a similar pattern. For example, in some units the storage decreases in the first six months of the year 1993, whereas in nearby upstream or downstream zones, the storage increases.

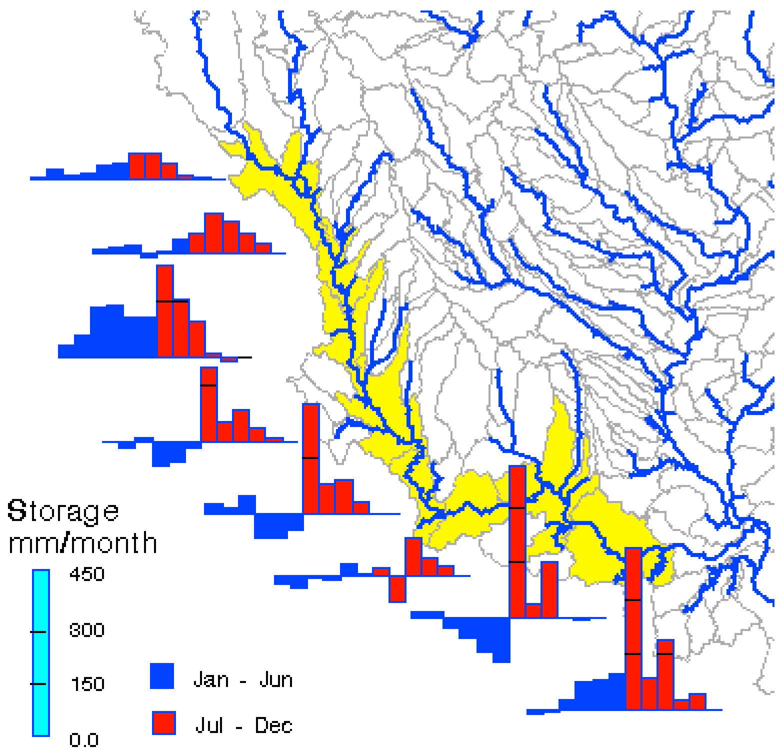


Figure 5.10 Monthly water storage depth in gauged zones along the Missouri River.

Figures 5.11a and 5.12b show examples of water balance along the Illinois River for different sized gauged zones. Figure 5.11a presents seven zones (listed in a downstream direction: 5558300, 5568500, 5586100, 5587450, 7010000, 7020500, and

7022000) from variant `b66` in which all gauging stations are utilized for zone delineation and water storage estimation. The lack of a common pattern is evident. Figure 5.11b shows a similar drainage area, but subdivided into three gauged zones 5586100, 5587450, 7020500 (variant `b67`). The agglomeration of units had a "smoothing" effect and the range of storage variation decreased from about 1,000 mm (Fig. 5.11a) to about 500 mm. Merging zones 7010000 and 7020500 that have diametrically different temporal storage distribution values resulted in an "oscillating" temporal pattern (high storage in July and September, and low storage in June, August, and October).

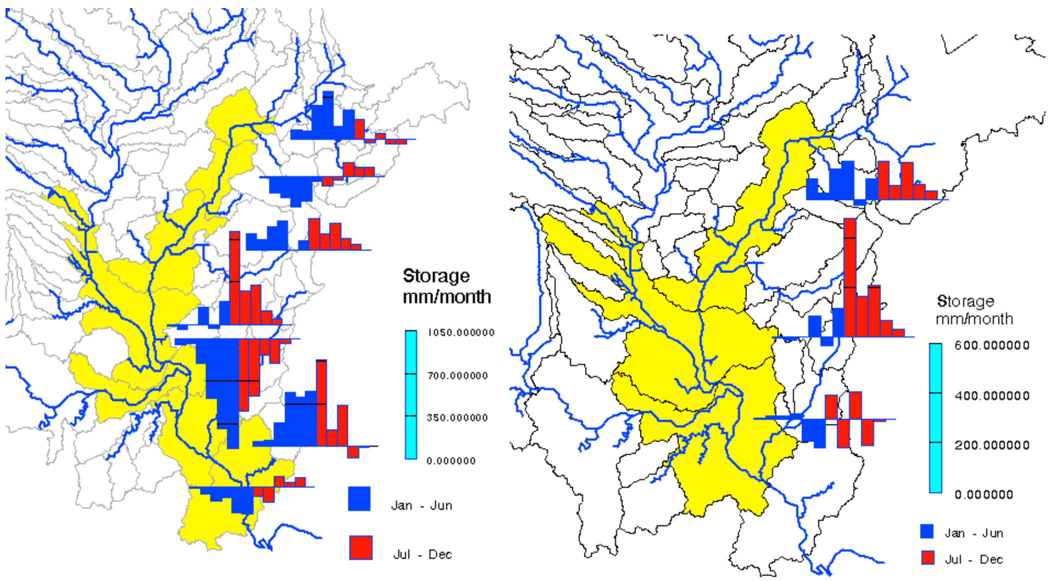


Figure 5.11 Monthly water storage along the Illinois River and Mississippi River; an analysis of the effect of zone merging on the temporal distribution of water storage(note: scales are not the same).

There are also gauged zones with discharge measurement errors. Figure 5.12 shows an example of water storage estimated from an incorrect flow record. It is not clear if the error resulted from incorrect measurements or from the corruption of the data. Further investigation of these flow stations is needed.

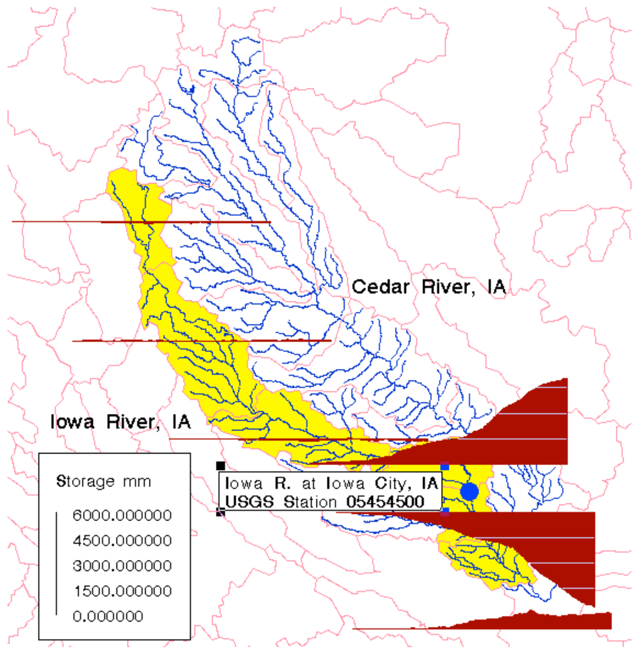


Figure 5.12 Water storage in gauged zones along the Iowa River; an example of influence of erroneous discharge time series on the local water balance (Station 5454500 at Iowa City, Iowa, Jan-Sep, 1993).

Figure 5.13 compares discharge measured at three sites along the Iowa River:

Upstream station, Iowa River at Marengo, IA , Station ID = 5453100
Middle station, Iowa River at Iowa City, IA, Station ID = 5454500
Downstream station, Iowa River near Lone Tree, IA, Station ID = 5455700

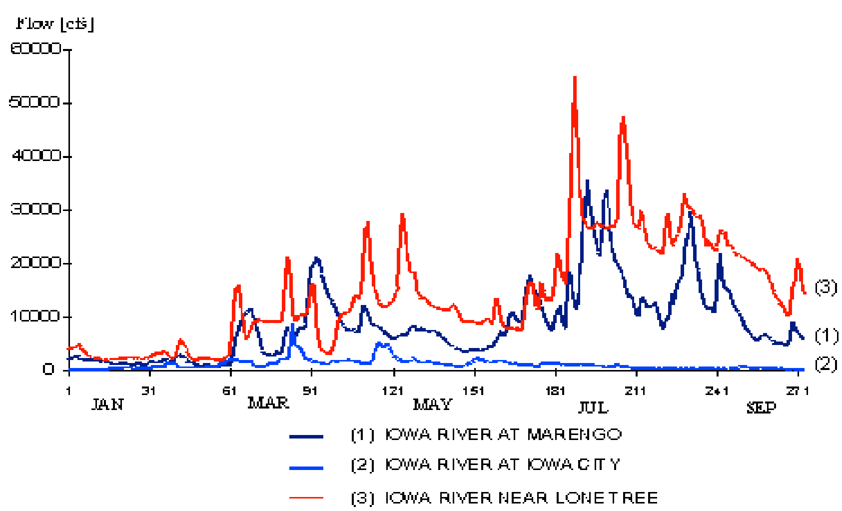


Figure 5.13 Example of discharge data measured at stations on the Iowa River, upstream, midstream, and downstream from Iowa City (stations 5453100, 5454500, and 5455700).

The final selection of the zones is shown in Figure 5.14. The results are stored in attribute tables of the following Arc/Info coverages (folder `/bal68ec/`):

`b68bal` = incremental storage (after evaporation adjustment)
`b68sto` = cumulative storage (after evaporation adjustment)
`x68bal` = incremental storage (no evaporation adjustment)
`x68sto` = cumulative storage (no evaporation adjustment)
`b68evcf` = evaporation multiplication factor

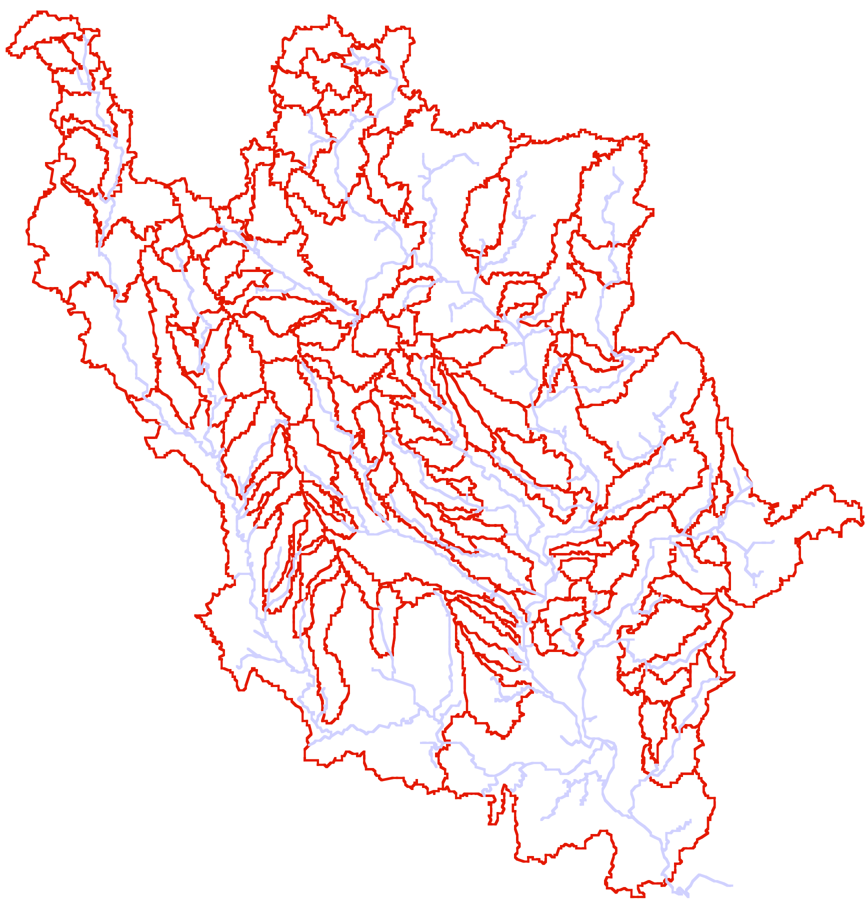


Figure 5.14 SAST region divided into 132 gauged zones (final ver. b68ec).

5.2.4 Averaging the Water Storage over Hydrologic Units

The water storage in Hydrologic Units (HUC) was calculated by the weighted average method. Results are stored in attribute tables of the following Arc/Info coverages:

`./bal68h4/huc4sast` = polygon coverage of 4-digit HUCs
`./bal68h6/huc6sast` = polygon coverage of 6-digit HUCs

Figure 5.15 introduces the SAST region subdivided into twenty 4-digit HUCs.

