Management of Network Resource Systems with Application to Critical Infrastructure Assessment

Emil Kelevedjiev & Zlatogor Minchev

Institute of Mathematics and Informatics, OR Department,

Bulgarian Academy of Sciences

OVERVIEW

A theoretical model and an experimental computer interactive implementation of predicting critical behaviors of large class network-flow systems will be presented.

The model is based on a linear programming approach that allows finding dynamic solutions with multi-criteria optimization of the involved graph-flow problem. Due to ability of **interactive re-computing** with different inputs and control data, an expert, using the proposed solution, can perform an adequate **decision making**.

Possible applications of the present approach in the management of the critical infrastructure in **water supplying system** or **electricity power submission network** are indicated.

GENERAL FLOW DISTRIBUTION MULTI-CRITERIA MULTI-STAGE PROBLEM

Possible results:

Minimization of the total resource insufficiency;

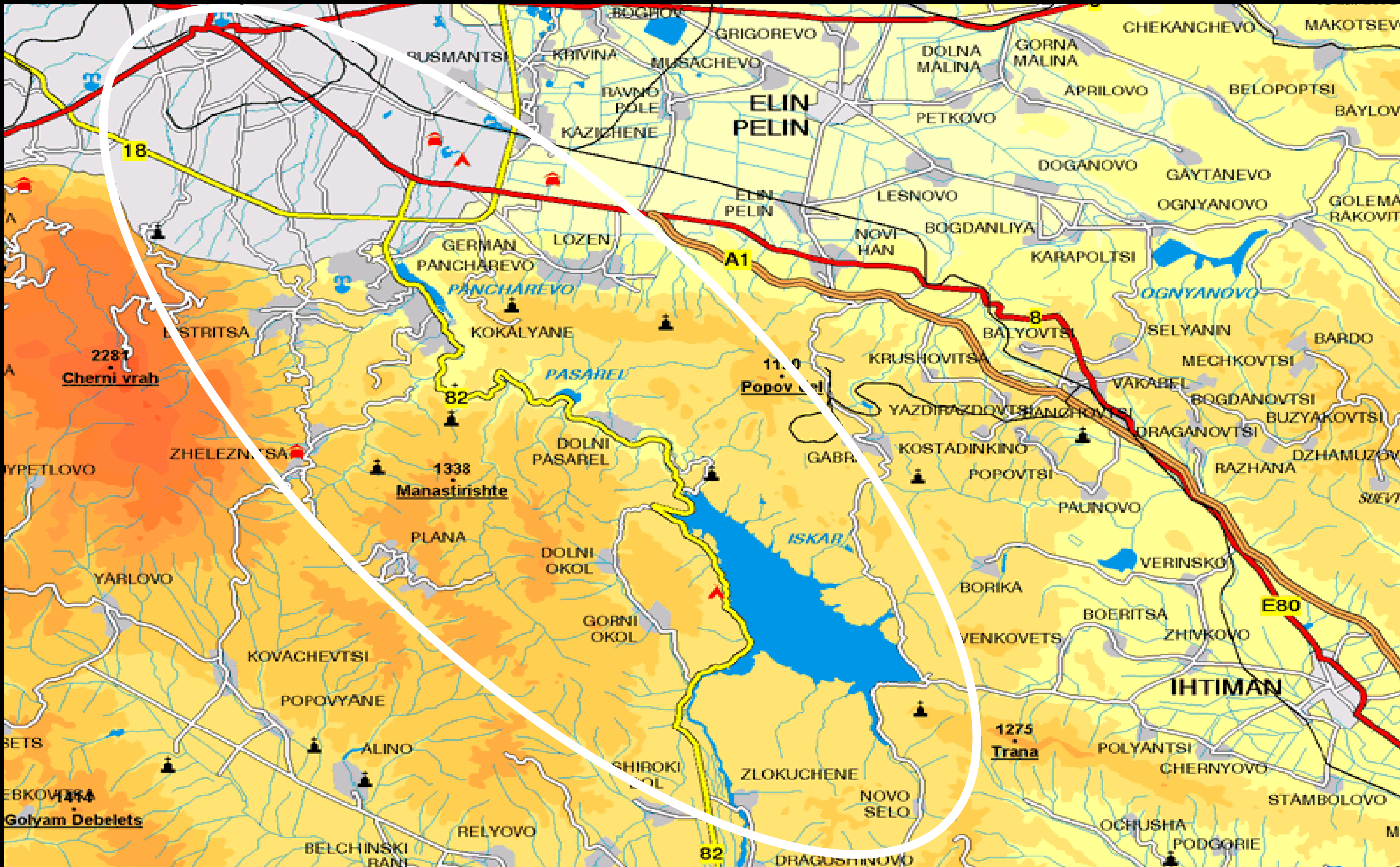
Equalization of resource insufficiency among desired nodes for all time periods;

