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Integrated Economic-Hydrologic Water Management and Planning Model for the Khorezm Region in Uzbekistan

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1 Introduction

The region Khorezm, situated in the Central Asian Republic of Uzbekistan, is one of the numerous examples of irrevocable, inefficient water consumption and management mainly for irrigation. Agrarian economic tendency based on irrigated agricultural development resulted and still results in drastic ecological, social, and economical problems.
To reduce the unsustainability and negative effects of water use on the local and national ecosystem and population, one factor is a more efficient water allocation and water use for various sectors and a more efficient, sustainable water resources management. The project „Economic and Ecological Restructuring of Water and Land Use in the Region Khorezm (Uzbekistan), a Pilot Project in Development Research“[1] has been initialized which takes into account a holistic economic-environmental approach to improve the current situation with the development of effective and ecologically sustainable concepts for landscape and water use restructuring.
In the following introduced study a regional, intersectoral analysis for different spatial resolutions of water allocation and use is carried out for the Khorezm Region. The main tasks of the study will be the detection and determination of water supply and demand and as a consequence thereof the water availability and water use patterns in the region of Khorezm and the identification of tradeoffs and complementarities for different water uses. Strategies for a more effective water use, management and allocation shall be developed as the major outcome of the research.

2 Regional Conditions

2.1 Amu Darya River

The Amu Darya River is the largest river in Central Asia. It extends some 2550 km from its headwaters[2]. The river flows generally northwest. The total catchment area of the Amu Darya basin is 227800 sq. km. The average annual flow of the Amu Darya is 75 cubic kilometers.

The receiving basin, the Aral Sea, experiences less than 150-200 mm of annual precipitation. Evaporation is dominant (up to 1700 mm per year). Because the water of the Amu Darya is used excessively for irrigation, the river has been stopped from replenishing the Aral Sea. Now the situation is that just maximal 10% of its former water amount reaches the Aral Sea (2-5 km^3/a) if any at all.

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2 or resp. 1437 km up to the junction

During the last 30 years the Amu-Darya waters have been used for large-scale irrigation projects[3]. There exist hundreds of canals and pumping stations supplying and distributing the Amu-Darya water to irrigated fields. A number of water storage reservoirs also appeared. As a result, an almost 100% irreversible use of water has been achieved.

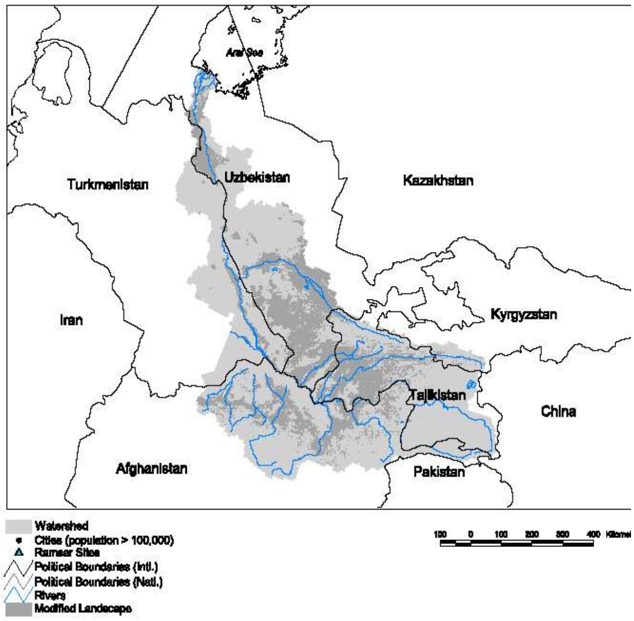


Figure 1: Amu Darya Watershed, World Resources Institute, http://www.wri.org/watersheds/asia/p2_71.pdf

2.2 Khorezm Region

Khorezm is one of the oldest centers of civilization in Central Asia. The Province is situated in the north-western part of Uzbekistan at the lower reaches of the Amu Darya. Its total area is is around 6300 square kilometers. The climate is continental, with moderately cold winters and dry hot summers.