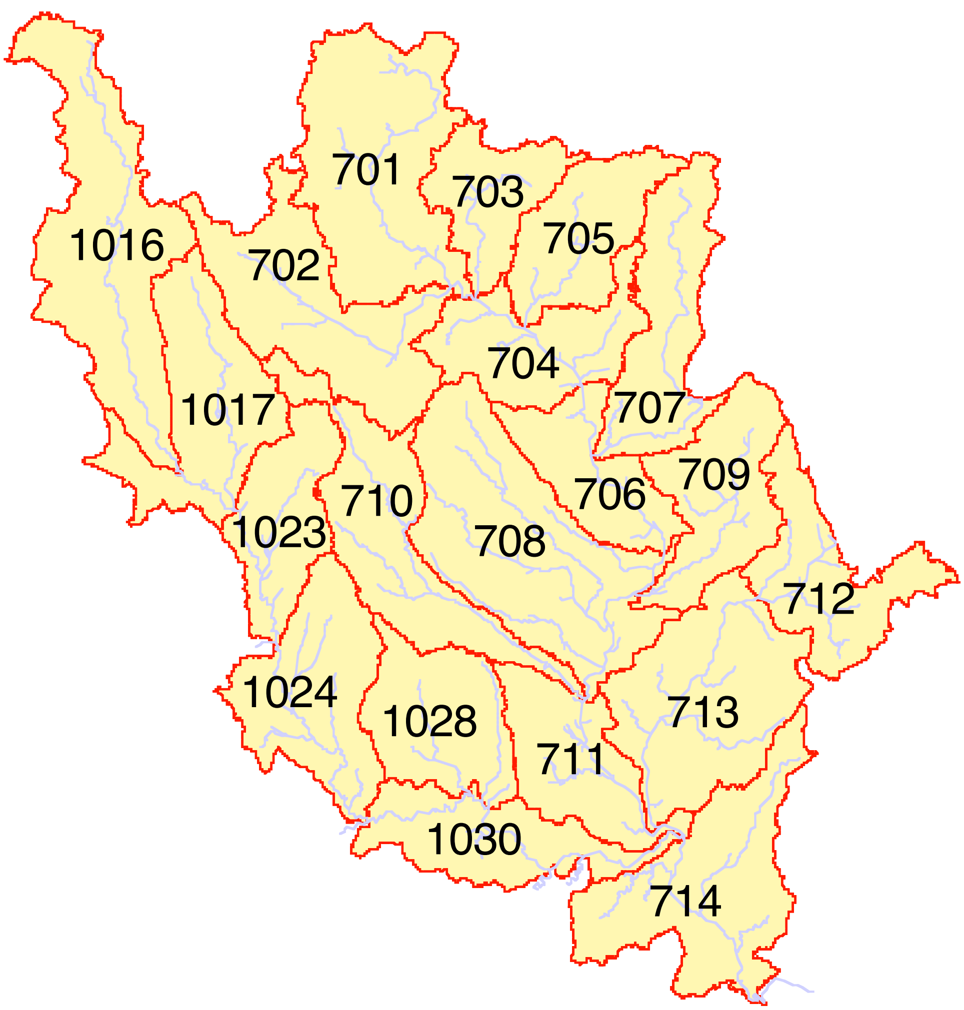


Figure 5.15 SAST region subdivided into 4-digit HUCs.

The temporal variation of the water storage in each HUC is presented in Figure 5.16. The largest increase in water storage occurred in HUCs located in the southwest portion of the study area, in late Spring- early Summer. The increase in storage was relatively small in the north (HUCs 702, 701, 703) and northeast hydrologic units (HUCs 704, 705, 707), in which the storage had risen by approximately 5 to 10 cm from May to

June. In the same period the rapid storage increase in the northwest (HUC 1016), west-central (HUCs 1017, 1023), and central areas (HUCs 710, 708, 713) was evident and varied the range from 10 to 15 cm, whereas the variations in the east-central HUCs are small enough that they can be attributed to typical water storage fluctuations.

The largest water storage increase occurred in the southwest (HUCs 1024, 1028, 1030, 711) and south (HUC 714). The average water storage over these units in the two month period increased more than 20 cm with the maximum in the most downstream units in the SAST region: the last section of the Missouri River before it joins the Mississippi River (HUC 1030, water rose about 27.5 cm in the two months) and HUC 714 on the Mississippi River downstream of the junction with the Missouri River (water rose more than 25 cm).

The time series of the storage in HUC 714 revealed two peaks in storage, equally high. The first one occurred at the end of June/beginning of August, and the other one occurred two months later, at the end of September.

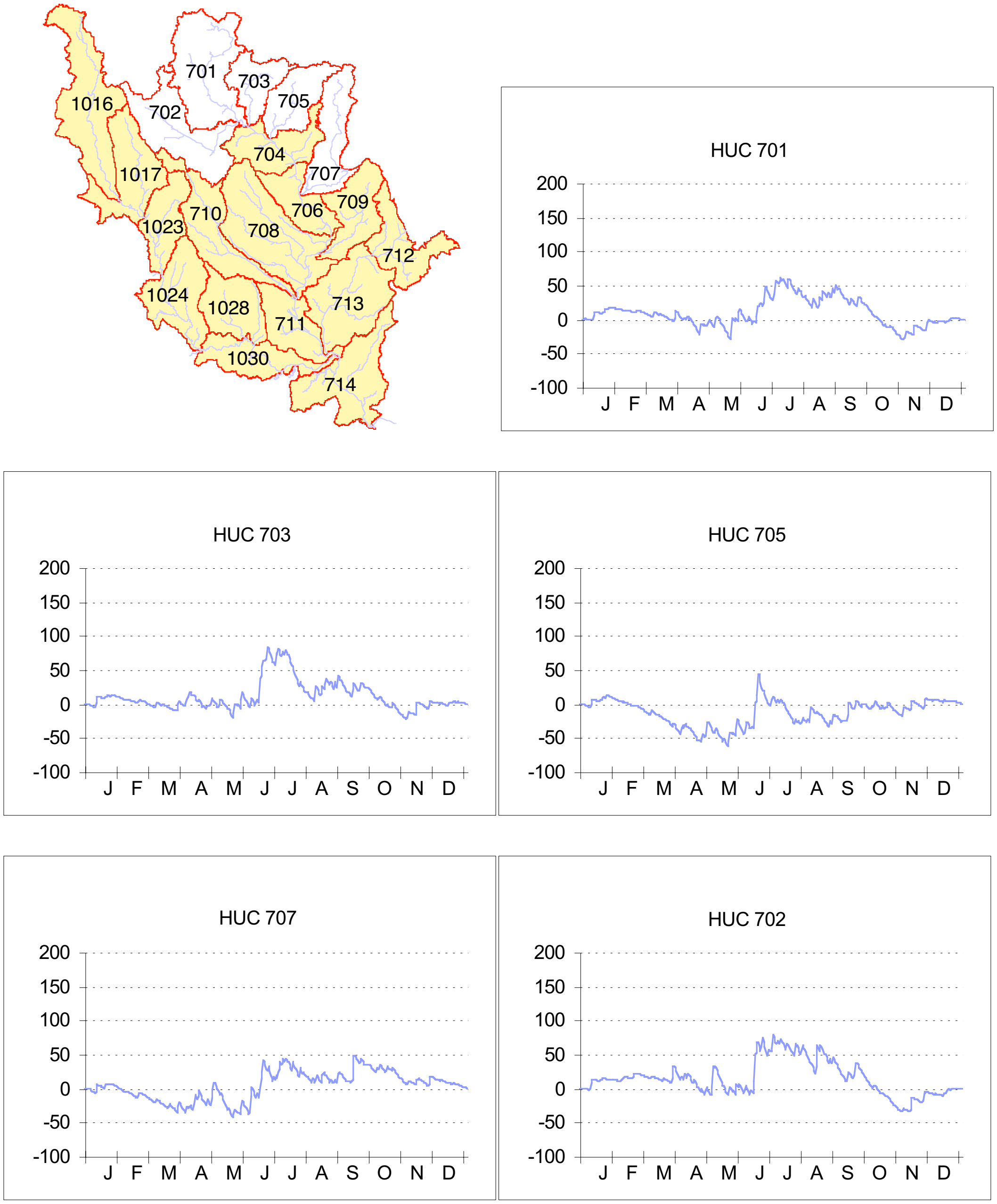


Figure 5.16 The water storage in 4-digit HUCs during 1993 in [mm] .

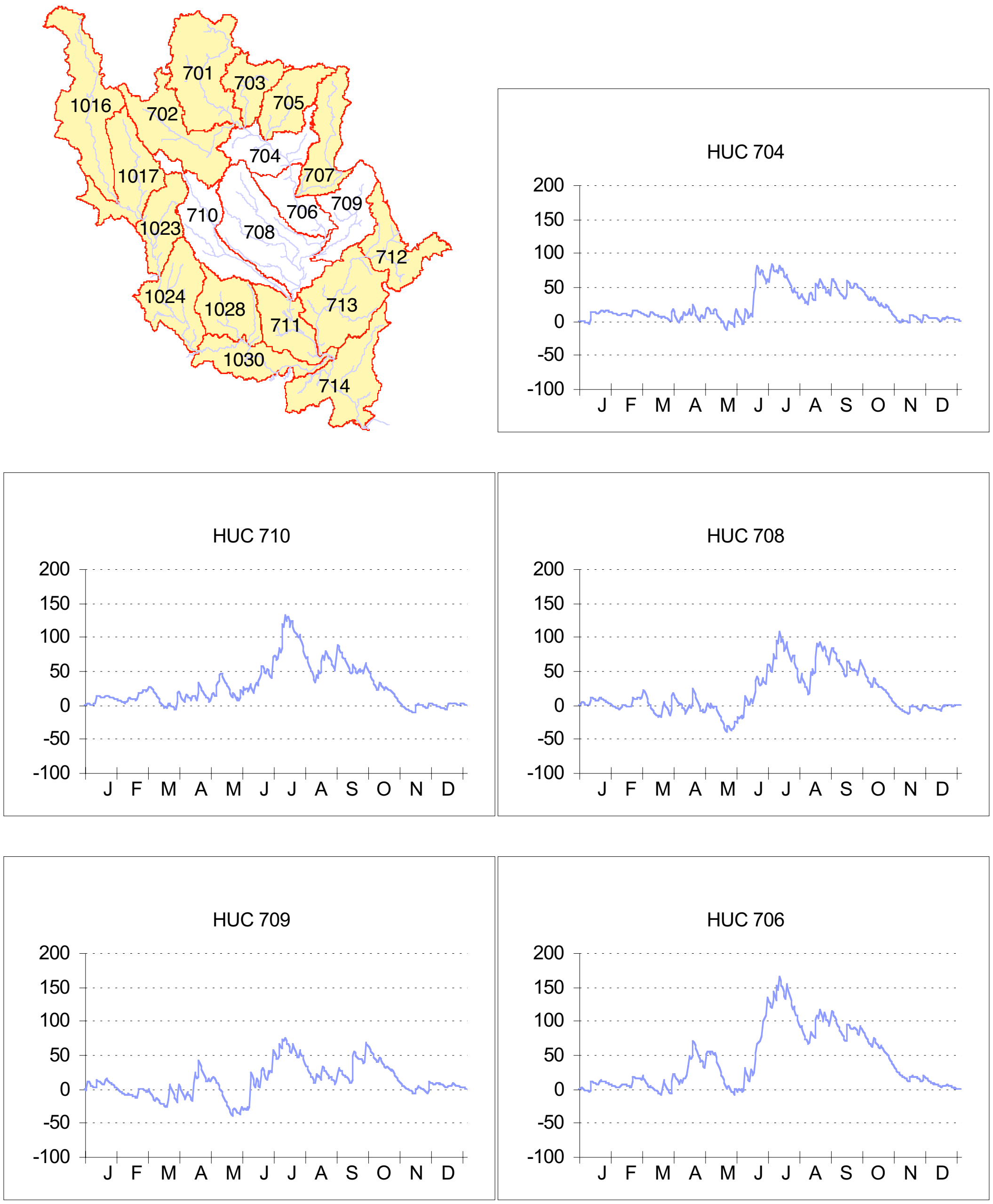


Figure 5.16 The water storage in 4-digit HUCs during 1993 in [mm] (con't).

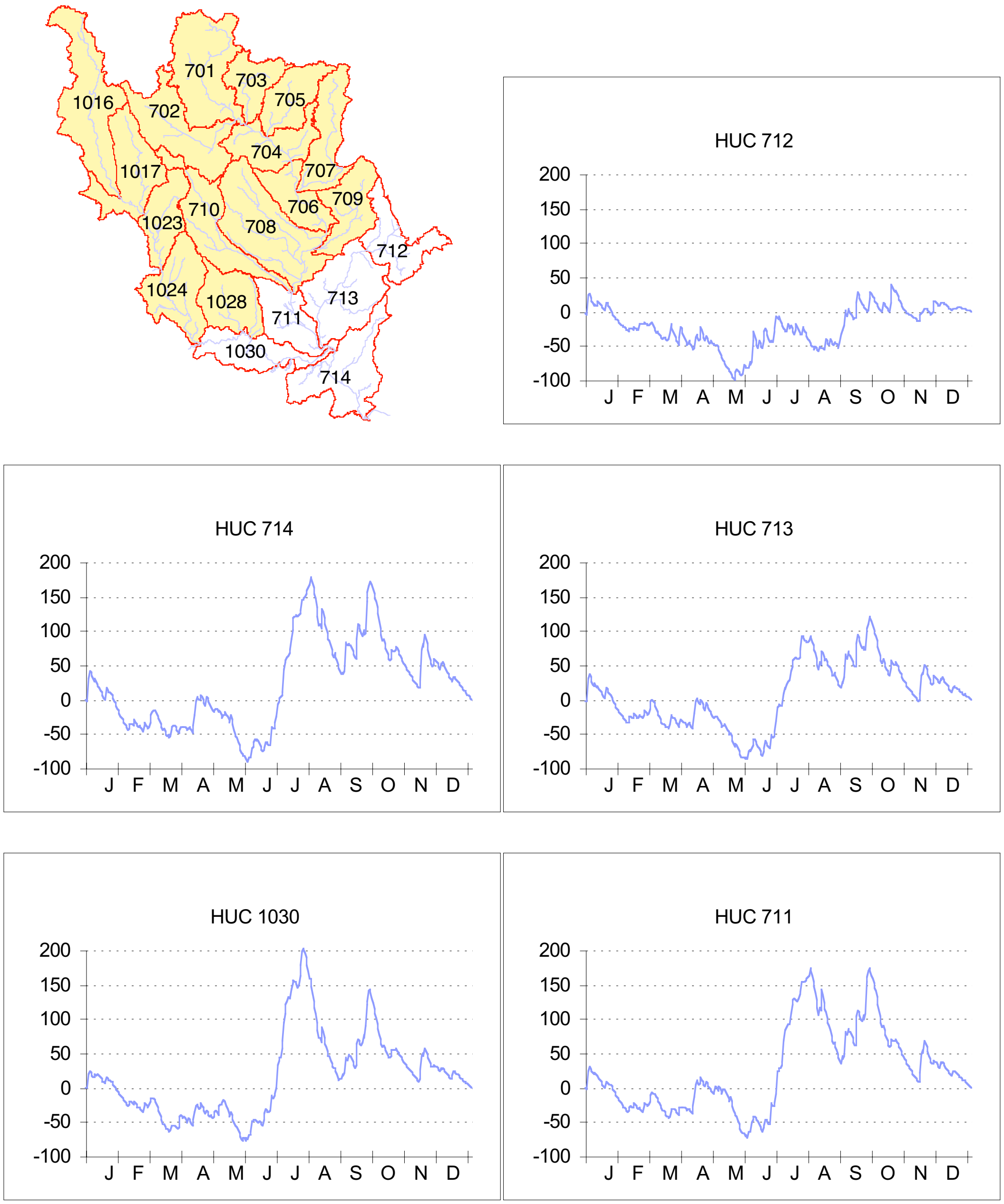


Figure 5.16 The water storage in 4-digit HUCs during 1993 in [mm] (con't).