Maximization of available water;

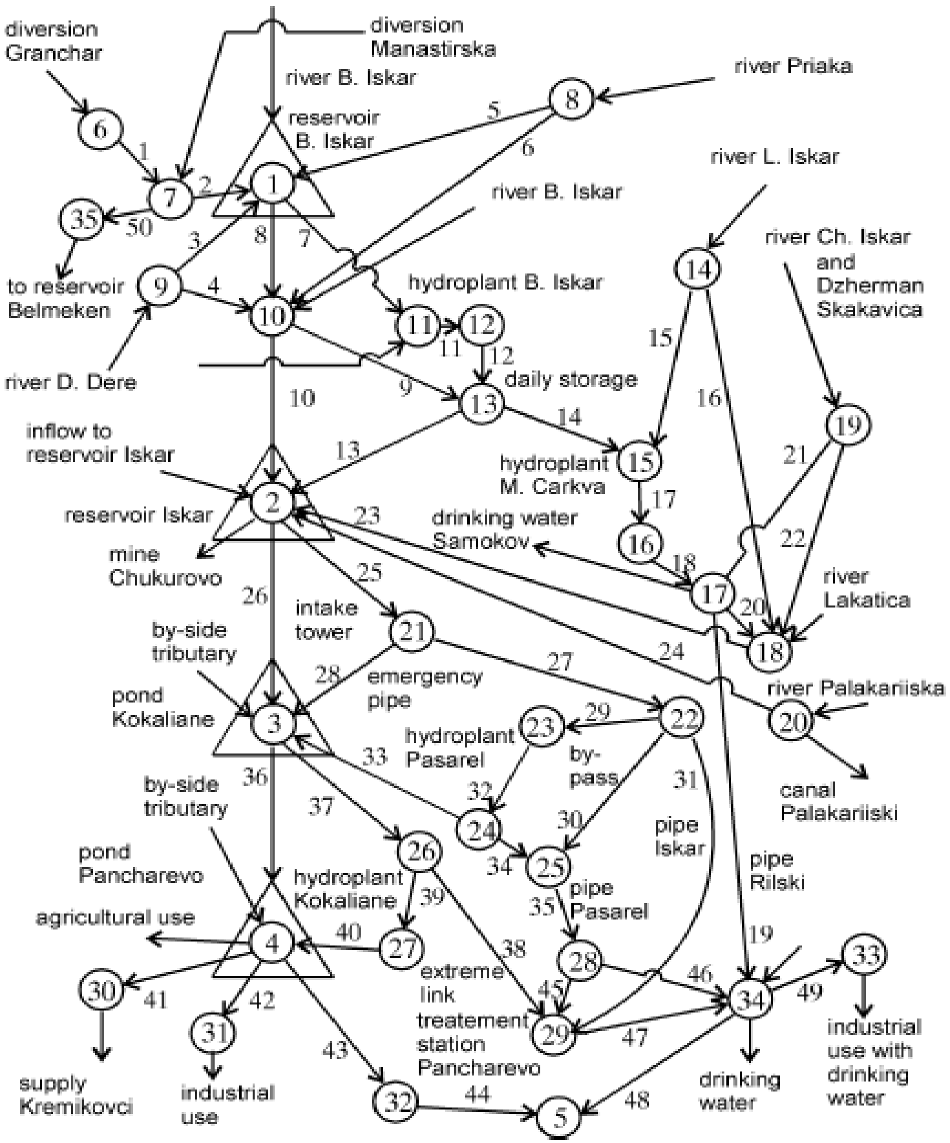
Minimization of total resource losses;

Minimization of the deviation of reservoir storage level form its target storage level.

GEOGRAPHICAL MAP OF THE MODELED REGION



THE GRAPH-FLOWS MODEL



MODEL VARIABLES

The process involves several time steps $t = 1, 2, ..., T$.

For each node $j = 1, 2, ..., n$ and for each time moment: $t = 1, 2, ..., T$, the following variables are introduced:

- $u(j,t)$ – amount by which the volume of j-th node increases at the t-th time step;
- $v(j,t)$ –amount by which the volume of j-th node decreases at the t-th time step;
- $r(j,t)$ – current volume.