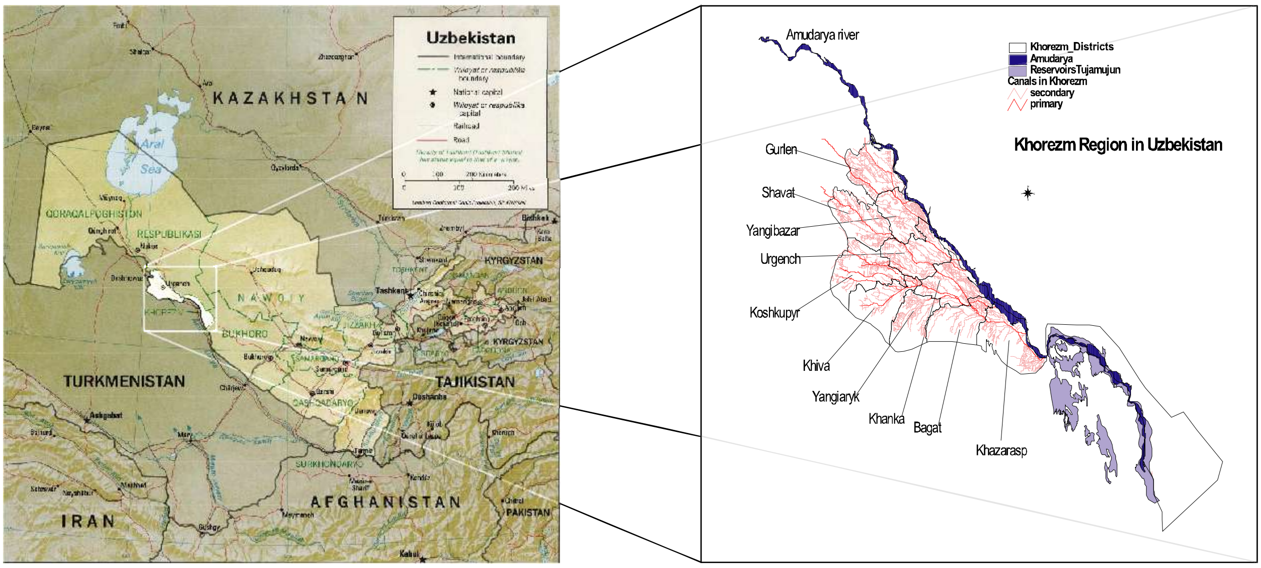


Figure 2: Khorezm Region

The population of the Province region's population exceeds 1.2 million, with about 80% living in the outlying areas. The Province is divided into 10 administrative districts with Urgench as the administrative center. Urgench has a population of 135.000.

The Khorezm Oasis is a highly irrigated Region with lots of primary and secondary channels. The Amu Darya provides irrigation water to some 231.000 ha of land in Khorezm (from which more than 12% are with highly salinization degree). The region contributes to 15% of the national Uzbekistan river water withdrawals. The water withdrawal for agriculture is estimated at 94% of the whole regional water withdrawals.

During Soviet times the production of agricultural commodities particularly of cotton was expanded far into the country's dessert and marginal land with a sharp increase of irrigated area.

3 There are more than 2Million hectares irrigated lands in the Amu Darya basin.

One of the areas with the most intensive agricultural use is the Khorezm Rayon (=Region). This resulted amongst others to an increase of environmental, social and economic problems like rise of soil and water salinity, water scarcity and competition, declining yields, health problems, rising groundwater level.
The main strategic crop in Khorezm region is still cotton which occupied more than 45% of all sown area in the period 1998-2001. Other basic crops in Khorezm are wheat and rice, potato, vegetables, melons, fruits and grapes. Cereal production, especially rice, has increased significantly during last several years.