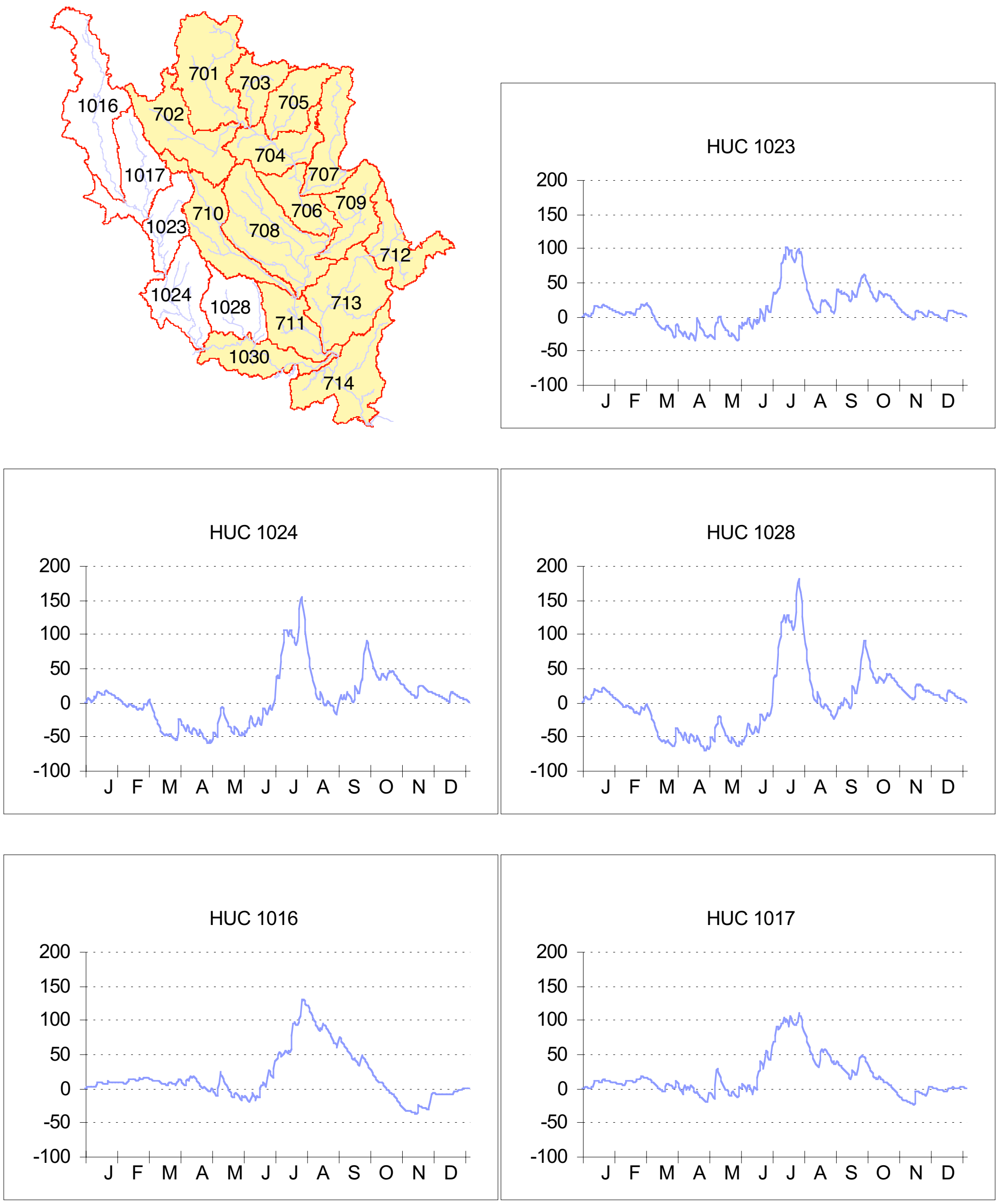


Figure 5.16 The water storage in 4-digit HUCs during 1993 in [mm] (con't).

5.3 Spatiotemporal pattern of retention time

To investigate the changes of retention time in different seasons of the year 1993, a Retention Time Index, RTI, was introduced. This indicator is described by the following formula:

$$RTI_i = \frac{2A_i(S_i - S_{\min,i})}{Q_{out,i} + \sum Q_{in,i}} \tag{5.3}$$

where: *RTI* is a Retention Time Index [day], A_i is the gauged zone area, S_i is the storage, $S_{min,i}$ is the minimum storage in 1993, $Q_{out,i}$ is the river outflow from *i*-th zone, $Q_{in,i}$ are the river inflows into the gauged zone, and *i* is the zone index. A new set of AMLs and a C program were developed to calculate RTI in each gauged zone, for each day of 1993. All data, programs, and results of calculations are stored in the folder `./bal68tim/`. The daily values of RTI were stored in the Polygon Attribute Table (PAT) of `b68tim` coverage.

Figure 7.17 shows RTI for selected catchments. A logarithmic scale is used to show all values. During the Winter months (January, February, and a portion of March), RTI values were extremely high due to the low flow in rivers. In some river the discharges were zero, thus to avoid division by zero (Eq. 5.3), a flow rate of 10^{-6} was assigned to these units.

There is no apparent change in RTI during the flood period, but there are significant differences between the average level of RTI among the gauged zones. For example, excluding winter months, the RTI for zone 5474500 varies from 1 to 10 days, for zone 5543500 it fluctuates around 10 days, and for zones 647600 and 6478500 (located in the northwest part of the study area) the range is 100-1,000 days. For the majority of the zones, the magnitude of RTI varies between 10 to 100 days.

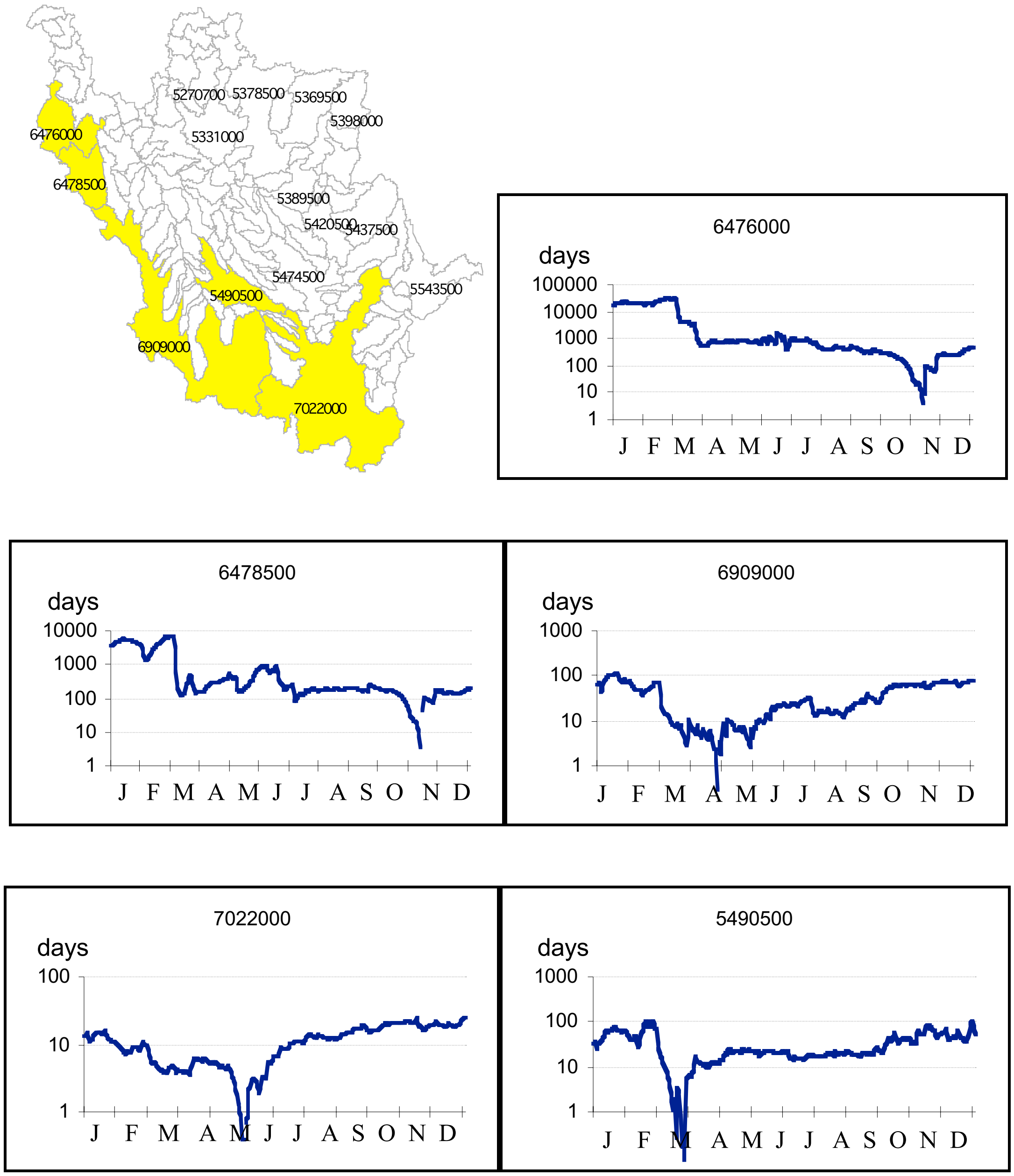


Figure 5.17 Indicator of the retention time in selected gauged zones [days].

