SYSTEMS RESEARCH INSTITUTE
POLISH ACADEMY OF SCIENCES

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CONTRACTED STUDY AGREEMENT REG / POL / 1

"CONCEPTS AND TOOLS FOR STRATEGIC REGIONAL SOCIO-ECONOMIC CHANGE POLICY"

STUDY REPORT

PART 2

POLISH CASE STUDY REPORT

COORDINATOR, IIASA: A. KOCHETKOV
COORDINATOR, SRI PAS: A. STRASZAK

ZTS/ZPZC/ZTSW 1-36/85

WARSAW 1986

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Consisting of 3 Parts

PART 2

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IV. AN INTRODUCTORY STUDY OF WATER CONDITIONS IN THE BEŁCHATÓW REGION

by Janusz Babarowski

IV.1 Introduction

The region under consideration is located in the south-western part of the Piotrków voivodship in central Poland. Industrial center of the region consists of

- Bełchatów lignite strip mine (in operation)
- Szczerców lignite strip mine (planned)
- Bełchatów energy power plant (lignite-fueled) with planned capicity of 4200-6000 MW. Now (1986), the capacity amounts to 2520 MW.

The exploitation time of both mines is anticipated at about 45 years, so that the end of time horizon under investigation is about 2030.

This large industrial center exerts a strong influence on the surrounding area. In particular, water conditions are strongly influenced by the strip-mining process. The process causes dewatering of the surrounding area and a groundwater table drop. The maximum surface of the resulting "groundwater crater" is estimated at about 1900 sq kms. The region is poor in water. There are no natural water reservoirs. The precipitation is low. The region is situated on the watershed between the Vistula and the Oder. There is only one narrow river (Widawka). Water is one of the most crusial resources in the region. The shortage of regional water resources may be a substantial barrier of its development.

For reasons mentioned above the present study was undertaken. The aims of the study are the following:

1. Recognition of the structure of water flows in the region.
2. An approximate description of the flows now and in the future.
3. Balancing of water needs and resources in the long time horizon.

4. A preliminary solution for water regional management planning problem in the future.

IV.2 Disposable water resources

There are two kinds of water resources in the region under consideration: the surface and underground water. The main source of the surface water is the Widawka River. The underground water is available owing to the dewatering process during the strip mining. This water is pumped out from the (hypothetical) underground reservoir.
General structure of the water flows is shown in Fig. IV.1.

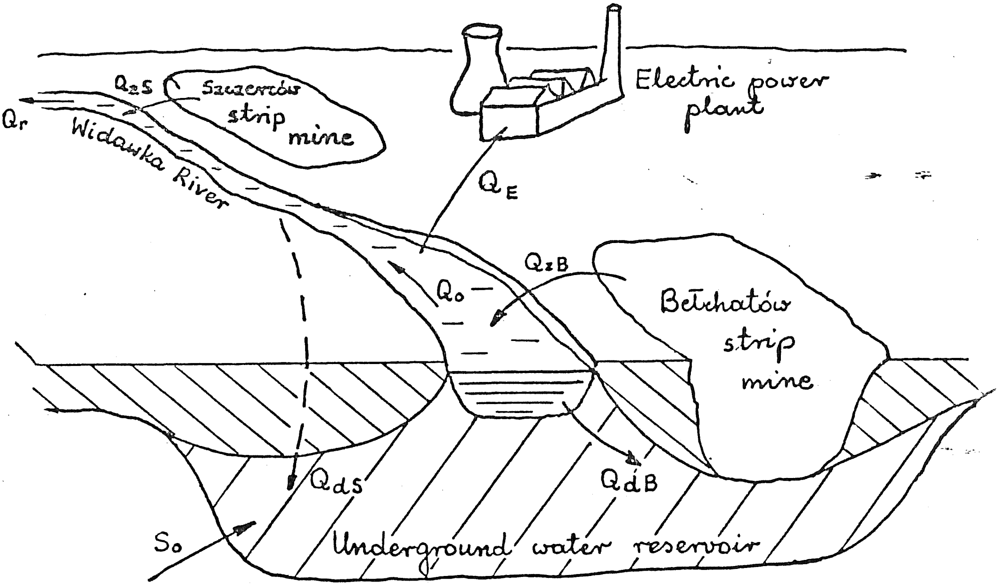

Figure IV.1. Simplified structure of water resources

We will propose the water balance equations within this structure. Water flow of the Widawka River is described by the following water balance equation

$$Q_r = Q_o + Q_{zB} + Q_{zS} - Q_{dB} - Q_{dS} - Q_E \qquad (IV.1)$$

where

Q_r - resulting flow

Q_o - natural flow (computed on the basis of the analog of water conditions for given hydrological year)

Q_{zB}, Q_{zS} - water discharges pumped out from Bełchatów and Szczerców strip mines respectively

Q_{dB}, Q_{dS} - flow losses (underground outflow) caused by dewatering of Bełchatów and Szczerców strip mines respectively

Q_E - water withdrawal (non-returnable losses) for electric power generation.