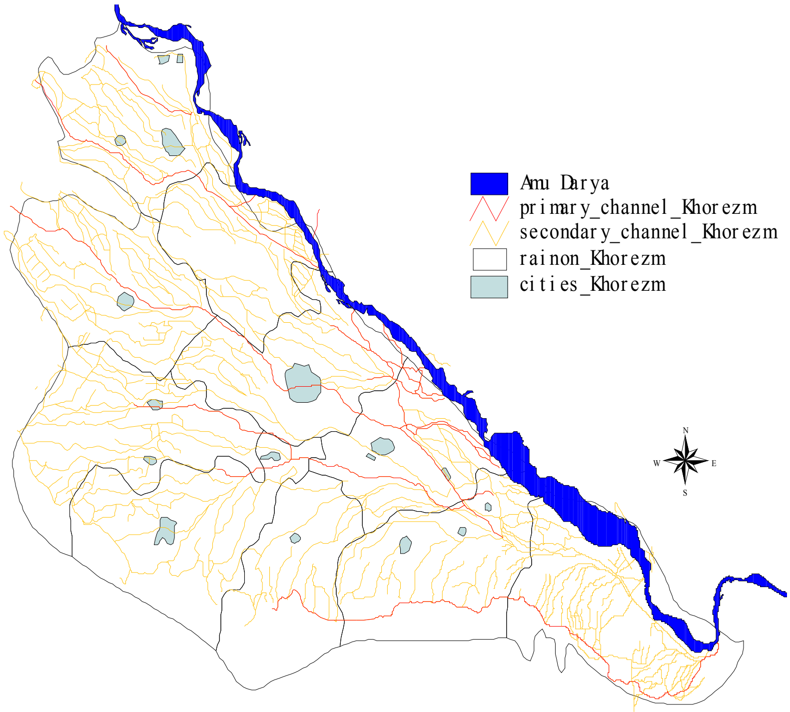


Figure 3: Irrigation channel network of Khorezm Raion

One of the central problems of the irrigation system seems to be its poor efficiency and maintenance. The average weighted efficiency of the irrigation network, which shows the water losses along the distance between the source and the irrigated field, is 63% (FAO, 1997). Due to the transition to a market economy there is a lack of economic incentives and financial resources to improve the irrigation system, and neither land-use nor water-use practices encourage efficiency in water use.
At present collector-drainage water is not treated at all. The annual discharge of collector and drainage water goes directly into the rivers, evaporation ponds, natural salt lakes, or is reused for irrigation.

3 Methodology

3.1 Water Management Models / Economic-hydrologic Models

Sustainable and efficient management of water resources requires an interdisciplinary approach. There are two types of hydrologic-economic modeling techniques: simulation and optimization. Simulation models simulate water resources behavior in accordance with predefined set of rules governing water allocations and infrastructure operations while optimization models optimize and select allocations and infrastructure based on objective function and accompanying constraints [McKinney et al., 1999]. In the following text I will refer to the optimization technique. Usually either the hydrologic or the economic component dominates the model depending on the objectives and specific problems of the analysis. Hydrologic based studies deal with hydrologic and system-control components, economic components are represented mainly by cost-benefit analyses and on the objective of optimization of net benefits.
Integrated hydrologic-economic models consist of a hydrologic and an economic system. The economic components are driven by the hydrologic system that is based on physical parameters and principles while the hydrologic components and their operation is driven by socio-economic (and environmental) objectives.

3.2 Khorezm Water Management Model

The purposes of the study and the model are:

- the identification of strategies and policies for more efficient water allocation among users, agricultural development and water resources demand management in Khorezm
- the detection and determination of water supply and demand and as a consequence thereof the water availability and water use patterns in the region of Khorezm
- the evaluation of economic and environmental consequences (costs, benefits, tradeoffs and complementarities) of water uses in the region, water based or related constraints to agricultural and economic development
- the exploration of impacts of economic incentives such as water prices, irrigation investment; salinity control measures; crop pattern change; climate variability and climate change.