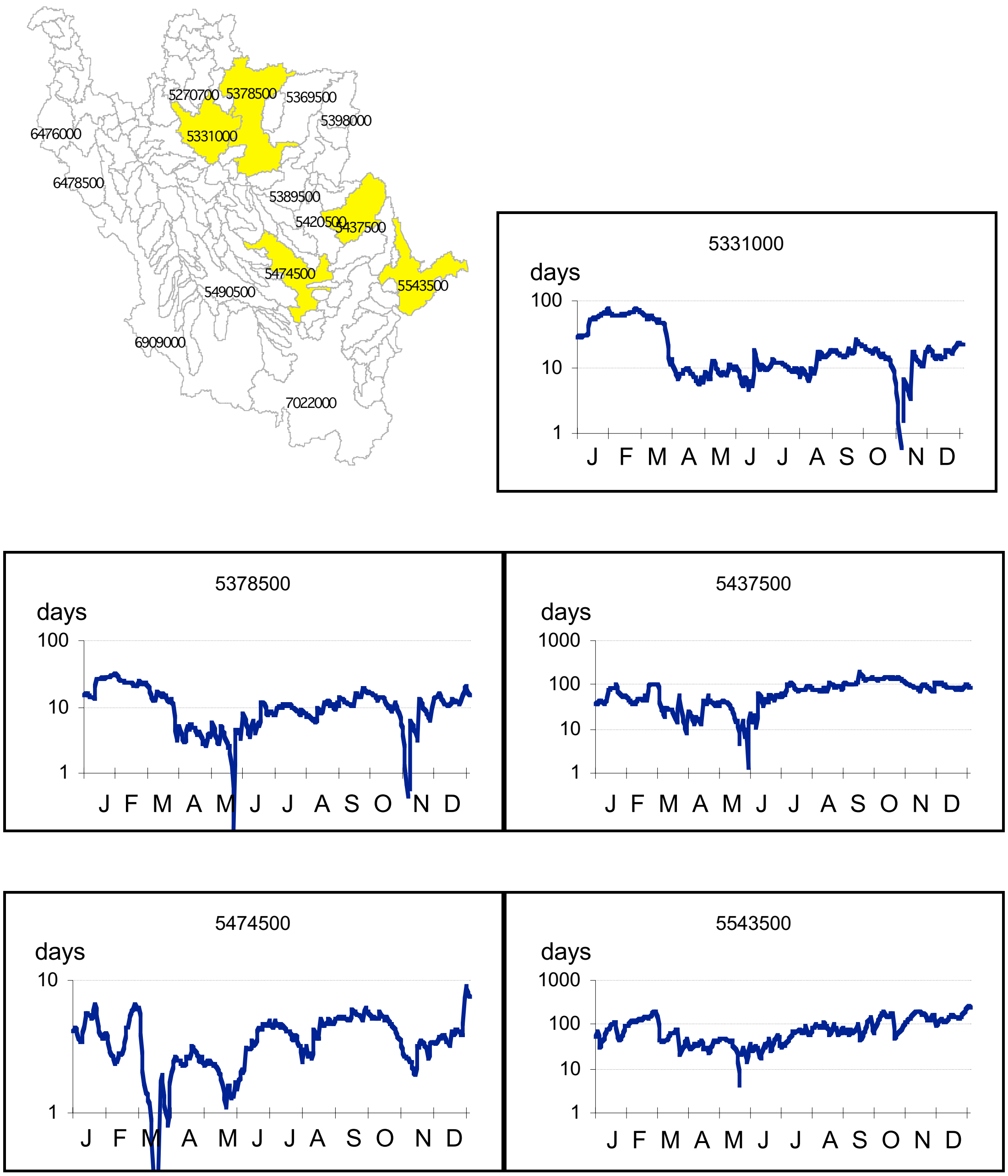
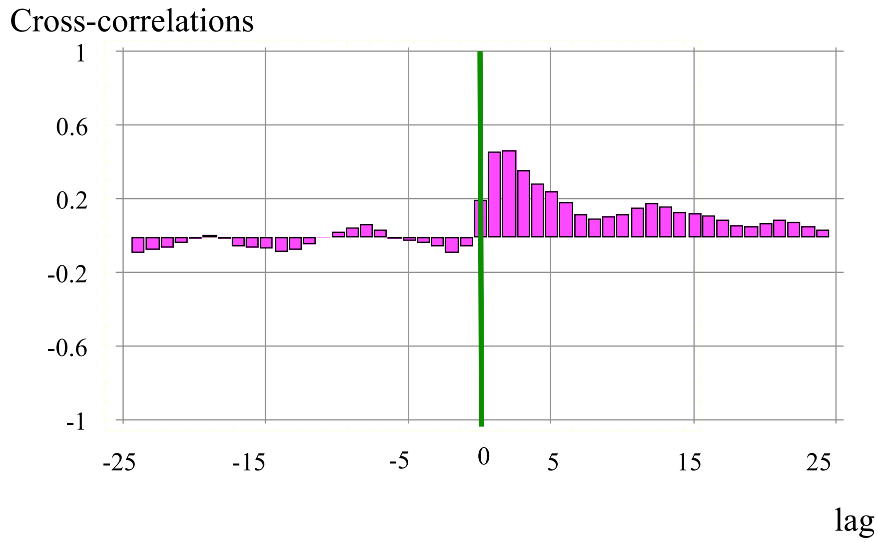


Figure 5.17 Indicator of the retention time in selected gauged zones [days] (con't).

There are other methods that can be applied to study the influence of the watershed morphometry and anthropogenic changes on the flood extent. For example,

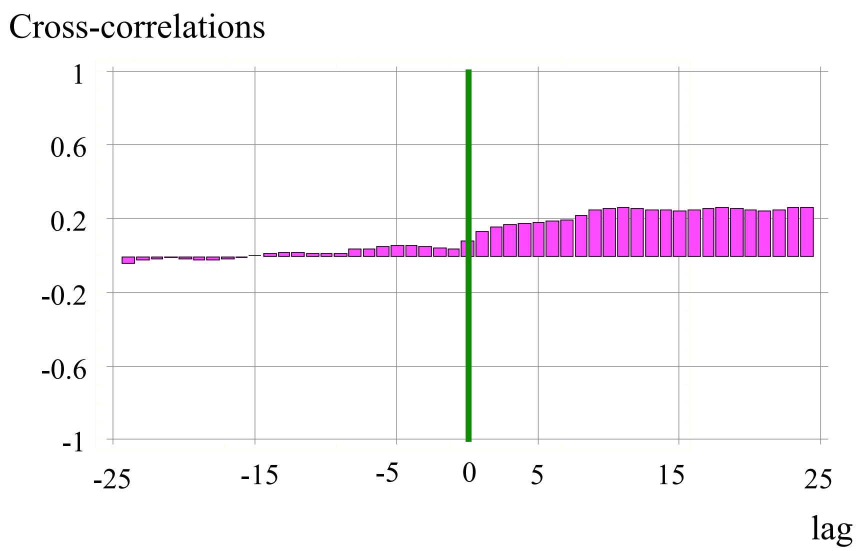
Figure 5.18 shows a cross-correlation of the outflow from two selected zones with precipitation time series lagged 0-13 days. For the outflow zone 5543500, the maximum cross correlation coefficient is for the precipitation time series lagged 1-2 days in relation to the discharge time series. The cross correlation coefficient decreases rapidly showing that the timing of the runoff response to precipitation is very short and practically ends after about 8 days.

Estimated Cross-correlations for q5543500 with p5543500



(a)

Estimated Cross-correlations for q6476000 with p6476000

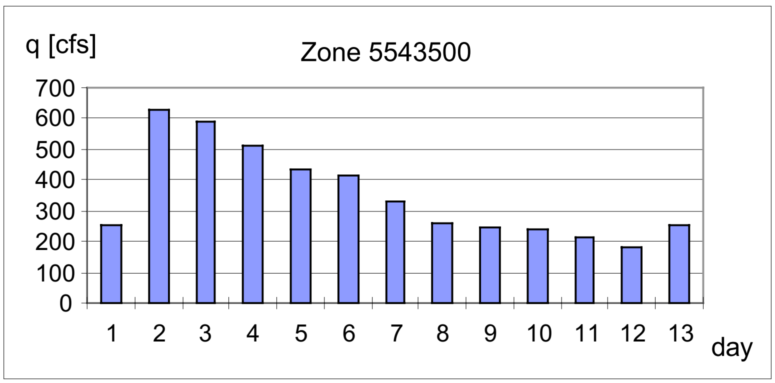


(b)

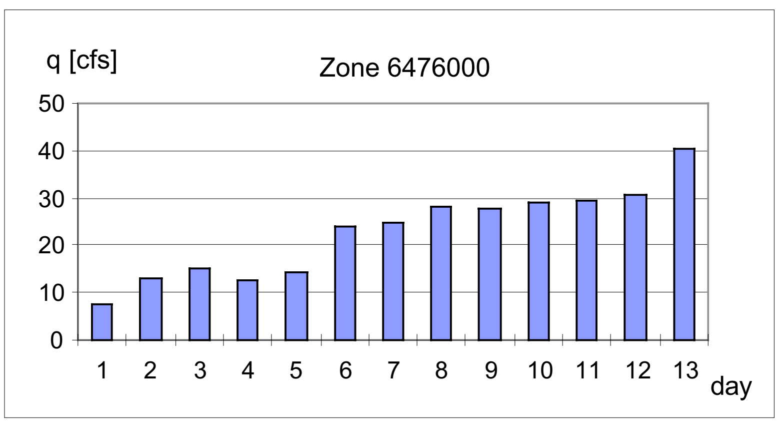
Figure 5.18 Cross-correlation between daily discharge and the lagged in time precipitation time series in 1993. (a) gauged zone 5543500 and

(b) gauged zone 6476000.

The other exemplary zone, 6476000, exhibits an opposite response to the precipitation. Although the average slope of this watershed is smaller than the slope of zone 5543500, the response of the river flow to the precipitation is much "longer". The cross-correlation gradually increases indicating that the discharge is more correlated to the precipitation that occurred earlier (e.g., two weeks earlier) than it is correlated to the precipitation that occurred later (just a few days earlier). The unit hydrographs shown in Figure5.19 supports these findings. Evidently, the water runoff was much faster from a highly urbanized catchment (zone 5543500 is located in the Chicago vicinity), then from the moderately urbanized region in zone 6476000.



(a)



(b)

Figure 5.19 Unit hydrographs estimated by the least squares method; daily values for 1993. (a) gauged zone 5543500 and (b) gauged zone 6476000.

6. Summary and Conclusions

A GIS methodology of estimating a spatially distributed daily water balance for a large region has been developed. A daily water balance was calculated for two sets of gauged zones within the SAST region: a full set of 256 zones (variant `bal66`) and reduced set of 132 zones (variant bal68). Then the water storage was averaged over 4, 6, and 8 digit Hydrologic Units (HUCs). The gauged zones as well as the flow connectivity between them were determined from the 15" DEM (Digital Elevation Model) and from the RF1 (Reach File 1) using Arc/Info GRID tools.

The following GIS databases have been created:

1) daily precipitation depth computed at more than 1,500 climate stations (records from 1,078 stations was used to create 365 grids of spatially distributed precipitation depth values over the SAST region)
2) monthly evaporation depth for 12 months of 1993 for NOAA Climate Divisions that are located at the SAST region
3) observed daily discharge in 261 USGS gauging stations, for 365 days (January 1, 1993 to December 31, 1993)

The water balance was calculated by a program written in the C language. The Arc/Info program TABLES was utilized to extract the data from the database, run the C program, and import the results into an Info file. To obtain the same water storage at the end of the year as was assumed for the beginning of the year, an evaporation multiplication factor was introduced.

On average, i.e. looking at the SAST region as one modeling unit, the storage in the Midwest elevated by about 110 mm of water depth in about two months (from the end of May/beginning of June to the end of July/beginning of August). Water rose by different amounts in each region of the SAST study area. The maximum variation occurred in western and southern hydrologic units. Although the storage increased in the eastern part of the SAST region during the June-July period, the magnitude was not significantly different from the storage variation in other months of the 1993. The highest storage depth increase took place in the most downstream units of the region under investigation, and it almost reached the value of 300 mm for the two month period.

The major findings of this research can be grouped into the four categories listed below:

Spatiotemporal hydrologic modeling

- The GIS technology was successfully applied to perform hydrologic analysis over the large region about 700,000 km^2 in area using a 500x500 m grid

- The GIS technology can be applied to study the hydrologic processes on a daily basis. Daily databases of precipitation and discharge were directly stored in attribute tables.
- The method of using the RF1 stream delineations to "burn in" the streams on the DEM significantly improves the DEM stream network and the watershed boundaries.
- Automatic division of the modeled region into a consistent system of gauged zones and the procedures for determining flow topology of the zones led to an efficient hydrologic modeling system and the ability to perform detailed hydrologic analyses.

Water balance calculation

- Given the available data, it is difficult to estimate water balance for a fraction of a year (i.e., the 1993 portion of the water year). This study showed that some adjustments to water balance components need to be done in order to obtain water balance closure. In this study, the evaporation data was multiplied by coefficients that varied from -0.5 to 2.5 (depending on the variant of the SAST region subdivision)
- The oscillations of the water balance between gauged zones located along large rivers suggests that possible errors in large discharge measurements (i.e. for extremely high river stages) are present
- The water storage increase in the SAST region, considered as a one zone, elevated by about 110 mm the water depth in a two months time period (from the end of May/beginning of June to the end of July/beginning of August). However, the increase in storage estimated for 4-digit HUCs in the southwest portion of the study area was as high as 300 mm.
- A set of digital maps of water storage was created for further analysis of the hydrologic conditions during the 1993 flood.

Residence time

- The residence time index of water in each unit did not exhibit significant change during the flood (summer months) as compared to other months of the year
- The Residence Time Index (RTI) is a useful tool to compare the water storage amounts in different gauged zones

Anthropogenic changes of the watershed response

- The preliminary analysis showed that the lagged cross-correlation coefficients can be applied to test the linear relationship between flow time series and the precipitation time series. This relation can be used to determine the changes in the watershed holding capacities due to human activities
- An alternative method of studying the watershed response functions that can be supported by GIS technology is the method of comparing unit hydrographs estimated for different years

Recommendations for extending and modifying the work

- Expand the analysis for different years from the past. This requires linking the flow, precipitation, and evaporation databases with the GIS system such as ArcView. Modeling water storage for a period of more than one year will help to determine the normal watershed conditions and it will support more precise closure of the water balance.
- The temporal nature of this study can be further enhanced through the use of scientific/geographic visualization technologies. The co-authors of this study, Scott White and Merrill Ridd, have built a suite of dynamic cartographic representations of the water balance study which will provide end users with a visual interpretation of the water storage changes that occurred during 1993.

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APPENDICES

Appendix A	Comparison of water balance at the Earth's surface with SAST region water estimates from moisture flux.
Appendix B	ARC/INFO macros and C-codes
Appendix C	CD-ROM description

Appendix A: Comparison of water balance at the Earth's surface with SAST region water estimates from moisture flux.

