4.12. Basin level water-salt balance model

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At basin level, the traditional concepts of irrigation system efficiency are not necessarily valid, largely because of opportunities to reuse water further downstream—water "savings" at one place are likely to reduce return flows to other users downstream in the basin (Seckler 1996). An integrated basin approach, considering all water users, is therefore necessary to assess whether water "saving" actions are real or are only local "savings".

Besides water quantity problems, many areas around the world encounter water quality problems in terms of industrial–urban pollution or in terms of natural salinity due to high evaporation rates. It is estimated that in Iran about 25 million hectares suffer from salinity or salinity related problems, which is 50 percent of the irrigable area (Pazira 1999). As water management includes many aspects and changes upstream in a basin are likely to affect water quantity and quality downstream, a basin-scale approach is essential. If groundwater is highly saline and not used, then any accessions to groundwater are in fact losses, and the conventional concept of efficiency is useful.

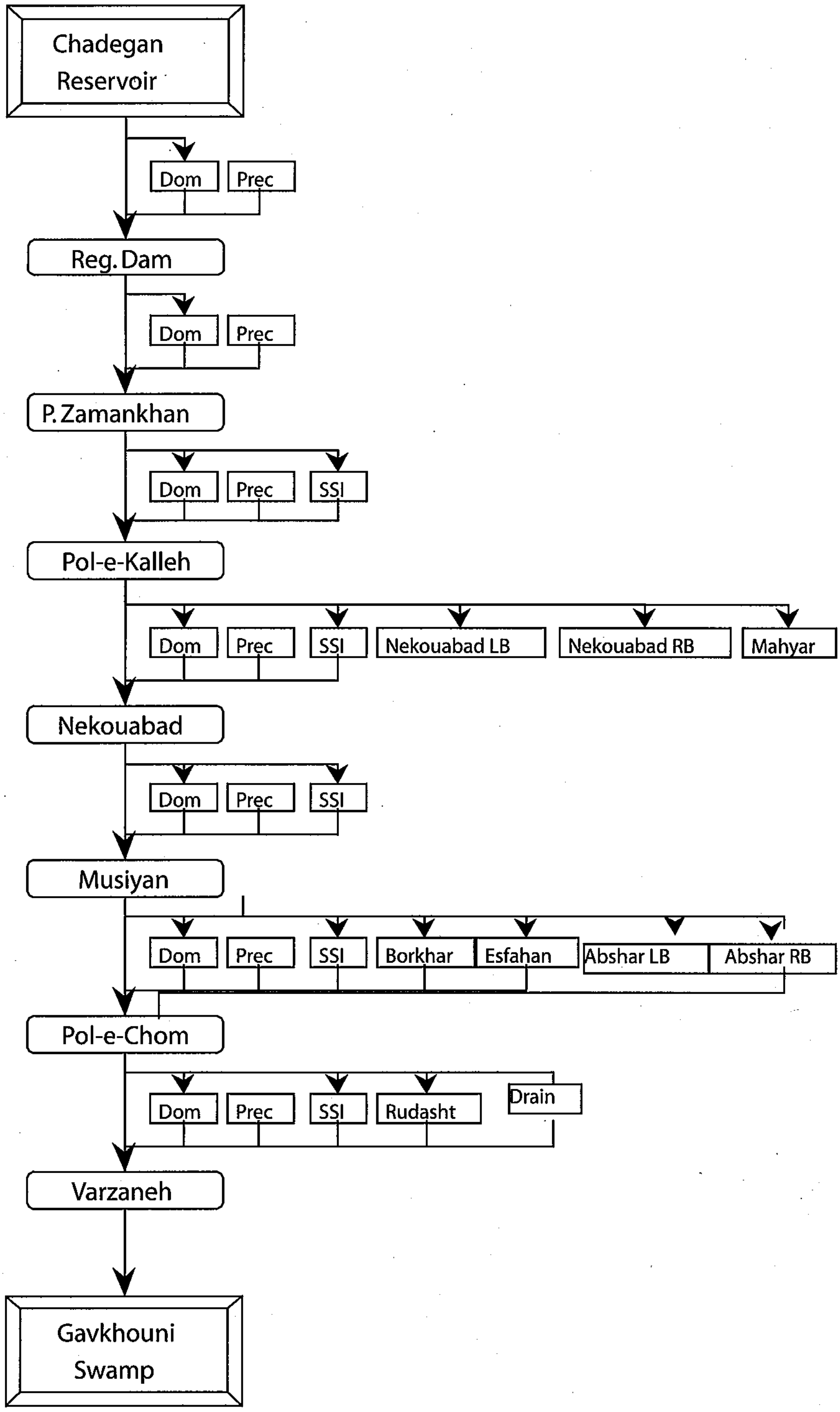
Simulation models have proved to be very useful in two ways. First of all, they can be used to fill the data gaps in measurements in terms of spatial and temporal resolution, but also in terms of difficult-to-measure properties. An example of the latter is the distinction between soil evaporation, considered as a loss in agronomy terms, and crop transpiration. This distinction is difficult to measure, but estimates can be easily made using simulation models (Droogers 2000). A second application of models is scenario analyses, to answer questions in the form of: what happens if...? An example of this is given by Voogt et al. (2000), where different scenarios were analyzed considering the distribution of surface water between irrigation and a wetland.