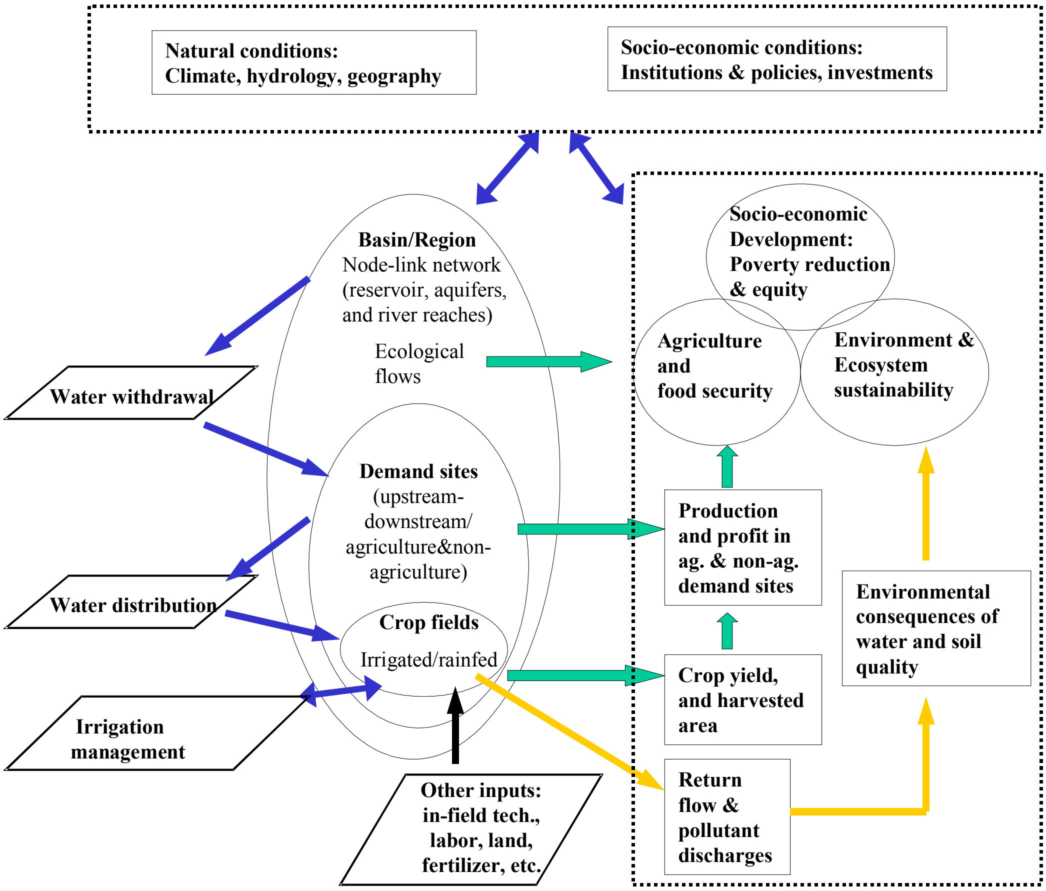


Figure 4: Integration of the hydrologic and economic components, Cai, X., 2004, unpublished

The water allocation model is built up as a system of nonlinear differential equations. The components of the model and according to it the interactions are based on existing water resource, allocation and optimization theories, and existing water resource models. As the model will be a water management model for the Khorezm region the scale will be on a regional level according to the project. In the Khorezm region the agricultural demand for irrigation purposes plays the most important role (other sectors are marginal), the allocation of water via irrigation canals of different order to the field level will be of special consideration (efficiencies, irrigation network, canal sealing, discharge…).

The model comprises of:

- The hydrologic components (water flow and salinity transport and balances, Groundwater and drainage balances)
- Economic components, production and benefit functions for different crops and water uses, costs, welfare, water prices, taxes…
- Agronomic components (crop parameters, yields, soil characteristics…)
- Irrigation management (efficiencies)
- Institutional rules, policies and economic incentives (as scenario analysis)