This appendix compares the amount of water in the SAST region estimated from precipitation, discharge, and evaporation data with the amount of water calculated from the moisture flux (NetFlux). NetFlux was estimated by Allen Bradley, University of Iowa, and David Maidment and Ye Zichuan, University of Texas at Austin. More information on this research is available at the following URL: http://www.ce.utexas.edu/prof/maidment/ce394k/atmobal/atmobal.htm

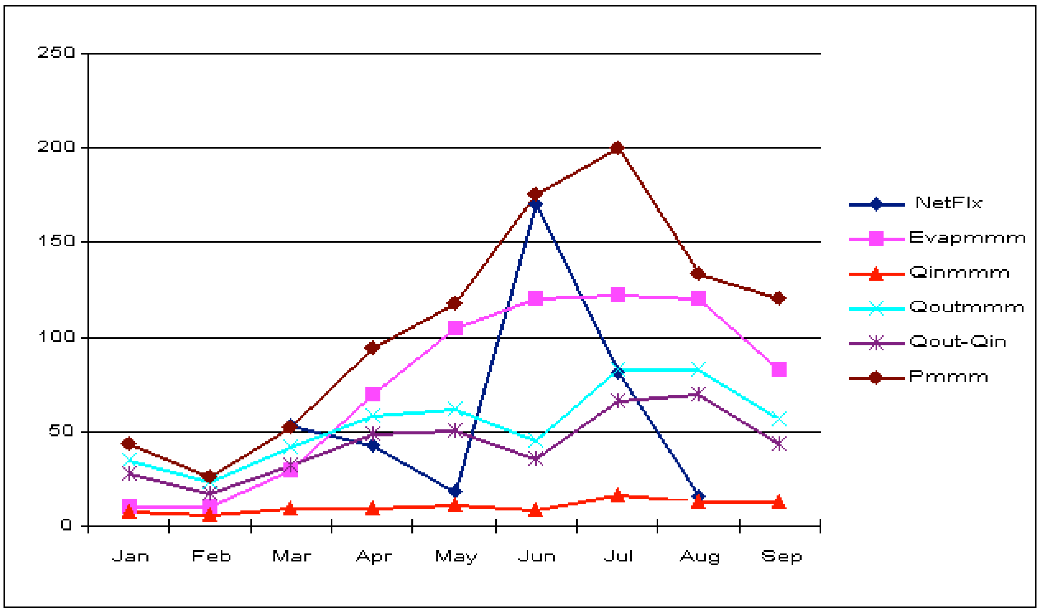

Figure A1. Average monthly hydrologic parameters for the SAST region, 1993.

NetFlx = water depth estimated from the atmospheric moisture flux through the SAST boundaries.
Evapmmm = Monthly evaporation depth [mm/month]
Qinmmm = monthly river inflow into SAST (includes the following rivers: (PLACODEE R AT LOUISVILLE NE, KANSAS R AT DESOTO, KS, GASCONADE RIVER NEAR RICH FOUNTAIN, MO, OSAGE RIVER NEAR ST. THOMAS, MO) as water depth [mm/month]
Qoutmmm = monthly total flow measured in the Mississippi River at Thebes. IL, (station 7022000) [mm/month]
Pmmm = monthly precipitation depth mm/month

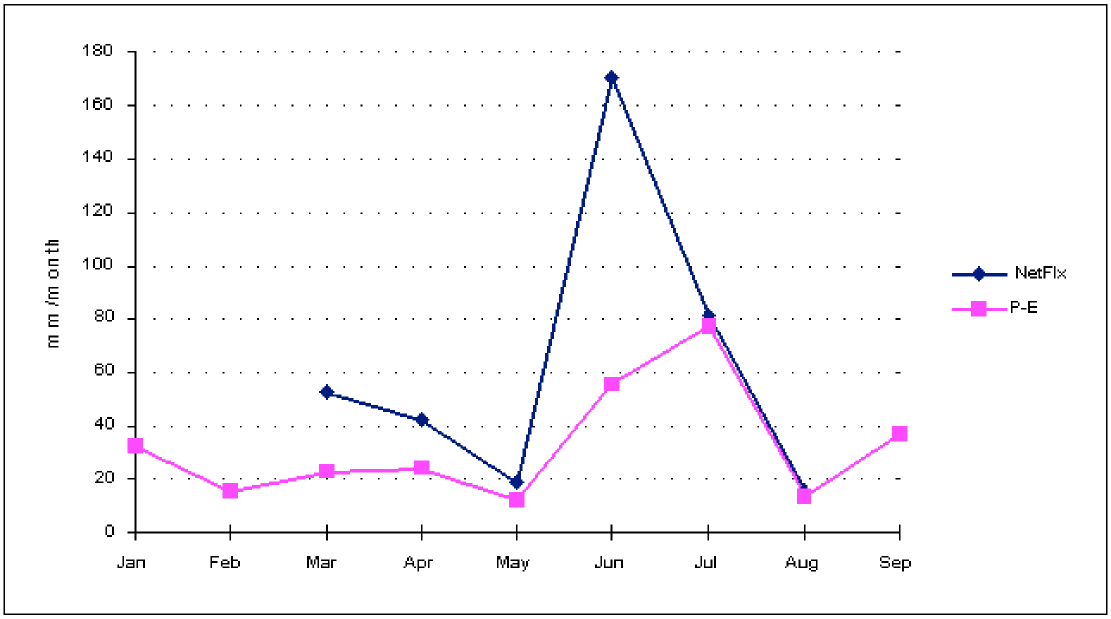

Figure A2. Atmospheric water over the SAST region estimated by two methods: 1) from balloon measurements of atmospheric water content NetFlx; 2) difference between precipitation P and evaporation E. Units: mm/month.

Appendix B: Arc/Info AMLs and C-codes

This appendix contains selected programs used in this research.

1) RAINSAST.AML - Creates grids of daily precipitation
2) NEXTWSH.AML - Creates an INFO file that contains two items: ID and the downstream watershed ID. Also creates a grid of watershed outlets with the value of the downstream watershed ID
3) RMAP56.AML - Creates an INFO table from the grids of daily precipitation
4) EMAP56.AML - Corrected RMAP56.AML to create an INFO file of evaporation
5) BAL1.AML - exports hydrologic data in ASCII format from INFO files, runs C program which calculates water balance, and then creates an INFO table of calculated balance
6) B4V1.C - C program that calculates water balance

B1. RAINSAST.AML

```
/* -----------------------------------------------------------------------
/*   Program: RAINSAST.AML
/*   Purpose: Creates GRIDS of daily precipitation (10e-3 cm/d)
/*            Before this AML runs IDW (inverse distance weight) it
/*            selects all stations that have precipitation depth record
/*            for a given day (set of stations selected can vary from
/*            day to day.
/*            Runs only in GRID
/* -----------------------------------------------------------------------
/*     Usage: &r RAINSAST <fm> <fd> <tm> <td> <wgrid> <xcell>
/*                       <xdat> {YES|NO}
/* Arguments: (input)
/*            (yr = 93)
/*            fm, fd = from year, from month
/*            tm, td = to year, to month
/*            wgrid = a grid for setting the GRID window
/*            xcell = cellsize of the new grids
/*            xdat = point coverage that contains data
/*            yes|no = yes - include records with values = 0
/*                     no - exclude records and stations that have 0
/*                          (default)
/* Temporary: xxxxx1
/*   Globals:
/*    Locals: templ, nitem, nit, mt,dy, selec (variables)
/* -----------------------------------------------------------------------
/*     Calls:
/* -----------------------------------------------------------------------
/*     Notes: Data are stored in PAT (point). Each record is related to
/*            gauging stations. The following naming convention is used
/*            for items: myymmdd, where m indicates monthly values,
/*            yy = year, mm = month,dd = day for example item that
/*            stores the records for 13 March 1976 has the name p760313
/* -----------------------------------------------------------------------
/*    History: Coded by Pawel Mizgalewicz  08/08/96
/*
/* -----------------------------------------------------------------------
&args fm fd tm td wgrid xcell xdat zero
&severity &error &routine bailout
&if [SHOW PROGRAM] <> GRID &then ; &return This only runs in GRID.
&if [null %xdat%] &then
 &do
  &call usage
  &return
 &end
&if [null %zero%] &then ; &s zero = YES
&s xx = [translate %zero%]
&select %xx%
  &when NO
    &s klm = gt
  &when YES
    &s klm = ge
  &otherwise
    &do
      &call usage
      &return
    &end
&end /* select
/* ========== settings !!! ================
```

```
/* year: 93
&s yr = 93
&s templ = pyy0m0d

&s nitem0 = [subst %templ% yy %yr% ]
/* unit convertion factor:
/* 1 inch = 25.4 mm = 0.0254 m (mm are multiplied by 1000
/*    to preserve accuracy when converted to INTEGER)
/* To get the results back to mm, the grids need to be
/* divided by 1000
&s cfac = 25400
/* ========================================
&messages &off
/* ======  set the window and the cell size ===========
setwindow %wgrid%
setcell %xcell%
&DO mt = %fm% &to %tm%
  &if %mt% lt 10 &then
    &sv nitem1 = [subst %nitem0% m %mt% ]
  &else
    &sv nitem1 = [subst %nitem0% 0m %mt% ]
  &DO dy = 1 &to 31
    &s ab = [calc %mt% = %fm%] AND [calc %dy% lt %fd%]
    &s bb = [calc %mt% = %tm%] AND [calc %dy% gt %td%]
    &s cc = %ab% OR %bb%
    &IF NOT %cc%  &THEN
      &do
           &if %dy% lt 10 &then
             &sv nitem = [subst %nitem1% d %dy% ]
           &else
             &sv nitem = [subst %nitem1% 0d %dy% ]
           &type %nitem%
/* check if the item exists
&s iexists = [iteminfo %xdat% -point %nitem% -exists]
&if %iexists% &then
&do
           /* &s namit%nit% = %nitem%
           &sv selec = res %nitem% %klm% 0
          &type selecting stations  %selec%
arc reselect %xdat% xxxxx1 point
%selec%
~
n
n
      &end
    arc build xxxxx1 point
    %nitem% = int ( %cfac% * idw ( xxxxx1, %nitem% ) )
    kill xxxxx1 all
&end
  &end
&end
&messages &on
&return
/*-------------
&routine USAGE
/*-------------
&type Usage: &r RAINSAST <from_mt> <from_dy> <to_mt> <to_dy> <a_grid>
&type              <cell_size> <point_coverage> {YES|NO}
&return &inform /*-------------
&routine EXIT
/*-------------
/* delete all temporary files:
&if [exists xxxxx1 -COVER] &then ; kill xxxxx1 all
&messages &on
```

```
&return
/*--------------
&routine BAILOUT
/*--------------
&severity &error &ignore
&call exit
&return &warning An error has occurred in SELDATA.AML


/* ------------------------------------------------------------------------
/*     EXAMPLE OF APPLICATION
/* ------------------------------------------------------------------------
/*      /* input
/* &s data = $HOME/flood/precip/poinmap/prec50    /* point coverage
/* &s wgrid = $HOME/flood/dem/buf50g              /grid window sample
/* grid
/* &run rainsast 1 1 1 4 %wgrid% 2000 %data% YES
/* q
/* &return                               /* return from the example AML
/* ------------------------------------------------------------------------
&r rs 1 1 1 4 ~/flood/dem/buf50g 2000 ~/flood/precip/poinmap/prec50 YES
```