The forecasted values of variables listed above are given in Table IV.1.

Table IV.1. Values of water flows in the region. Available forecasts.

m^3/sec years	Q_r	Q_o	Q_{zB}	Q_{zS}	Q_{dB}	Q_{dS}	Q_E
1980	9.41	5.3	6.6	0	2.49	0	0
1995	7.2	4.86	5.67	5.6	3.62	2.79	2.7
2030	5.19	4.86	0	2.16	0	0.43	1.1

The prognosis was made by experts and is connected with three characteristic time instants of the problem: the beginning of exploitation, maximum intensity and end of exploitation of the strip mines.

The state of the underground water reservoir is described by the following (yearly) balance equation:

$$S_r = S_o + S_{dB} + S_{dS} - S_{zB} - S_{zS} \qquad (IV.2)$$

where

S_r - the real state of the underground water reservoir

S_o - annual (constant) water inflow from surroundings of the reservoir

S_{dB}, S_{dS} - annual water inflow from surface water caused by dewatering of Bełchatów and Szczerców strip mines respectively

S_{zB}, S_{zS} - annual amount of mining water pumped out from Bełchatów and Szczerców strip mines respectively.

All values in equation (IV.2) are measured in 10^6 m^3/yr, but in equation (IV.1), they are measured in m^3/sec. For this reason the following relations hold

$$S_d = a\,Q_d \;;\quad S_z = a\,Q_z \qquad \text{(IV.3)}$$

where $a = 31.536 \; 10^6$ sec/yr.

Forecasts for the balance equation (IV.2) are given in Table IV.2.

Table IV.2. Forecasts of the underground water resource state.

10^6 m^3/yr year	S_r	S_o	S_{dB}	S_{dS}	S_{zB}	S_{zS}	$0.4(S_{zB}+S_{z}$
1980	31.13	160.6	78.53	0	208	0	83.2
1995	7.8	160.6	114.2	88	179	176	142
2030	105.8	160.6	0	13.2	0	68	27.2

By adding both sides of equations (IV.1) and (IV.2) one may obtain

$$S_r + a\,Q_r = S_o + a\,Q_o - a\,Q_E \qquad \text{(IV.4)}$$

This means that the total amount of water in the system is constant and is diminished only by the non-returnable losses.

The last column in table IV.2 contains the values of so called disposable underground water resources. Only forty per cent of mining water is guaranteed for water management computations.

Disposable surface water resources are estimated at least at 58 million m^3/yr and are constant within the time horizon considered.

Let us note that the underground (mining) water can not be used for all purposes. In this case we may use it for electric power generation and for grasslands irrigation.

IV.3 Water needs

In the Bełchatów region we may distinguish three kinds of water users: urban areas, industry and agriculture. Each of them has its specific water needs. Basing on the plans of regional development a forecast of water needs over time horizon considered has been made. This forecast is presented in Table IV.3 and it takes into account two variants of irrigation for

a) 800 ha of meadows and 900 ha of ploughland,

b) 5600 ha of meadows and 900 ha of ploughland.

All values in the table are expressed in 10^6 m^3/yr.

Table IV.3.

user \ year		1980	1995	2030
Urban areas		3.54	20.2	31.8
Industry		14.7	118.4	60.8
including electric power plants		0	100.9	37.8
Agriculture	a	23.2	44.5	48.4
	b		50.2	58.9
including rural pipe-lines		1.6	19.1	23.0
Total	a	41.44	183.1	141.1
	b		188.8	151.5

These water needs may also be presented in the continuous manner, as shown in Fig. IV.2.

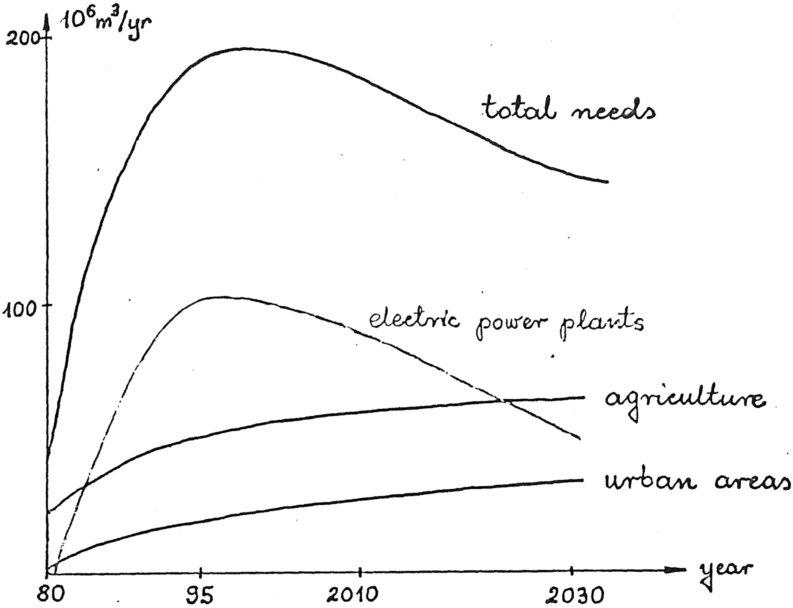

Figure IV.2. Qualitative forecast of the water needs.