3.3 Structure, components and modules of the model

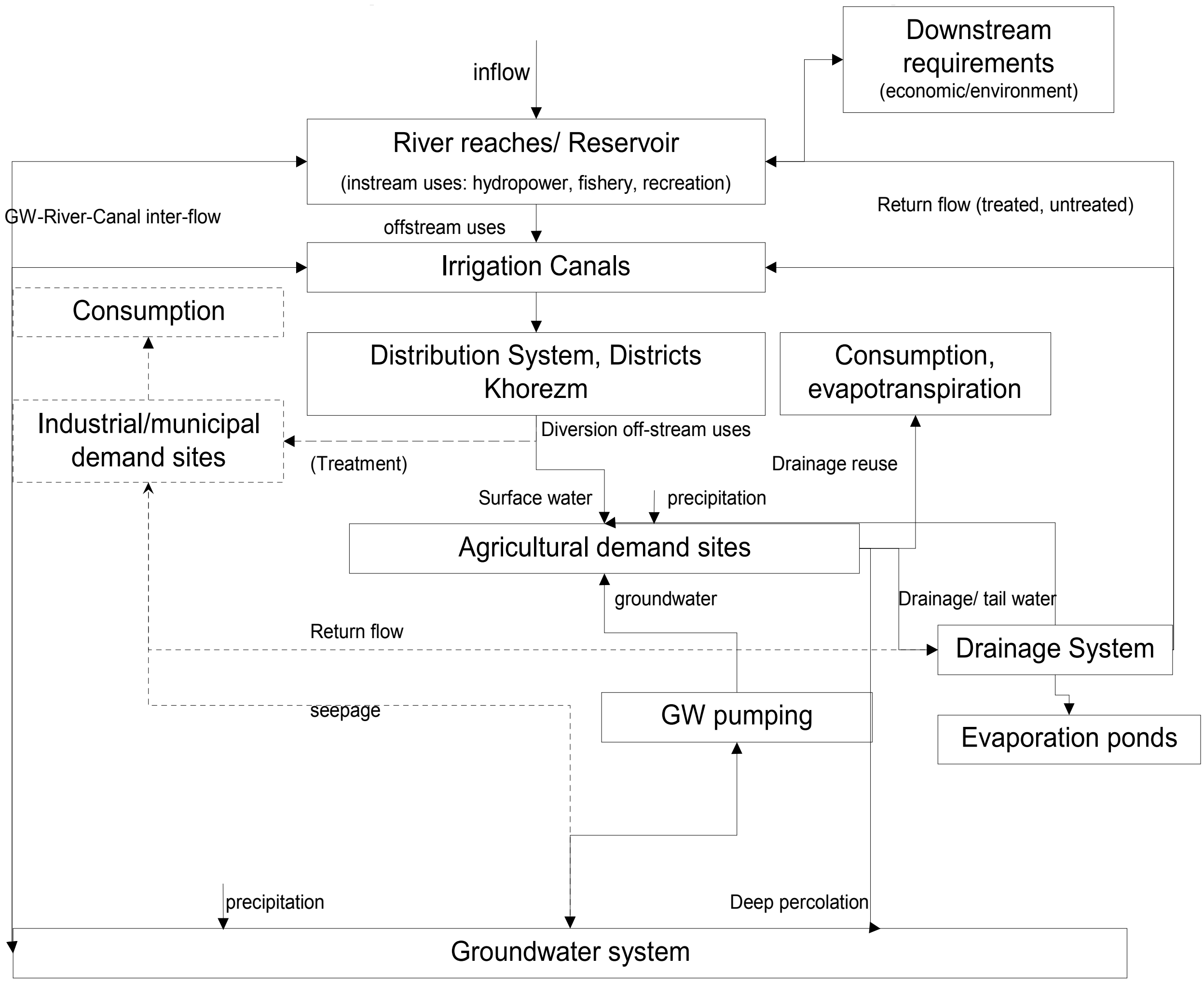


Figure 5: Schematic representation of the water distribution process in the Khorezm water management model, adapted from Daza and Peralta, 1993, modified

The water of a river Amu Darya can be used for different offstream and instream purposes. Within the Amu Darya river basin the hydropower generation (upper course) and agricultural demand for irrigation are the main factors of water use. But due to untreated drainage water (and industrial, municipal) which returns to the river and a generally lower amount of water in the river the water quality of downstream water declines which has to be represented in the treatment of the model (salinity component).

Due to high groundwater levels and the deliberately afflux of irrigation and drainage water within the canals the influence of groundwater and groundwater exchange should not abstract away from the modeling framework (see Figure 5).

The competition of different water users should enter the model through social benefit components, which in turn act as the basis for an efficient water management and optimization tool. Water institutions and organizations and their water related policies and future programs should also be included in the model. Those institutional regulations will be modeled as different scenarios.
The demand of water is determined endogenously within the model by using empirical agronomic production functions. Water supply is determined through the hydrologic water balances (surface water balance (river, canals) groundwater balance, drainage water balance, reservoir balance) in the river basin with extension to the irrigated crop fields at each of the irrigation demand sites. Water demand and water supply are then integrated into an endogenous system, and balanced based on the economic objective of maximizing water use, including irrigation and hydropower benefits (and eventually later for salinity damages, and fishery benefits).