B2. NEXTWSH.AML

```
/* ----------------------------------------------------------------------
/*   Program: NEXTWSH.AML
/*   Purpose: Creates an info file that contains two items: ID and the
/*            downstream watershed ID. Also creates a grid of watersheds'
/*            outlets that contains the ID of downstream watershed.
/*            Runs only in GRID
/* ----------------------------------------------------------------------
/*     Usage: &r NEXTWSH <fdir> <fwsh> <flpp> <infn> <idin> <nxin> <fnxt>
/* Arguments: (input)
/*            fdir = (grid) flow direction
/*            fwsh = (grid) watersheds (partial drainage areas)
/*                          value in VAT = unit_id number
/*            flpp = (grid) pour points ( watershed outlets)
/*                          value in VAT = unit_id number
/*            (output)
/*            infn = (info file) name of the info file to be created
/*            idin = (item) name of the item in which the unit_id number
/*                          will be stored
/*            nxin = (item) name of the item in which the downstream
/*                          unit_id will be stored
/*            fnxt = (grid) similar to the %flpp% (watershed outlets):
/*                          the values in VAT are not equal to the unit_id
/*                          number, they equal to the downstream unit
/*                          ID number.
/* Temporary: xxxtmp, xxxcomnx, (GRIDS)
/*            xxxtmp1 (INFO)
/*   Globals:
/*    Locals: see Temporary
/* ----------------------------------------------------------------------
/*      Calls:
/* ----------------------------------------------------------------------
/*      Notes: The ID of the next watershed for the most downstream
/*             watershed equals 0.
/*             If the flowdirection in watershed pour point can't be
/*             determined, the next watershed ID = -1
/*             This AML checks neither for the existence and correctness
/*             of the input files nor for the existence of files that have
/*             the same names as the temporary files and the files to be
/*             created.
/*             If an error occurs then all grids and all info files that
/*             have the same name as output grids/info files and temporary
/*             grids/info are erased !!!
/* ----------------------------------------------------------------------
/*    History: original coding by Pawel Mizgalewicz  12/20/93
/*             (tested on the Allegheny River basin). Major part
/*             extracted from net4.aml ( tested for the Cedar River
/*             - Iowa River basin, grid = 3000^2 cells, basin =
/*             3.2*10e6 cells of size 100m*100m),
/*             and converted into a stand alone procedure 06/10/95
/*             e-mail: pawel@nile.crwr.utexas.edu
/*  ======================================================================
&args fdir fwsh flpp infn idin nxin fnxt
&severity &error &routine bailout
&if [SHOW PROGRAM] <> GRID &then
   &return This only runs in GRID.
&if [null %fnxt%] &then
 &do
  &call usage
```

```
  &return
 &end
&messages &off

/* -----------------------------------------------------------------------
/*       Downstream watershed
/* -----------------------------------------------------------------------
&type searching for next watershed [date -vfull]
&sv wsh = xxxtmp
%wsh% = con ( isnull ( %fwsh%), 0, %fwsh% )
&type start %fnxt% [date -vfull]
%fnxt% = con (%flpp% > 0, con (%fdir% == 1, %wsh%(1,0), ~
        con (%fdir% == 2, %wsh%(1,1), ~
        con (%fdir% == 4, %wsh%(0,1), ~
        con (%fdir% == 8, %wsh%(-1,1), ~
        con (%fdir% == 16, %wsh%(-1,0), ~
        con (%fdir% == 32, %wsh%(-1,-1), ~
        con (%fdir% == 64, %wsh%(0,-1), ~
        con (%fdir% == 128, %wsh%(1,-1), -1)))))))))
kill xxxtmp all
&if not [exists %fnxt%.vat -info] &then
    buildvat %fnxt%
/* the %fnxt% grid is similar to the %flpp%, watershed outlets grid.
/* The cell value is equal to the next watershed ID number
xxxcomnx = combine ( %flpp% , %fnxt% )
/* -----------------------------------------------------------------------
/*      Create info file
/* -----------------------------------------------------------------------
arc additem xxxcomnx.vat xxxtmp1 %idin% 4 8 B
arc additem xxxtmp1 xxxtmp1 %nxin% 4 8 B
cursor xxnext declare xxxtmp1 info rw
cursor xxnext open
&do &while %:xxnext.aml$next%
  &s :xxnext.%idin% = [value :xxnext.%flpp%]
  &s :xxnext.%nxin% = [value :xxnext.%fnxt%]
  cursor xxnext next
&end
cursor xxnext close
cursor xxnext remove
arc pullitems xxxtmp1 %infn%
%idin%
%nxin%
end
kill xxxcomnx all
&s x = [delete xxxtmp1 -info]
&messages &on
&return
/*-------------
&routine USAGE
/*-------------
&type Usage: &r NEXTWSH <fdir_grid> <wsh_grid> <pourpt_grid> <newINF_name>
&type               <id_item_name> <next_id_item_name> <nextwsh_grid>
&return &inform
/*-------------
&routine EXIT
/*-------------
/* delete all temporary files:
&if [exists xxxtmp1 -info ] &then ; &s x = [delete xxxtmp1 -info]
&if [exists xxxtmp -GRID] &then ; kill xxxtmp all
&if [exists xxxcomnx -GRID] &then ; kill xxxcomnx all
&if [exists %fnxt% -GRID] &then ; kill %fnxt% all
&return
/*--------------
&routine BAILOUT
```

```
/*--------------
&severity &error &ignore
&call exit
&return &warning An error has occurred in NEXTWSH.AML
/* ---------------------------------------------------------------------------
/*     EXAMPLE OF APPLICATION
/* ---------------------------------------------------------------------------


/* grid
/*      /* input
/* &s fdir = $HOME/iowa/data/crfdr     /* crfdr = flowdirection(elev_grid)
/* &s fwsh = crwsh                     /* watersheds
/* &s flpp = crlpp                     /* pour points
/*     /* output
/* &s fnxt = crnxt                     /* outflow,value=downstream wshd ID
/* &s infn = %fnxt%.dat                /* new info file
/* &s idin = unit_id                   /* item (unit ID)
/* &s nxin = next_id                   /* item ( downstream unit ID)
/*
/* &run nextwsh %fdir% %fwsh% %flpp% %infn% %idin% %nxin% %fnxt%
/*
/* q                                   /* quit from GRID
/*
/* &return                             /* return from example AML
/* ---------------------------------------------------------------------------
```

B3. RMAP56.AML

```
/* -----------------------------------------------------------------------
/*   Program: RMAP56.AML
/*   Purpose: Creates INFO file that contains average value of rainfall
/*            (or other parameter) for specified zones. The daily
/*            values are extracted from the precipitation grids.
/*   Method:  Zonal average values are calculated and then stored
/*            in INFO table (in field), day by day.
/*            Runs only in GRID
/* -----------------------------------------------------------------------
/*     Usage: &r RMAP56 <fm> <fd> <tm> <td> <p_path> <zone> <outinf>
/*                        <id_itm> <prc> <kcell> {prx}
/* Arguments: (input)
/*            fm, fd = from month, from day
/*            tm, td = to month, to month
/*            p_path = folder in which maps(grids) of rainfall are stored
/*            zone   = (grid) defines zones and their IDs
/*                     = it means that the grid name is used
/*            outinf = (info) output info file to be created
/*            id_itm = (item) name of the item in which the zone ID will
/*                     stored
/*            prc    = (number) "precision" - the data must be converted
/*                     into integer values. Before they are converted they
/*                     are multiplied by <prc> to preserve decimal part
/*                     of value.
/*            prx    = (prefix). Prefix of the names of precipitation maps
/*                     and the names of the items that are created
/*                     in <outinf> info file = <prx> + names
/*                     ("p" = default).
/* Temporary: xxx, xxx2, xxxcom (grid), xxxtmp1 (info)
/*   Globals:
/*    Locals: ab, bb, cc, nitem, prfnitem, yr,mt  (variables)
/* -----------------------------------------------------------------------
/*     Calls:
/* -----------------------------------------------------------------------
/*     Notes: The following naming convention is used for items in PAT
/*            pyymmdd,     where:  p indicates precipitation)
/*            (there is also user defined prefix),  yy= year,
/*            mm = month, dd = day, for example an item that contains
/*            records for 17 March 1976 has the name "prefix"+"p19760317"
/*            !!!!  Grids of precipitation I used are in 10e-3 [mm]
/*            To go back to [mm] the %prc% inside this AML is
/*            multiplied by 1000 before values are stored in INFO table !!
/* -----------------------------------------------------------------------
/*    History: Adopted from RAININFO.AML  09/10/95
/*             PM.
/* -----------------------------------------------------------------------
&args fm fd tm td p_path zone outinf id_itm prc prx
&severity &error &routine bailout
&if [SHOW PROGRAM] <> GRID &then ; &return This only runs in GRID.
&if [null %prc%] &then
 &do
  &call usage
  &return
 &end
&if [null %prx%] &then ; &s prx = p
&messages &off
/* GRID settings:
&s xxcell = [show setcell]
&s xxwindow = [show setwindow]
/* -----------------------------------------------------------------------
```

```
/*       Make a copy of %zone%.VAT file and add item %zone%
/* --------------------------------------------------------------------------


arc additem %zone%.vat xxxtmp1 %zone% 4 5 B
cursor xxcur1 declare xxxtmp1 info rw
cursor xxcur1 open
&do &while %:xxcur1.aml$next%
  &s :xxcur1.%zone% = %:xxcur1.VALUE%
  cursor xxcur1 next
&end
cursor xxcur1 close
cursor xxcur1 remove
/* ========== settings !!! ================
/* year: 93
&s yr = 93
&s templ = yy0m0d
&s nitem0 = [subst %templ% yy %yr% ]
/* ==========================================
/* --------------------------------------------------------------------------
/*       Do it for all selected years and months
/* --------------------------------------------------------------------------
&DO mt = %fm% &to %tm%
 &if %mt% lt 10 &then
   &sv nitem1 = [subst %nitem0% m %mt% ]
 &else
    &sv nitem1 = [subst %nitem0% 0m %mt% ]
 &DO dy = 1 &to 31
  &s ab = [calc %mt% = %fm%] AND [calc %dy% lt %fd%]
  &s bb = [calc %mt% = %tm%] AND [calc %dy% gt %td%]
  &s cc = %ab% OR %bb%
  &IF NOT %cc%  &THEN
    &do
      &if %dy% lt 10 &then
        &sv nitem = [subst %nitem1% d %dy% ]
      &else
        &sv nitem = [subst %nitem1% 0d %dy% ]
      &type processing item %nitem% ... [date -vfull]
/* -------------------------------------------------------------------------
/* &DO yr = %ty% &to %fy% &by -1
/*   &DO mt = 12 &to 1 &by -1
/*    &s ab = [calc %yr% = %fy%] AND [calc %mt% lt %fm%]
/*    &s bb = [calc %yr% = %ty%] AND [calc %mt% gt %tm%]
/*    &s cc = %ab% OR %bb%
/*    &IF NOT %cc%  &THEN
/*      &do
/*        &s templ = mxxxx0y
/*        &s nitem = [subst %templ% xxxx %yr% ]
/*        &if %mt% lt 10 &then
/*            &sv nitem = [subst %nitem% y %mt% ]
/*          &else
/*            &sv nitem = [subst %nitem% 0y %mt% ]
/*        &type  processing item %nitem% ... [date -vfull]
/* ------------------------------------------------------------------------
        /* put together the name of precipitation grid
        /*
        &sv xxx = %p_path%%prx%%nitem%
        setcell %zone%
        setwindow %zone%
        /* calculate zonal mean ( units micrometers/d ?)
        xxx3 = zonalmean ( %zone% , %xxx% )
        /* multiply by precision ... ( 10 ?)
        xxx4 = %prc% * xxx3
        kill xxx3 all
```

```
        xxx2 = int ( xxx4 )
        kill xxx4 all
        /* xxx2 = int ( %prc% * zonalmean ( %zone% , %xxx% ))
        xxxcom = combine (%zone%, xxx2)
/* here an error may occur.
        kill xxx2 all
        &s prfnitem = %prx%%nitem%

        arc additem xxxcom.vat xxxcom.vat %prfnitem% 4 12 F 4 xxx2
        cursor xxcur1 declare xxxcom.vat info rw
        cursor xxcur1 open
        /* !!! %prc% is multiplied by 1000, because precipitation grids
        /* were not in [cm] but in 10-3 [mm] (to preserve precision
        /* in integer form

       &s prc2 = [calc %prc% * 1000]
       &do &while %:xxcur1.aml$next%
           &s :xxcur1.%prfnitem% = [calc %:xxcur1.xxx2% / %prc2%]
           cursor xxcur1 next
        &end
        cursor xxcur1 close
        cursor xxcur1 remove
        arc joinitem xxxtmp1 xxxcom.vat xxxtmp1 %zone% %zone%
        arc dropitem xxxtmp1 xxxtmp1 xxx2
        kill xxxcom all
      &end
 &end
&end
/* ------------------------------------------------------------------------
&type Adding ID item ... [date -vfull]
/* ------------------------------------------------------------------------
arc additem xxxtmp1 xxxtmp1 %id_itm% 4 8 B # %zone%
cursor xxcur2 declare xxxtmp1 info rw
cursor xxcur2 open
&do &while %:xxcur2.aml$next%
           &s :xxcur2.%id_itm% = [value :xxcur2.%zone%]
           cursor xxcur2 next
&end
cursor xxcur2 close
cursor xxcur2 remove
/* ------------------------------------------------------------------------
&type Cleaning INFO table (dropping redundant items) ... [date -vfull]
/* ------------------------------------------------------------------------
arc dropitem xxxtmp1 xxxtmp1 value
arc dropitem xxxtmp1 xxxtmp1 count
arc dropitem xxxtmp1 %outinf% %zone%
&s x = [delete xxxtmp1 -info]
/* restore GRID settings:
setcell %xxcell%
setwindow %xxwindow%
&messages &on
&return
/*-------------
&routine USAGE
/*-------------
&type Usage: &r RMAP56 <fm> <fd> <tm> <td> <p_path> <zone> <out_inf>
&type                    <ID_item> <prc> {prefix}
&return &inform
/*-------------
/* &routine CHECK
/*-------------
/* IF temporary file exists, inform and exit
/* If file to be build exists , inform and exit
/* If input file is not correct or does not exist, inform and exit
```

```
/* return
/*-------------
&routine EXIT
/*-------------
/* delete all temporary files:
&if [exists xxxtmp1 -info ] &then;   &s x = [delete xxxtmp1 -info]
&if [exists xxx -GRID] &then ; kill xxx all
&if [exists xxx2 -GRID] &then ; kill xxx2 all
&if [exists xxx3 -GRID] &then ; kill xxx3 all
&if [exists xxx4 -GRID] &then ; kill xxx4 all
&if [exists xxxcom -GRID] &then ; kill xxxcom all


/* restore GRID settings:
setcell %xxcell%
setwindow %xxwindow%
&messages &on
&return
/*--------------
&routine BAILOUT
/*--------------
&severity &error &ignore
&call exit
&return &warning An error has occurred in RAININFO.AML
/* ---------------------------------------------------------------------------
/*     EXAMPLE OF APPLICATION
/* ---------------------------------------------------------------------------
/* grid
/* &s fm = 1
/* &s fd = 1
/* &s tm = 1
/* &s td = 31
/* &s p_path = $home/iowa/rainmaps/
/* &s zone = crwsh
/* &s id unit_id
/*
/* &r rmap56 %fm% %fd% %tm% %td% %p_path% %zone% prcinf2 %unit_id% 10 p
/*
/* q
/* &return
/* ---------------------------------------------------------------------------
```

