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RIVERTWIN

A regional model for integrated water management in twinned river basins

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PP	Restricted to other programme participants (including Commission Services)	
RE	Restricted to group specified by the consortium (including Commission Services)	
CO	Confidential, only for members of the consortium (including Commission Services)	

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1 INTRODUCTION

1.1 Preamble

The work is done within the framework of the project ***"A Regional Model for Integrated Water Management in Twinned River Basins (Rivertwin)"*** started in 2004 and to be completed in 2006.

1.2 Task objective

Developing and adapting the integrated set of models **MOSDEW-Chirchik** for the **Chirchik-Akhangaran-Keles** basin. Determining composition of models and an order of their interaction within the general set of tasks providing operation of the **Integrated Regional Model**. Testing of model output is the scope of work of BWO "Syrdarya".

1.3 Status of research

For the **Chirchik-Akhangaran-Keles** basin, the following original set of models describing various physical and technological processes used in the Neckar and Oueme basin, was adapted to the local conditions due to (1) heavily anthropogenically modified water flows in the lower section of the basin (downstream Charvak reservoir) in contrast to the other two basins and (2) nescessity of a real-time water management tool for the annual planning of the most efficient water allocation taking into account environmental flow requirements:

Hydrology – includes soil water balance and surface waters (**HBV**),
Hydraulics – water movement in river network,
Groundwater - (**MODFLOW**),
Water quality – Models for surface water (**MONERIS, Qual-Chirchik**),
Socio-economic model, SEM**,** with specific agricultural model, which describes agricultural productivity and environmental pollution with account of land management and soil conditions in field - (**EPIC**), on a regional scale, supported by database (**SLISYS**),
Regional water demand –**WEAP** model, which considers water demand and supply in the context of institutional, legal, economic and environmental restrictions,
Regional areal model for results visualization– MOSDEW, supported by common database and ArcGis architecture.
Hierarchical structure of the model objects is as follows:
- Basin (areal object),
- Rayons, catchment zone, irrigation zones, crop areas (areal objects),
- Rivers (linear objects),
- River sections, canals, collectors (linear objects),
- Cities, intake points, well clusters, wastewater discharge points (point objects).

According to the initial scheme of **MOSDEW**, order of modeling is as follows:

1. **Climatic block**. By using ArcGis tools, climatic parameters are distributed over the project area, with spatial resolution of 1 km^2. Historical series taken from weather stations are used for model adaptation, and data of climatic scenarios are used for future analysis.
2. **Regional development scenarios block**. Proceeding from the analysis of current regional conditions and future regional development, indicators of probable changes in socio-economic characteristics of the basin are formed for the near 25 years (changes in population, production volumes, energy demand, etc.). Based on values of those indicators, new water demand, in terms of its quantity and quality, is formed per economic sector.

3. **Hydrological block.** By using climatic parameters as input data and basic characteristics of project area, the Hydrological block (**HBV, Hydraulic model, MODFLOW**) is started. As a result of the modeling, an infomedia, which can be referred to as ***hydrological infomedia*** is formed. A group of indicators is selected from this information for visualization of hydrological block output, and information collections for operation of the next blocks are formed. .
4. **Ecological block.** Models in this block (**MONERIS, Qual-Chirchik**) use the information collections from the **Climatic** and **Hydrological** blocks plus additional data on inflow of chemical and biological pollutants. As a result of block operation, a new infomedia is created, which, similarly to previous one, can be referred to as ***ecological infomedia***. A group of indicators is also selected from this information for visualization of ecological block output.
5. **Economic block**. The block includes a set of models representing **socio-economic model**, which describes all sectors of economy besides agricultural one, **the specific model of agricultural productivity (EPIC, SLISYS),** and **regional water demand** (**WEAP).** Besides simulation calculations, operation of the models in the economic block includes optimization components reflecting management processes in agriculture and water distribution. Furthermore, the database, which uses soil productivity characteristics (**SLISYS**) and regional infrastructure parameters (**WEAP**) is rigidly linked with actual time intervals. Thus, ***economic information layer*** has a complex composition, including both economic characteristics of objects and parameters of management in various contexts (such as institutional, legal, economic). Like in the above-mentioned blocks, part of information is used for visualization through GIS system.
6. **Resulting visualization and analysis (MOSDEW)**. At present, taking into account uncertainty regarding selection of a set of indicators from each ***information layer***, only their color spectrum is proposed.