The regional model and accordingly the model framework is developed as a node-link-network with abstracted spatial representation of the physical entities (see figure beside). Nodes represent a location where certain water activities occur like demand sites, river reaches and/or reservoirs; in- and outflows like evaporation and rainfall are also included (supply situation); links or branches represent the linkage between these entities.
The node-link network of the Khorezm model consists of 10 districts, river nodes and links, irrigation canals, groundwater, drainage and the main reservoir Tujamujun in the south-east of the region. All the nodes are connected depending on the real situation (like the main irrigation canal network and the river water junctions). It is assumed that every single district consist of an evaporation pound and a groundwater tank. There also exist connections between the river/ irrigation canal network and the drainage and groundwater system.

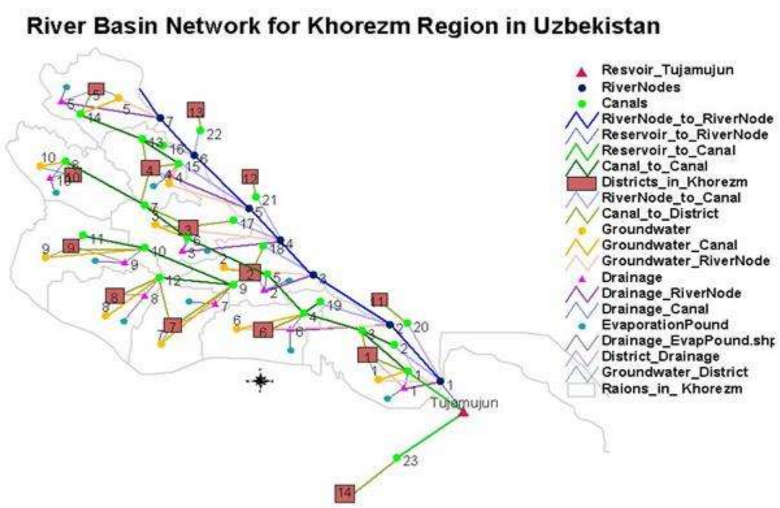


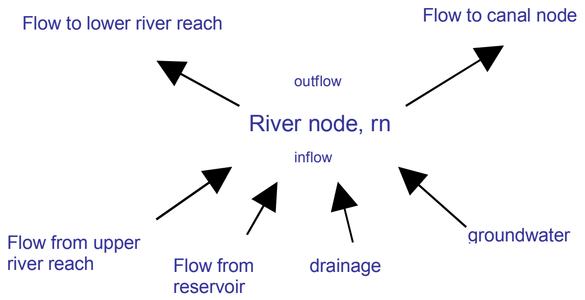
Figure 6: Node-link network of the water management model

Hydrologic Component
The hydrologic precesses are based on the node-link flow network. The main hydrologic processes include: flow balance in reservoir Tujamujun, river reaches, canal nodes, root zones, groundwater, drainage and irrigation, and the flow between those entities.
At each modeled period a mass balance of the water flow for every node is calculated. The quantity of water that can be withdrawn or stored at any of those nodes is a function of the amount of water available at that node. And the availability of water and respectively the storage depends on inflow (*IN*) from upstream node n1 to node n and outflow (*OU*T) from node n to downstream node n2 during time period t.

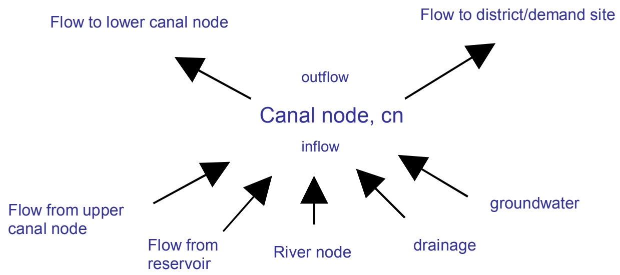
$$\sum IN^t(n1,n) - \sum OUT^t(n,n2) = ST^t - ST^{t-1} \qquad \textit{Equation 1}$$

As the modeled time period is one month the storage effect for river and canal nodes can be neglected (Loucks, 1996; Cai, 1999) and *IN=OUT*.