B4. EMAP56.AML

```
grid
&messages &off
/* -----------------------------------------------------------------------
/*   Program: eMAP56.AML
/*  !!!! this is a version of rmap56.aml !!! some comments written here
/*      are not valid !!! parameters are set inside this AML, they are
/*      not passed through &args. Monthly time step is applied !!!!!
/*   Purpose: Creates INFO file that contains average value of Evaporation
/*            (or other parameter) for specified zones.
/*   Method:  Zonal average values are calculated and then stored
/*            in INFO table (in field), day by day (month by month).
/*            Runs only in GRID
/* -----------------------------------------------------------------------
/*     Usage: &r RMAP56 <fm> <fd> <tm> <td> <p_path> <zone> <outinf>
/*                        <id_itm> <prc> <kcell> {prx}
/* Arguments: (input)
/*            fm, fd = from month, from day
/*            tm, td = to month, to month
/*            p_path = folder in which maps(grids) of rainfall are stored
/*            zone   = (grid) defines zones and their IDs
/*                    = it means that the grid name is used
/*            outinf = (info) output info file to be created
/*            id_itm = (item) name of the item in which the zone ID will
/*                     stored
/*            prc    = (number) "precision" - the data must be converted
/*                     into integer values. Before they are converted they
/*                     are multiplied by <prc> to preserve decimal part
/*                     of value.
/*            prx    = (prefix). Prefix of the names of precipitation maps
/*                     and the names of the items that are created
/*                     in <outinf> info file = <prx> + names
/*                     ("p" = default).
/* Temporary: xxx, xxx2, xxxcom (grid), xxxtmp1 (info)
/*   Globals:
/*    Locals: ab, bb, cc, nitem, prfnitem, yr,mt  (variables)
/* -----------------------------------------------------------------------
/*     Calls:
/* -----------------------------------------------------------------------
/*     Notes: The following naming convention is used for items in PAT
/*            pyymmdd,     where:  p indicates precipitation)
/*            (there is also user defined prefix),  yy= year,
/*            mm = month, dd = day, for example an item that contains
/*            records for 17 March 1976 has the name "prefix"+"p19760317"
/*            !!!!  Grids of precipitation I used are in 10e-3 [mm]
/*            To go back to [mm] the %prc% inside this AML is
/*            multiplied by 1000 before values are stored in INFo table !!
/* -----------------------------------------------------------------------
/*    History: Adopted from RAININFO.AML  09/10/95
/*             PM.
/* -----------------------------------------------------------------------
/* &args fm fd tm td p_path zone outinf id_itm prc prx
&s fm = 1
&s tm = 13
&s zone zones56
&s outinf evap.dat
&s id_itm unit_id
&s prc = 10
&s prx = e
```

```
&severity &error &routine bailout
&if [SHOW PROGRAM] <> GRID &then ; &return This only runs in GRID.
&if [null %prc%] &then

 &do
  &call usage
  &return
 &end
&if [null %prx%] &then ; &s prx = e
&messages &off
/* GRID settings:
&s xxcell = [show setcell]
&s xxwindow = [show setwindow]
/* ---------------------------------------------------------------------------
/*       Make a copy of %zone%.VAT file and add item %zone%
/* ---------------------------------------------------------------------------
arc additem %zone%.vat xxxtmp1 %zone% 4 5 B
cursor xxcur1 declare xxxtmp1 info rw
cursor xxcur1 open
&do &while %:xxcur1.aml$next%
  &s :xxcur1.%zone% = %:xxcur1.VALUE%
  cursor xxcur1 next
&end
cursor xxcur1 close
cursor xxcur1 remove
/* ========== settings !!! ================
/* year: 93
&s yr = 93
&s templ = yy0m00
&s nitem0 = [subst %templ% yy %yr% ]
/* ========================================
/* ---------------------------------------------------------------------------
/*       Do it for all selected years and months
/* ---------------------------------------------------------------------------
&DO mt = %fm% &to %tm%
 &if %mt% lt 10 &then
   &sv nitem = [subst %nitem0% m %mt% ]
 &else
    &sv nitem = [subst %nitem0% 0m %mt% ]
      &type processing item %nitem% ... [date -vfull]
/* --------------------------------------------------------------------------
/* -------------------------------------------------------------------------
        /* put together the name of precipitation grid
        /*
        &sv xxx = %prx%%nitem%
        setcell %zone%
        setwindow %zone%
        /* calculate zonal mean ( units micrometers/d ?)
        xxx3 = zonalmean ( %zone% , %xxx% )
        /* multiply by precision ... ( 10 ?)
        xxx4 = %prc% * xxx3
        kill xxx3 all
        xxx2 = int ( xxx4 )
        kill xxx4 all
        xxxcom = combine (%zone%, xxx2)
/* here an error may occur.
        kill xxx2 all
        &s prfnitem = %prx%%nitem%
        arc additem xxxcom.vat xxxcom.vat %prfnitem% 4 12 F 4 xxx2
        cursor xxcur1 declare xxxcom.vat info rw
        cursor xxcur1 open
        /* !!! %prc% is multiplied by 1000, because precipitation grids
        /* were not in [cm] but in 10-3 [mm] (to preserve precision
        /* in integer form
```

```
       &s prc2 = [calc %prc% * 1000]
       &do &while %:xxcur1.aml$next%
           &s :xxcur1.%prfnitem% = [calc %:xxcur1.xxx2% / %prc2%]
           cursor xxcur1 next
        &end
        cursor xxcur1 close


        cursor xxcur1 remove
        arc joinitem xxxtmp1 xxxcom.vat xxxtmp1 %zone% %zone%
        arc dropitem xxxtmp1 xxxtmp1 xxx2
        kill xxxcom all
/*       &end
/*  &end
&end
/* ---------------------------------------------------------------------
&type Adding ID item ... [date -vfull]
/* ---------------------------------------------------------------------
arc additem xxxtmp1 xxxtmp1 %id_itm% 4 8 B # %zone%
cursor xxcur2 declare xxxtmp1 info rw
cursor xxcur2 open
&do &while %:xxcur2.aml$next%
           &s :xxcur2.%id_itm% = [value :xxcur2.%zone%]
           cursor xxcur2 next
&end
cursor xxcur2 close
cursor xxcur2 remove
/* ---------------------------------------------------------------------
&type Cleaning INFO table (dropping redundant items) ... [date -vfull]
/* ---------------------------------------------------------------------
arc dropitem xxxtmp1 xxxtmp1 value
arc dropitem xxxtmp1 xxxtmp1 count
arc dropitem xxxtmp1 %outinf% %zone%
&s x = [delete xxxtmp1 -info]
/* restore GRID settings:
setcell %xxcell%
setwindow %xxwindow%
&messages &on
&type end of dec [date -vfull]
q
q
&return
/*-------------
&routine U.S.AGE
/*-------------
&type Usage: &r eRMAP56 <fm> <fd> <tm> <td> <p_path> <zone> <out_inf>
&type                  <ID_item> <prc> {prefix}
&return &inform
/*-------------
/* &routine CHECK
/*-------------
/* IF temporary file exists, inform and exit
/* If file to be build exists , inform and exit
/* If input file is not correct or does not exist, inform and exit
/* return
/*-------------
&routine EXIT
/*-------------
/* delete all temporary files:
&if [exists xxxtmp1 -info ] &then;   &s x = [delete xxxtmp1 -info]
&if [exists xxx -GRID] &then ; kill xxx all
&if [exists xxx2 -GRID] &then ; kill xxx2 all
&if [exists xxx3 -GRID] &then ; kill xxx3 all
```

```
&if [exists xxx4 -GRID] &then ; kill xxx4 all
&if [exists xxxcom -GRID] &then ; kill xxxcom all
/* restore GRID settings:
setcell %xxcell%
setwindow %xxwindow%
&messages &on
&return
/*--------------
&routine BAILOUT
/*--------------
&severity &error &ignore
&call exit
&return &warning An error has occurred in RAININFO.AML
/* -------------------------------------------------------------------------
/*     EXAMPLE OF APPLICATION
/* -------------------------------------------------------------------------
/* grid
/* &s fm = 1990
/* &s fd = 1
/* &s tm = 1990
/* &s td = 12
/* &s p_path = $home/iowa/rainmaps/
/* &s zone = crwsh
/* &s id unit_id
/*
/* &r ermap56 %fm% %fd% %tm% %td% %p_path% %zone% prcinf2 %unit_id% 10 p
/*
/* q
/* &return
/* -------------------------------------------------------------------------
```

B5. BAL1.AML

```
/* version for daily time step ! JANUARY !!!
&s flw = d56eqp1.dat   /* total flow and evap, jan precipitation
/*  specify period JANUARY
&s fm = 1
&s fd = 1
&s tm = 1
&s td = 31
&s out = bal1   /* output info file must exist
copyinfo data56 %out%
/*  input1 xxflwin (what is it ? = name of the file for unload command)
/*  input2 xxprcin
/*  input3 xxevain
/*  output xxbalout
&sv oldname = unit_id
tables
/* ========== settings !!! ================
/* year: 93
&s yr = 93
&s templ = yy0m0d
&s nitem0 = [subst %templ% yy %yr% ]
/* ========================================
/* -----------------------------------------------------------------------
/*       Do it for all selected (years and) months and days
/* -----------------------------------------------------------------------
&DO mt = %fm% &to %tm%
 &if %mt% lt 10 &then
   &sv nitem1 = [subst %nitem0% m %mt% ]
 &else
    &sv nitem1 = [subst %nitem0% 0m %mt% ]
 &sv nitem00 =  [subst %nitem1% 0d 00 ]
/*   ====== unload monthly evaporation depth =============================
/*  select %eva%
/*  unload xxevain unit_id unit_nx area_km2 order e%nitem00% DELIMITED INIT

 &DO dy = 1 &to 31
  &s ab = [calc %mt% = %fm%] AND [calc %dy% lt %fd%]
  &s bb = [calc %mt% = %tm%] AND [calc %dy% gt %td%]
  &s cc = %ab% OR %bb%
  &IF NOT %cc%  &THEN
    &do
      &if %dy% lt 10 &then
        &sv nitem = [subst %nitem1% d %dy% ]
      &else
        &sv nitem = [subst %nitem1% 0d %dy% ]
      &type processing item %nitem% ... [date -vfull]
/* ----------------------------------------------------------------------
&sv ddd = [substr %nitem% 5 2 ]
&sv mmm = [substr %nitem% 3 2 ]
&sv yyy = [substr %nitem% 1 2 ]
&sv scott = q%mmm%%ddd%%yyy%
/* &sv eva = [substr %nitem% 1 4 ]
/* &sv eva2 = e%eva%00
select %flw%
unload xxflwin unit_id next_id areakm2 e%nitem00% %scott% p%nitem% DELIMITED INIT
/* select %prc%
/* unload xxprcin unit_id p%nitem% DELIMITED INIT
/* select %eva%
/* unload xxevain unit_id unit_nx gswsh area_km2 order e%nitem% DELIMITED INIT
```

```
&sys b4v1 xxflwin xxbalout
&s i = 0

&do &until [exists xxbalout -file]
  &s i = %i% + 1
&end
define x%nitem%.dat
unit_id,4,8,B
b%nitem%,4,12,F,6
~
add from xxbalout
select x%nitem%.dat
/*      ------- delete what is not needed ---------
&s x = [delete xxbalout -file]
&if %x% eq 0 &then
   &type file xxbalout has been deleted
&else
   &type ERROR: could not delete file xxbalout
&s x = [delete xxflwin -file]
&if %x% eq 0 &then
   &type file xxflwin has been deleted
&else
   &type ERROR: could not delete file xxflwin

&sys arc joinitem %out% x%nitem%.dat %out% unit_id %oldname%
kill x%nitem%.dat
&sv oldname = b%nitem%
      &end
 &end
&end
q
q
&return
```