Spatial resolution of the basin objects, as accepted for modeling a variety of hydrological, biological and physical process, is suggested to be ~1 km^2 for areal objects and ~12 km for linear objects. Models, which will be applied on a larger scale, should be brought to common space-time grid. Time resolution for output of the **Integrated Model** is accepted to be 6 months (one growing or non-growing period), though time steps for some of the models can vary from 24 hours (plant growth model, hydrological model) to several months (agricultural sector model). Investigated period of time in the **Regional Integrated Model** should meet **RBMP** requirements in context of global climate changes (0-25 years).

Description of models interrelation (diagram in Fig.3.1) is given in Chapter 3.

2 NOTATION CONVENTIONS AND ASSUMPTIONS

The main tools of the **Integrated regional model** are:

- Set of models used,
- GIS,
- Database.

Approach used in the project in modeling of basin functioning and development is usually called as «***algorithm concept*»**. Such approach considers a set of models $\mathbf{M^1, M^2, \ldots, M^k}$, that describe various aspects of system behavior. Then, the algorithm of system behavior as a whole is formed though different combinations of operating models. Taking into account great number of various models used in the project, with different variable sets, dimensions, programming languages, and data formats, for correct assembling of the **Integrate model** it is necessary to take a range of assumptions on formal description of model interaction that make it possible to operate uniquely with variables of various models at different stages of their operation.

2.1 Time

Let introduce symbols of current time "t" and period [t]. Actually, [t] is a discrete time sequence where variable values are defined. For various models, those sequences can be different, therefore additional specification is needed: $[t]^M$ is a time sequence, where particular model "M" operates, for example, $y(t),\ t \in [t]^{HBV}$ means that variable "y(t)" is specified in time sequence of the model "HBV". Besides, variable "t" takes values with interval, which is set just by the model "HBV". Capital letter "T" would be used for temperature; T, ^oT are Kelvin scale temperature and Celsius scale temperature, respectively ($T = {}^oT + 273.15$).

2.2 GIS variables

Let set symbols for spatial variables processed by GIS tools. Geoinformation systems usually use two types of mapping data presentation – first, location of an object relative to the earth, i.e. $\mathbf{x}=[x^1, x^2]$ – spatial coordinates, and, second, attributive (descriptive) characteristics of the object, for example, $z(\mathbf{x})$ – raster layer of elevations. For the Chirchik-Akhangaran-Keless basin, this layer is realized in cells 90×90 m and is a reference relative to which other raster and vector layers are formed. Each raster layer has one attribute, for instance, $z^g(\mathbf{x})$ – raster layer of water tables. Each vector layer corresponds to specific objects having a set of attribute information, for instance, cities, rivers, rayons, etc. In vector layers, boundaries and orientation of objects are determined by a set of points that, if joined straightly, make images of the objects. The points themselves are defined by coordinates:

1 – point objects, by one coordinate "$\mathbf{x}$",

2 – linear objects, by a set of "k" coordinates "$[\mathbf{x}_0, \mathbf{x}_1, \ldots, \mathbf{x}_{k-1}, \mathbf{x}_k]$",

3 – areal objects (polygons), by a set of "k" coordinates "$[\mathbf{x}_0, \mathbf{x}_1, \ldots \mathbf{x}_{k-1}, \mathbf{x}_0]$".

Certain attribute information stored in the **Database** corresponds to every vector object in GIS. A link is established between these two types of information through identificator assigned to relevant object. GIS does not operate with time, and any variable as a function of time is represented in GIS through a set of layers, number of which is equal to number of elements in concrete time sequence "$[t]^M$", for example, every climatic scenario forms its own temperature fields, precipitation fields, which are presented in GIS by sets of thematic layers $T_t(\mathbf{x}), q_t(\mathbf{x}), \ldots, t \in [t]^{Clim}$. Formal procedures of variable processing in GIS depend on type of a layer (raster or vector), and on used GIS-system, for example, "Idrisi32" or "ArcGis", and therefore their description should be related directly to particular GIS-system. The common is that exchange with the **Database** is made through SQL language.