Some of the nodes are considered as sources:

- $s(j,t)$ – inflow into the j-th node at the t-th time step.

Other nodes are considered as sinks:

- $d(j,t)$ – outflow from the j-th node at the t-th time step.

For each arc i=1, 2, ...m, and for each time step t:

$f(i,t)$ – flow through the i-th arc at the t-*th* time step.

MODEL CONSTRAINTS

1. Nodes accumulation: For those nodes j, that are reservoirs, and for any time step t:

$$r(j,t) = r(j, t_0) + \sum\{u(j,k) - v(j,k) : \ k = t_0, ..., t\}.$$

2. Continuity equations for each node j and for any time step t:

$$\sum\{f(i,t) : i \in A^+(j)\} - \sum\{f(i,t) : i \in A^-(j)\} + s(j,t) - d(j,t) + u(j,t) - v(j,t) = 0,$$

where:

- $A^+(j)$ is the set of all such i, that the i-th arc is directed into the node j.
- $A^-(j)$ is the set of all such i, that the i-th arc emanates from the node j.

3. Equality and inequality constrains for the variables:

3a. Storage of the reservoirs are within allowable limits:

$$r_{\mathrm{min}}(j) \le r(j,t) \le r_{\mathrm{max}}(j).$$

3b. Inflow from sources is equal to available quantities: $s(j,t) = s_{\mathrm{const}}(j,t)$.

3c. Demand values at any demand point: $d_{\mathrm{min}}(j) \le d(j,t) \le d_{\mathrm{required}}(j)$.

3d. Pipe capacities (upper bounds) and operational limits (loewer bounds):

$$f_{\mathrm{min}}(j) \le f(j,t) \le f_{\mathrm{max}}(j).$$

MODEL GOAL FUNCTION

•min: $\sum \{C_1(j,t)d(j,t)\} + \sum \{C_2(j,t)f(j,t)\} + \sum \{C_3(j,t)u(j,t)\} +$
•$\sum \{C_4(j,t)v(j,t)\}$, where:

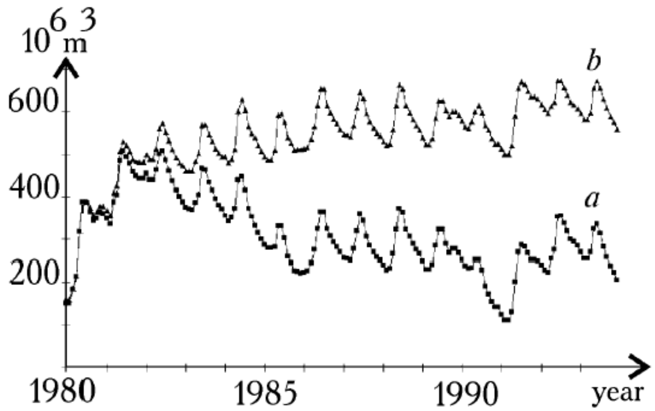
•$C_1(j,t)$, $C_2(j,t)$, $C_3(j,t)$ and $C_4(j,t)$ are constants. Their values are chosen by experts during the interactive mode communication with the modeling system. Typically:

•$C_1(j,t) << 0$ or $>> 0$, depending on node's purpose, where the flows that go out the system. The other constants $C_2(j,t)$, $C_3(j,t)$ and $C_4(j,t)$ are taken close to the init values.

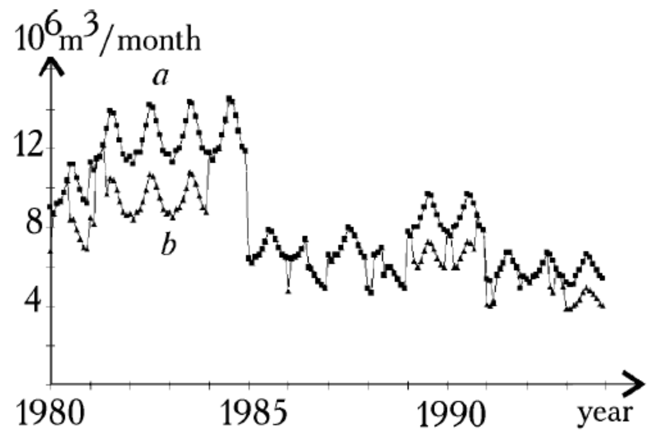
NUMERICAL EXPERIMENTS

Water: Calculations are made for a really existing system including the upper part of Iskar river (near Sofia) for the period of 39 years (1956 - 1994). The model consists of 35 nodes and 50 arcs. The total number of constraints and variables in the resulted LP task were 58036 and 42124 respectively. The computed results showed a good coincidence with the real data. Two main cases (scenarios) are considered: **normal operation - priorities of minimizing shortages** and situation of a **minimizing water losses for a given water volume in the reservoirs** (e.g. dams, ponds, etc.).