B6. B4V1.C

```
#include <stdio.h>
#include <math.h>
#define size 512
main (argc, argv)
  int argc;
  char *argv[];
  /* arg 1) q input (flw) must have: id and flow.
 2) p input (prc) must have id and prec
 3) e input (evp) must have id and prec
 4) d input ( ) must have id, next, order and area.

            flow [cfs/s], prc[mm] evp[mm]
 5) name_out */
 {
  char loop, notfound;
  int i, j, gsni, gsnn;
  long unid[1000], unnx[1000], id, nx ;
  float gsqo[1000], unar[1000], unev[1000], unpr[1000], bal[1000],
  gsin[1000], ar, qo, pr, ev, x1;

  char buf[size];
  FILE *fqin, *ftable2;
  if (argc < 2 )
   {
    printf ("wrong number of arguments = %d \n", argc);
    exit(1);
   }
/* ------------------------  flow data ----------------------- */
  fqin = fopen (argv[1], "r");
  /*  fgets(buf, size, fqin);  */
  i = 0;
  while (fscanf(fqin, "%li,%li,%f,%f,%f,%f", &id, &nx, &ar, &ev, &qo, &pr) != EOF)
   {
    unid[i] = id;
    unnx[i] = nx;
    unar[i] = ar;
    unev[i] = ev;
    gsqo[i] = qo;
    unpr[i] = pr;
/*    printf(" record %li, %li,%f,%f,%f,%f \n", unid[i], unnx[i], unar[i], unev[i],
gsqo[i], unpr[i]);
*/
    ++i;
   }
  gsnn = i-1;
  gsni = i;
  fclose(fqin);
/* Set initial values: change evaporation */
  for (i = 0; i <= gsnn; ++i )
    {
      gsin[i] = 0.0;
    }
/* Calculate river water inflow: */
  for (i = 0; i <= gsnn; ++i )
    {
      for (j = 0; j <= gsnn; ++j )
       if ( unnx[i] == unid[j] )
       {
```

```
  gsin[j] = gsin[j] + gsqo[i];
      }
    }


/* Calculate (outflow - inflow) * conversion factor / area: */
/* cfs => 2446.6 m3/d => 2446.6 * 1000 * 1000 * 1000 mm
/*  area km2 * 1000 * 1000 m
/* cfs * 2446.6 / 10^6 = m/d => 2446.6 / 1000 mm/d
/* cfs * 2.4466 /areakm2 [mm]
/* Calculate (outflow - inflow) * conversion factor / unar: */
  for (i = 0; i <= gsnn; ++i )
    {
      x1 = 2.4466 * (gsqo[i] - gsin[i] ) / unar[i];
      bal[i] = unpr[i] - unev[i] - x1 ;
    }
 /* replace very large numbers by -999  */
/*   for (i = 0; i <= gsnn; ++i )
    {
       if ( fabs(bal[i]) > 999 )
        {
          bal[i] = -999 ;
        }
    }
*/
  /* Write results to output file */
  ftable2 = fopen (argv[2], "w");
  /* arc view version:
  fprintf ( ftable2, "\"%s\",\"%s\"\n", argv[3], argv[4]);
  */
  for (j = 0; j <= gsnn; ++j )
    fprintf(ftable2, "%li,%f\n", unid[j], bal[j] );
  fclose(ftable2);
  return 0;
 }
```

Appendix C: CD-ROM description

This appendix contains a short description of the CD-ROM on which information such as data used in this study, partial and final results, procedures, and documentation are stored.

1) Selected Directories and Files
2) Detailed description of /bal66b/ calculation variant
3) RMAP56.AML - Creates an INFO table from the grids of daily precipitation
4) EMAP56.AML - Corrected RMAP56.AML to create an INFO file of evaporation
5) BAL1.AML - exports hydrologic data in ASCII format from INFO files, runs C program which calculates water balance , and then creates an INFO table of calculated balance
6) B4V1.C - C program that calculates water balance

C. Description of Selected Directories and Files on CD-ROM

MAJOR RESULTS:

./bal66ec/ 256 zones, 365 days final results

S(i) = P(i) - cf(i)*E(i) + Qin(i) - Qout(i)

./bal66ec/b66bal = incremental storage (after evaporation adjustment)
./bal66ec/b66wshc = zones
./bal66ec/oldtxt
./bal66ec/b66sto = cumulative storage (after evaporation adjustment)
./bal66ec/x66bal = incremental storage (no evaporation adjustment)
./bal66ec/x66sto = cumulative storage (no evaporation adjustment)
./bal66ec/b66evcf evaporation correction factor

./bal67ec/ reduced # of zones (161), 365 days, analogous to bal66ec

S(i) = P(i) - cf(i)*E(i) + Qin(i) - Qout(i)

./bal67ec/b67wshc = zones
./bal67ec/b67bal = incremental storage (after evaporation adjustment)
./bal67ec/b67sto = cumulative storage (after evaporation adjustment)
./bal67ec/x67bal = incremental storage (no evaporation adjustment)
./bal67ec/x67sto = cumulative storage (no evaporation adjustment)
./bal67ec/b67evcf = evaporation multiplication factor

./bal68ec/ reduced # of zones (132), 365 days, analogous to bal67ec

S(i) = P(i) - cf(i)*E(i) + Qin(i) - Qout(i)

./bal68ec/b68wshc = zones
./bal68ec/b68bal = incremental storage (after evaporation adjustment)
./bal68ec/b68sto = cumulative storage (after evaporation adjustment)
./bal68ec/x68bal = incremental storage (no evaporation adjustment)
./bal68ec/x68sto = cumulative storage (no evaporation adjustment)
./bal68ec/b68evcf = evaporation multiplication factor

./bal68h4/ final results recalculated for the 4-digit HUCs

./bal68h4/huc4sast = polygon coverage of 4-digit HUCs
attribute table contains daily cumulative storage by 4-d. HUC
./bal68h4/h4g = GRID version of huc4sast
./bal68h4/z68wsh = GRID, gauged zones, version 68
./bal68h4/z68bal = GRID, storage averaged over 4-digit HUC units

./bal68h6/ final results recalculated for the 6-digit HUCs

./bal68h6/huc6sast = polygon coverage of 6-digit HUCs
attribute table contains daily cumulative storage by 6-d. HUC
./bal68h6/h6g = GRID version of huc6sast
./bal68h6/z68wsh = GRID, gauged zones, version 68
./bal68h6/z68bal = GRID, storage averaged over 6-digit HUC units

./bal68h8/ final results recalculated for the 8-digit HUCs

./bal68tim/ calculations of the Retention Time Index

./bal68tim/b68tim = coverage, daily values of RTI

DATA and RESULTS OF INTERMEDIATE CALCULATIONS:

./data

./data/huc4sast	polygon	SAST divided into four digit HUCs
./data/huc6sast	polygon	SAST divided into six digit HUCs
./data/hucmiss	polygon	
./data/hucsast	polygon	SAST divided into eight-digit HUCs
./data/huc2sast	polygon	SAST divided into two digit HUCs
./data/info	INFO	
./data/k10a	arc	selected rivers from RF1
./data/k11a	arc	selected rivers from RF1
./data/k5a	arc	selected rivers from RF1

```
./data/k6a      arc       selected rivers from RF1
./data/k7a      arc       selected rivers from RF1
./data/k9a      arc       selected rivers from RF1
./data/rf1sast   RF1 within SAST region
./data/rf1_sel
./data/rf1_txt
./data/sast
```

./year93 two GIF images (total balance and a map of SAST)

./pcdata ASCII + INFO daily discharge for HY 93 and 94

./flow = coverage and data (discharge) for the first
approach (9 month calculations)

./evapor/ EVAPORATIN FOLDER

```
clim_div = climate divis•"n, continental U.S.,
ev4      = SAST region divisions, contains evaporation data (in/month)
ev4clip  = same as ev4 but clipped to the SAST region boundaries
e930100  = grid of evaporation for January (1000 * mm / month )
...
e931200  = grid of evaporation for December
e931300  = grid of evaporation for 1993
evmmd.dat = Info file, evaporation in mm/d for zones56 (266 units)
evap.dat  = Info file (looks same as evmmd.dat)
(see: documentation on CD)
```

./evaday/= monthly - to - daily evaporation

./precip/ = PRECIPITATION FOLDER

```
./precip/prc67     INFO of daily precipitation estimated from GRIDs
                   variant 67 (reduced)
./precip/prc66     variant 66 (all zones that have complete flow record
                   from Jan 93 to Dec 93
./precip/poinmap   ascii data (precipitation depth and X-Y to create
                   point coverage of climate stations
./precip/gridprc   365 grids of precipitation
                   ./precip/gridprc/p930101  ...  ./precip/gridprc/p931231
./precip/amls
```

./b66m1/ = MONTHLY TIME INTERVAL

```
./b66m1/z66mtot  poly 256 zones (PAT created by joining
                 q93m2.dat, i93m2.dat, p93m2.dat, e93m2.dat
./b66m1/z66mmpm  same as z66mtot except discharge in mm/month
./b66m1/z66x2
  q93m2.dat = monthly discharge volume in [10^3 m3/month]
              (sum of individual days * 86.400 )
  I93M2.DAT = inflow into a zone
  p93m2.dat = monthly precipitation depth [mm/month]
  e93m2.dat = monthly evaporation depth [mm/month]
              from data obtained through Internet
  other data (daily values copied from other folders, see doc.txt):
  evaporation data (xe3.dat)
  precipitation data (p93v66.dat)
  flow data m3/s(q93v2.dat)
  flow in ft/s + station description (q93v1.dat)
  watershed parameters (wsh66.dat)
```

./bal66/ all zones, 365 days, no evaporation

```
        V(i) = P(i) + Qin(i) - Qout(i)
        Partial results of an analysis of the spatial and
        temporal evaporation distribution estimated from
        the water balance V(i).
```

./bal66b/ all zones, 365 days, evaporation adjusted (0.775)

```
        S(i) = P(i) - 0.775*E(i) + Qin(i) - Qout(i) + error(i)
./bal66b/b66b = coverage, cumulative daily storage S(i)
./bal66b/b66ber = coverage, error (item b931231 of cumulative
                  daily storage)
```

./model66/ ELIMINATION OF QUESTIONABLE UNITS (going from ver. 66 to ver. 67 and ver. 68)

```
b01.c = c program that recalculates average precipitation depth,
        evaporation depth and inflow into zone for a specified
        set of stations:
    arguments:
         1) input_file data
            unit_id, next_id, areakm2, p[1..12], e[1..12]
            qout[1..12], qin[1..12]
            file name: d1 (256 stations/zones)
         2) input_file
            unit_id = reduced set of stations
            for example: select.txt, sel4ot.txt
         3) output file (recalculated input file)
            for example: ou1v1.txt
         4) output file (cumulative storage)
            for example: ou2v1.txt (this file contains
              intermediate results.
         5) an indicator of the correction method
 the file "reduced set of stations" is exported using ArcView.
  z66mtot = coverage, 256 zones, P, E, Q, I monthly values
 z66mbal = coverage, 256 zones,
           IS(incremental storage),CS(cumulative storage),
           EVFACTOR (evaporation multiplication factor),
           JAN-DEC (corrected monthly storage)
 z67mbal = same as z66mbal but for 156 zones
```

./model68/ ELIMINATION OF QUESTIONABLE UNITS (going from ver. 66 to ver. 68 (?))

./data66/ = DATA FOR 66 balance (all units, all months of 1993)

```
./data66/out56    grid of original outlets (9 months)
./data66/b66wshc polygon zones 66
./data66/out66   grid, zone outlets (USGS stations)
./data66/tot66wsh grid, watersheds
./data66/zones66
./data66/z66b1
./data66/out66nxt  grid of outlets, value points the downstream zone
./data66/b66base
./data66/xcomnxt
./data66/sta66p
./data66/sta66
./data66/modoutg
./data66/modout
./data66/link66  arc coverage, rivers that connect USGS stations
./data66
./c66  temporary directory
```

./data67/ DATA FOR VERSION 67

```
./data67/zones67  grid of zones
./data67/out67    grid of stations
./data67/b67wshc  coverage of zones
./data67/out67nxt grid of stations, value points downstream unit
```

./data68/ DATA FOR VERSION 68, analogous to ./data67

/data2/ - general data for the SAST region

```
buf50g = grid, 50 km buffer around the SAST region
buffer50 = coverage, 50 km buffer around the SAST region
umbr_ss = all (572) stream sites within SAST region (from GCIP CD-ROM)
fldem2 = original 500m DEM within buffered SAST region
          fldem2 = con ( buf50g > 0, /databases/usa/bigdem/usdem2 )
rf1lg  = Midwest rivers from RF1 converted into grid
          rf1lg = linegrid ( rf1mmc, rf1mmc-id, #, #, #, ZERO )
rf1pg  = Midwest polygons from RF1 converted into grid
          rf1pg = polygrid ( rf1mmp, rf1mmp#)
rf1v1  =  contains both rf1lg and rf1pg (no-stream cells contain zero)
```

```
border = SAST region
demr5   = input for flow direction calculation (edited DEM
           can only be used to determine the flow direction!!!)
st5fdr  = flow direction grid (used for almost all delineations!)
ed5v6   = grid, contains stations, dummy stations, and streams
          after station location correction.
out56   = grid, gauging stations including dummy stations
          out56 = con (ed5v6 > 1, ed5v6 )
out56c => out56c = gridpoint (out56 , id)
gst56   = gauging stations
out56nxt => gauges but ID points the next station in the flow system

tot56wsh = all watersheds, including dummy watersheds
         = watershed ( st5fdr , out56 )
tot56wc =>  tot56wc = gridpoly(tot56wsh , 1200 )
zones56 => grid, watersheds without dummy areas
           zones56 = con ( tot56wsh > 1000000, tot56wsh)
zones56c= coverage, zones56c = gridpoly ( zones56 , 1000 )
```

./bal1/ = first approximation for 9 months

./flow/ = coverage and data for a first approach (9month calculations)

./text/ = text, read-me, mail and other files related to USGS,

./bal68huc/= grids, and coverages of the SAST region divided into different HUC resolutions