2.3 Database

The central concept in the **Database** is «***information object***»**.** In order to define various objects uniquely in the whole space-time project set, the composite coding system (place:time) is used. Each object, during its registration, takes a unique code ”j:t” , where: the first index “j” characterizes its location, while the second index “t” is a year when the object was created physically. This composite code is assigned to the object during the whole period of its existence; moreover, in the period of reconstruction or putting out of operation, the object is re-registered, while the first index remains. Such coding gives an opportunity to keep track of infrastructure changes in time. Every code (object) has a table of attributes reflecting affiliation of the information object with various GIS layers and models in different periods of time. Information in the database is stored in form of relevant information structures (set of tables) linked with particular objects. In given project, influence of an object on another one is considered mainly through the perspective of water flows directed to various economic sectors $Q_j^s(t)$, where: “j” is index of object, “s” is index of economic sector. Four economic sectors were pointed out in the Chirchik-Akhangaran-Keless basin:

1 – Industrial sector, including energy production (hydropower and heat power),
2 - Agriculture,
3 - Agro-industry,
4 – Service sector, including communal sector.

Distribution of flows among the economic sectors, besides their quantitative characteristics, requires a special component such as “water quality”. Here, simple indexation is not sufficient since the term “quality of water resources” has very complex structure, which differs between the sectors. At present stage, it is expedient to fix the component “water quality” only partly, by strictly defining only a part of this vector, while further extension of this component should be made as far as various individual models are introduced and adapted in the Integrated regional model. Let define “water quality” as vector “$P_j^s(t)$”, $P \equiv [p^1, p^2, p^3, \ldots, p^k, \ldots]$, which would be connected with particular water flow $Q_j^s(t)$. Every element “p^k” in the vector “P” corresponds to certain physical, chemical or biological characteristic of water flow in specific point of time. Full list of vector “P” elements is given in QUAL2K model documentation (see Section 5.1, output variables: elements a)-d)). It should be noted here that the basic property of the vector is that when adding or dispersing water flows, all the elements are recalculated uniformly, viz:

$$p_{j,i}^k = \frac{Q_j p_j^k + Q_i p_i^k}{Q_j + Q_i}, \forall \text{ k} \qquad (2.1)$$

From physical point of view, vector “P” can be viewed as coordinates of the state of water flow. Each economic sector has own quality standard “$P^{s,N}$” for supplied water; therefore, the following inequality should be met: $P_j^s(t) \le P^{s,N}$, ∀ j, s, t. In given project, operation of treatment plants is not modeled; therefore, distribution of flow among economic sectors is considered as a function of cost (table of cost) needed to transform a portion of flow from state $P_j^{s4}(t) \Rightarrow P_j^{s0}(t)$. Next tables (tables of quality) determine change in vectors $Q_j^s(t)$, $P_j^s(t)$ after their supply to respective economic sector. The general change in the state of flow results from composition of various project models. For complex objects and systems, rarely one can find the required ratios in an explicit form; usually, they are expressed through sets of individual processes (models) with a range of free parameters, on the basis of which those are adapted to actual conditions.

2.4 Coupling of objects in space

Spatial coupling of objects is based on network theory, where every object “j”, according to its type (point, linear or areal) is associated with a set of arcs reflecting its links in the general water infrastructure in the basin. Each arc corresponds to particular water flow directed to relevant economic sector of a particular object. Direction of arcs is based on direction of water movement[1]. Set of all objects $\{j\}$ and set of arcs “$\{j,k\}$” (flows) form connected oriented graph $G(J,I,t)$, $j \in J \equiv \{j\}$, $(j,k) \in I$, $\forall (j,k)$, $j \in J$, $k \in J$, $k \neq j$, corresponding to water infrastructure in the basin in specific period of time “t”. Every mathematical model works only with a part of information objects; therefore, own interface is needed for a particular model to form respective partial oriented graph, for example, $G^{HBV}(J,I,t)$, $j \in \{j\}^{HBV} \supset \{j\}$, $j,k \in I^{HBV} \supset I$; where $\{j\}^{HBV}$, I^{HBV} – subsets of objects and arcs providing operation of the model “**HBV**” (selection of information objects is made to the proper model). In addition of physical flows directed along the arcs, the system has counter information flows referred as requests. Based on requests and the state of object, a management vector “$U_j(t)$” is formed in specific point of time.