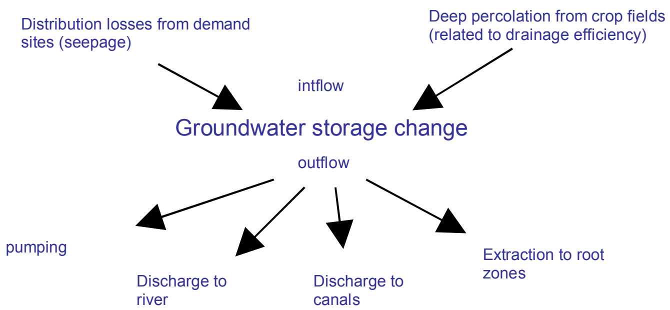
The node balance for river reaches includes:



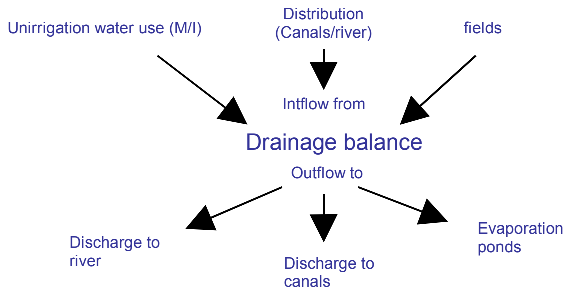
The canal node balance includes:



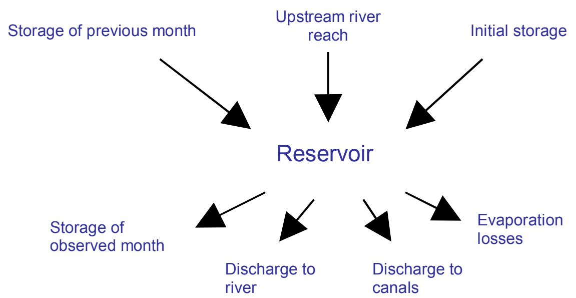
The groundwater balance looks like this:



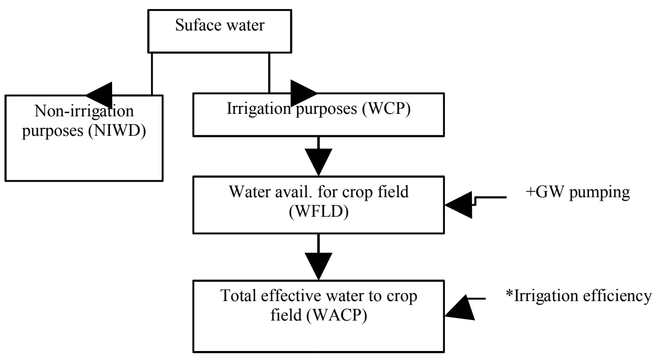
The drainage balance includes:



And the reservoir storage balance includes:



The water allocation within a demand site and the allocation among crops can be described as follows: water that is coming from canals, rivers and the reservoir is mixed and allocated to different districts in Khorezm. Depending on the distribution efficiency then the water is allocated to non-irrigation (M/I) and irrigation purposes (WCP). This water for irrigation purposes together with the groundwater pumping accumulate to the water that is available for a crop field (WFLD). But the total effective water, a crop field gets (WACP) also depends on the irrigation efficiency that lowers the water amount the



field finally obtains.

Soil water balance at root zone:
The water a single crop can use depends on those water application (WACP) per area, a small amount of rainfall Khorezm region gets (effective rainfall), the water that is extracted by the roots from the groundwater zone and the actual evapotranpiration losses.

Economic Component

The objective of the model is to maximize profits from water uses for irrigation in Khorezm.
The main economic part will be the analysis of economic incentives and their influences on benefits and costs, the hydrologic system operations and the water uses via scenario analysis.
Possible incentives could be: investments in infrastructure improvement, taxes and subsidies on salt discharges, modified flow balances (e.g. water conservation) and their effects,
introduction of surface and groundwater prices.

The model is performed in the modeling language of a General Algebraic Modeling System (GAMS) [Brooke et al., 1988], a system for programming mathematical problems. GAMS is used to allow for planned linkages with another model that is developed within the project (an economy wide Computable General Equilibrium model). The temporal resolution amounts to a one year time horizon with 12 month modeling periods.

Literature

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