Models differ in their complexity, and in their physical soundness. For the Zayandeh Rud basin in Iran, a simplified approach has been tested. A water balance model, based on a spreadsheet, was developed to study water quantity and salinity problems at a river-basin scale. Current and past water resources were analyzed and scenarios were defined and evaluated using the model developed to improve water management. The main water consumer in the Zayandeh Rud is irrigated agriculture and the simulation model will therefore focus on this.

4.12.1. Simulation model

The main objective of the simulation model developed—WSBM (Water and Salinity Basin Model)—was to create a simple and transparent water and salt accounting model, to be used for quick analyses of river basin processes. The model focuses on extractions for irrigation and the associated return flows from these systems. The model also includes a simplified urban and industrial water extraction component. In order to accomplish this, we decided to create the model in a spreadsheet to ease data input, transparency and flexibility. Moreover, the model was setup in an oriented style to support this transparency and flexibility.

Figure 4.45. Schematic stream flow network of the Zayandeh Rud.



Note: Dom = domestic; Prec = precipitation; SSI = small-scale irrigation

WSBM assumes that the river is divided into reaches defined between two successive nodes. Nodes are located at typical points in the river where stream gauges are present or output is required. Water extractions, or supplies, occur only in the reaches. Using this approach water and salt flow along the river can be simulated by subtracting extractions, or adding supplies, from one node to get the value for the next node. As mentioned before, extractions are defined for urban-industrial and irrigation supplies. For both types of extractions the amount of water, the return flow as a percentage of the extraction and the accumulation of salt as percentage of the total inflow, must be specified. Obviously, values can be either real data or hypothetical values to explore the effects of different interactions. The whole model was set up to run with a monthly time-step and it was assumed that the response time of the river was within one month, so no time-lag in water and salt flow between months occurs.

Input data

A schematic representation of the stream network can be seen in figure 4.45. The Borkhar and Mahyar irrigation schemes started to function in 1997 and 1998, respectively. Table 4.15 shows the different nodes, and extractions between nodes considered in the model. Data can be divided into data required to run the model (releases from the reservoir and extractions) and data to verify model performance (flows at nodes). Because variation in deliveries to the different irrigation schemes considered is low, monthly averages from the other years were used to fill in the missing data. Model performance was checked at seven sites along the river where monthly gauge data are available.

For all the irrigation systems, some return flow is assumed. As a best estimate return flows were set at 20 percent of total delivery (table 4.15). This relatively low value was assumed to be realistic as this is the overall irrigation scheme return flow because internal return flows within a scheme are not considered. Moreover, almost all water-scarce systems tend to have low return flows.

Salt inflow to an irrigation scheme was equal to the amount of water inflow multiplied with the salinity level at the intake node. A fixed amount of salt accumulation was assumed, which can be flowed to the deep groundwater, some uptake by the crop, and storage in the soil profile. This accumulation was assumed to be 10 percent of the total salt inflow, resulting in a salt return flow of 90 percent. This salt return flow of 90 percent combined with the water return flow of 20 percent is the primary cause of increasing salinity levels downstream along the river.

For each reach, a fixed amount of 1.9 $m^3\ s^{-1}$ for urban and industrial use was assumed. Return flows of these extractions are normally high and were set at 50 percent, while salt accumulation was considered to be negligible. For Esfahan, an additional extraction was calculated based on a population of 2 million and a per capita requirement of 200 $l\ d^{-1}$.

Precipitation is very low with annual values of about 130 mm. Observed monthly values were used and a contributing area was defined, which can be considered as representing the area that contributes to the river discharge. This is the so-called "effective precipitation" in hydrological terminology. As this effective precipitation is so low, this rough approximation was considered to be sufficiently accurate.

Table 4.15. Nodes defined in the simulation model and observed annual average extractions at reaches.