2.5 Operation chain of the main blocks

Operation chain of the models is determined by cause and effect relationships that are actually present in physical and technological processes providing accumulation and distribution of water resources in the basin. The general modeling period as accepted in the project is 25 years. For the Chirchik-Akhangaran-Keles basin, only ***climatic scenarios*** are independent of the general system of tasks in this time interval. ***Development scenarios*** are linked with economic indicators that are used in agricultural and industrial production and, hence, they are interdependent. The largest time interval, from which information is received, is one year (economic block). By assuming this interval as the minimum one for the **Integrated regional model**, we would get conditions for required operation of models from all the blocks during 1 year. Water-management year, which starts on October 1 of current year and ends on September 30 of the next year, is considered for the Chirchik-Akhangaran-Keles basin.

Groups of models operate within each block and have own time intervals and iteration cycles. Links within the groups of models will be shown in sections describing relevant block.

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[1] Short-term flows with opposite direction of water movement can occur in some river sections. In this case, discharge would be negative and basic equations would be valid.

3 COMMON SET OF MODELS AND THEIR INTERRELATIONS

The set of the above mentioned models has strong interrelation in form of input, output, transfer of data from the database, back coupling (Fig. 3.1).

The more independent block that has influence on surface and ground waters, as well as on water requirements is climatic block, which is described by equations of the model HadCM2 or the model proposed by Wei. From this block precipitation and temperature are going to HBV-IWS related to flow formation zone, same as Modflow. Climatic data feed also WEAP model. WEAPs irrigation system part that presents water requirements of irrigated lands. The same climatic output (temperature, humidity, precipitation, wind) is applied to SLYSIS and Moneris.

The Hydrological block consists of HBV-IWS-surface water of flow formation zone with addition of Modflow (groundwater) introduce water regime and water features in GAMS model (water balance, regulation, delivery and allocation).

Balance of water and regulation are built with input from WEAP (water requirements for irrigation – irrigation system model and other water use model).

WEAP has strong interrelation with SEM and its SLYSIS part, then they both have iterative correlation with HBV-GAMS depending on results of possibility of water balance in terms of quantity and time.

Output from SLYSIS to Moneris and later to QUAL-Chirchik with its hydrodynamic sub-model WAVE should assess quality of water and can give interrelation to GAMS model, if environmental requirements would not be satisfied by river regime.

Results of all the models will be presented to MOSDEW.

Taking into account that SEM (socio-economic model) and SLYSIS, as specific block of SEM was presented in specific deliverable D-27, we are describing below only hydrological block and interface as a tool for integration.