RESULTS

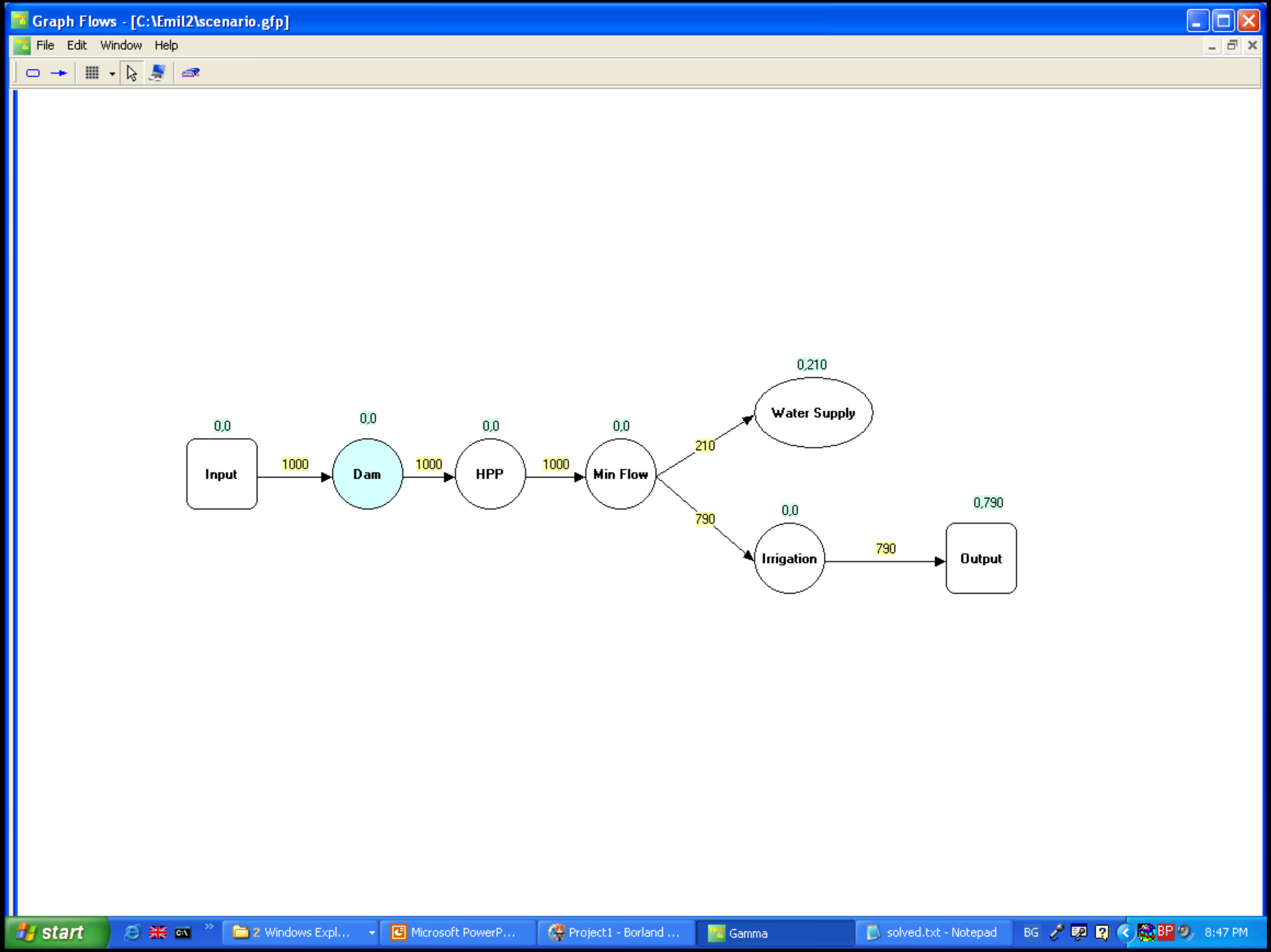


Volume level dynamics of Iskar dam for the period 1980 - 1994



Computed delivery rate of irrigational water at Pancherevo pond - 1980 - 1994

GRAPH-FLOW PROGRAM SCREEN SHOT



THANK YOU FOR THE ATTENTION !