Node	Extraction	Avg. flow m3/s	Return flows %	Salt accumulation %
Chadegan Reservoir				
	Domestic	1.9	50	0
	Precipitation	0.1	-	-
Regulating dam				
	Domestic	1.9	50	0
	Precipitation	1.2	-	-
Pol-e-Zamankhan				
	Small-scale irrigation	1.9	20	10
	Domestic	1.9	50	0
	Precipitation	1.2	-	-
Pol-e-Kaleh				
	Mahyar	1.7	0	10
	Nekouabad LB	16.4	20	10
	Nekouabad RB	6.9	20	10
	Small-scale irrigation	4.7	20	10
	Domestic/industrial	1.9	50	0
	Precipitation	1.2	-	-
Nekouabad				
	Small-scale irrigation	4.7	20	10
	Domestic/industrial	1.9	50	0
	Precipitation	1.2	-	-
Musiyan				
	Borkhar	1.1	20	10
	Esfahan	4.6	80	10
	Small-scale irrigation	4.7	20	10
	Domestic/industrial	1.9	50	0
	Precipitation	1.2	-	-
Pol-e-Chom				
	Abshar LB	7.2	20	10
	Abshar RB	7.0	20	10
	Rudasht	0.4	20	10
	Small-scale irrigation	4.7	20	10
	Domestic/industrial	1.9	50	0
	Drain inflow	9.4	-	-
	Precipitation	1.2	-	-

Note: Return flows and salt accumulation are estimated values.

The model was set up for an 11-year period (1988-1998). Missing data were assumed to have the same value as the average ones from the same months, as described before. Recorded flow data were used to adjust some unknown required input data, such as small-scale irrigation and domestic/industrial extractions. After the calibration for these data, a generalized model was created taking the average simulated flow for each month from the period 1995-1998. This generalized model is used for scenario analyses in chapter 5.

4.12.2. Results

Model performance

After completing the model and including the data, the performance of the model was tested. Some preliminary test runs showed that the performance of the model for the last reach, Chom-Varzaneh, was less accurate, showing much higher estimated flow rates at the Varzaneh node then measured. Increasing the small-scale irrigation extractions resulted in negative values during some months and still high values during other months. The nature of this downstream irrigation is a clear example of water extractions in a water-scarce area. As long as water is available, irrigators will use it, and no clear irrigation season can be distinguished. However, if flows are too high, not all the water is extracted and a threshold value of 50 MCM (19 $m^3 s^{-1}$) was assumed.

Including this adaptation in the model, recorded and simulated streamflows were compared for the seven locations along the river. Table 4.16 shows this comparison and some statistics. Observed and simulated values for the Regulating Dam were similar to the Pol-e-Zamankhan ones. Calculated values were close to observed ones, especially for the more upstream nodes.

Table 4.16. Comparison between observed and calculated monthly streamflows.

Node	RMSE $m^3 s^{-1}$	r^2	Absolute Difference $m^3 s^{-1}$
Regulating dam	3.87	0.99	0.67
Zamankhan	5.09	0.98	1.63
Pol-e-Kaleh	5.63	0.98	3.17
Nekouabad*	13.43	0.69	5.63
Musiyan	7.48	0.71	2.85
Pol-e-Chom	10.65	0.81	5.78
Varzaneh	15.48	0.67	10.18

*Values ignoring the apparent measurement errors in spring 1993 are: 6.90, 0.89, 3.56.

The excellent performance of the model for the Regulating Dam, Pol-e-Zamankhan and Pol-e-Kalleh nodes is related to the fact that almost no extractions take place in the upstream part. Between Pol-e-Kalleh and Nekouabad, a substantial amount of water was extracted (about 20 $m^3 s^{-1}$), but recorded and calculated flows were in reasonable agreement. An exception is the peak flow in spring 1993, where a big deviation between observed and calculated stream flow can be seen. Most likely the peak flow was missed at the Nekouabad station, as it was observed more downstream in Pol-e-Chom and Varzaneh. In general, calculated flows were somewhat higher then observed ones and model performance was better for the upstream nodes than for the downstream nodes.

For the upstream part of the basin, salinity levels are around 1 dS m^{-1} and not much fluctuation occurs. For the middle-part of the basin, levels have increased to about 2-3 dS m^{-1}, with some peaks reaching levels up to 8 dS m^{-1}. Huge fluctuations occur at the tail-end of the basin, with very high salinity values if water levels are low, such as at the end of 1991 for Pol-e-Chom and at the beginning of 1991 for Varzaneh. Average calculated values, excluding peak values, are about 2.5 and 6.5 dS m^{-1}, for Pol-e-Chom and Varzaneh respectively.

4.12.3. Conclusions

For the Zayandeh Rud, a simple spreadsheet-based water and salt balance model has been developed that can produce reliable results as compared with observed data. The generalized model, developed by combining simulated results over the last 4 years, is a transparent and easy to use tool for scenario analyses.

Some general conclusions can be drawn from this study. The flow to the Gavkhouni Swamp is very small and the quality of this water is so poor that it is unsuitable for any further use. At the tail-end, water is fully committed even while salinity levels are too high for a sustainable irrigation practices. A further expansion of agriculture can only be accomplished by increasing the inter-basin transfer of water, or a higher productivity in terms of kg produced per cubic meter of water used. Improved field-scale management, more productive crops, minimizing accessions to saline groundwater and decreased non-beneficial evaporation are ways to achieve this higher agricultural productivity.

The Water Salt Balance Model is an important element of the scenario analyses made in chapter 5, because it enables us to examine not just production impacts of alternative water management options but also some of the environmental ones as well, which are discussed later in the text.