IV.4 Supply - needs balance and distribution

The next step of our study consists in balancing of supply possibilities and needs. In the previous section we have mentioned two variants of water needs for agriculture (less and more intensive irrigation). Moreover, we may use mining water for electricity production only or not only for this purpose. Hence, we will consider four variants of balance according to the Table IV.4 below.

Table IV.4 Water use variants.

irrigated area use of underground water for:	a	b
electric power plant	I	II
electric power plant and irrigation	III	IV

Let us define some symbols:

W^s, W^u - disposable surface and underground water resources, respectively.

S^s, S^u - shortages of surface and underground water resources, respectively.

The results of supply-needs balance for long time horizon and for four variants are shown in Table IV.5. All values in the table are expressed in 10^6 m^3/yr.

Table IV.5 Water balance results.

year	disposable resources of two kinds of water	needs and shortages			
		I	II	III	IV
1995	$W^s = 58$	82.2	87.9	56.8	56.8
	S^s	24.2	29.2	0	0
	$W^u = 142$	100.9	100.9	126.3	132.0
	S^u	0	0	0	0
2030	$W^s = 58$	103.2	113.7	77.8	77.8
	S^s	45.2	55.7	19.8	19.8
	$W^u = 27.2$	37.8	37.8	63.2	73.7
	S^u	10.6	10.6	36.0	46.5

It follows from the table that for the first stage variant IV would be the best solution. There are no shortages and intensive irrigation is implemented over a large surface. However, in the second part of the planning horizon, we have obtained shortages of surface as well as of underground water in all the variants.

We are able to moderate the disadvantages caused by the water shortages. This may be achieved by:

1. Diminishing of irrigated area
2. "Distribution" of the shortages among users.

The second way is equivalent to water distribution in such a way that "dissatisfaction" of different users will be identical. In order to do this we will use the minimization of taxi-relative norm approach presented by Umnov (1984).

We will solve the following distribution problem (compromise shortages)

$$\min_{\{w_i,\, w_j\}} \left\{ \max \left[\max_i \left(\left| \frac{w_i^s - w_i^{so}}{w_i^{so}} \right| \right),\ \max_j \left(\left| \frac{w_j^u - w_j^{uo}}{w_j^{uo}} \right| \right) \right] \right\} \qquad \text{(IV.5)}$$

under constraints

$$\sum_i w_i^s \leqslant W^s \qquad\qquad \sum_j w_j^u \leqslant W^u \qquad \text{(IV.6)}$$

where

w_i^{so}, w_j^{uo} - desired level (needs) of surface and underground water consumption, respectively

w_i^s, w_j^u - resulting level of surface and underground water consumption, respectively

i,j - index for surface and underground water users, respectively

Table IV.6 Dissatisfaction minimization results.

variant		III		IV	
user	i	w_i^{so}	$\hat{w}_i^s$	w_i^{so}	$\hat{w}_i^s$
urban areas	1	31.8	23.5	31.8	23.5
industry, without electric power plants	2	23.0	17.0	23.0	17.0
rural pipe-lines	3	23.0	17.0	23.0	17.0
	j	w_j^{uo}	$\hat{w}_j^u$	w_j^{uo}	$\hat{w}_j^u$
electric power plants	1	37.8	16.2	37.8	15.1
irrigated fields	2	25.4	10.9	35.9	14.4
The minimal value of the norm - measure of the minimal relative shortages		0.57		0.6	

In the Table IV.6, the optimal solution for compromise shortages problem (IV.5), (IV.6) is shown. It was obtained for the most interesting water balance variants III and IV. This leads us to the final conclusion.

IV.5 Conclusions

Now, we are in the position to formulate the main conclusion which follows from this study:

If it is possible to apply mining water for irrigation, then from the beginning of planning horizon till about year 2015 one should apply the variant IV. This will allow making of full use of the available water resources and maximization of agricultural production.

After year 2015 one should switch to compromise distribution of shortages or to successive diminishing of the irrigated area (through variant III) down to zero.

If it is not possible to use mining water for irrigation, then one should not irrigate at all.

The above conclusion may be regarded as a preliminary solution to the water management planning problem.

At the further stages of the study, the modelling of different kinds of users should be carried out in order to establish their water demands functions (Kindler, 1984).

IV.6 References

Kindler,J., and C.S. Russel (Eds.) (1984). Modelling Water Demands. Academic Press, London. 248 pp.

Umnov, A. (1984). Impacts of price variation on the balance of world trade. Economic Modelling, 1, pp. 63-90.

STUDY REPORT

PION III

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