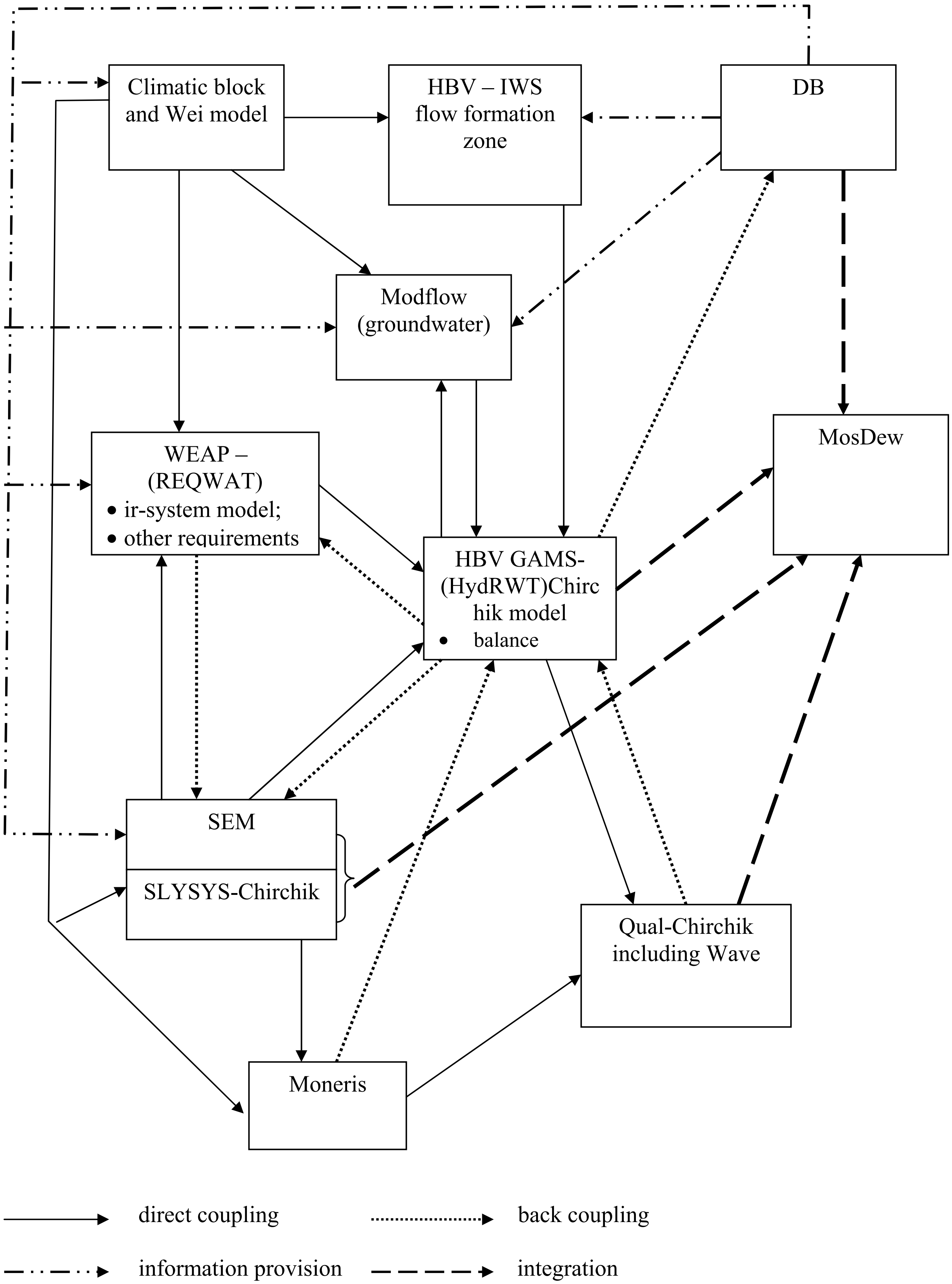


Fig. 3.1

Diagram of relations between models

4 HYDROLOGICAL BLOCK

The hydrological block operates the models that reflect water formation and distribution in project area. The hydrological block starts to operate by using climatic parameters as input data and basic project area characteristics. Initially, the Hydrological block included the following models: (**HBV, GAMS model, MODFLOW**). However, according to the protocol of February 2005 and taking into account specificities of the Chirchik-Akhangaran-Keles basin, it was decided to extend the block through inclusion of the following models:

- model describing dynamics of operation of the long-term regulation reservoirs, HEPS, and head intake structures;
- model of irrigation systems in flow dispersion zones, with further linkage with tasks of agricultural, industrial, and public utility sector.

4.1 HBV model

HBV-Chirchik is a surface water model relating to the class of conceptual models describing the relatively small amount of components, each of which is a schematized similarity of processes that take place in simulated system.

HBV-Chirchik is a version of HBV-IWS [Y.Hundecha, A.Bardossy. Modeling of the effect of land use changes on the runoff generation of a river basin through parameter regionalization of a watershed model. Journal of Hydrology 292 (2004) 281-295] adapted to conditions of the Chirchik-Akhangaran-Keles basin. The analysis showed that for conditions of given basin it was better to test the model HBV-IWS which had smaller set of input data than, for example, the model LARSIM (which originally was also considered, together with HBV-IWS, as a potential basic model). The model HBV-IWS has less complex description and considers a number of parameters, and, at the same time, the model is more flexible and has a lot of adjustment coefficients so that to take into account specificities of flow formation in mountains. The main HBV-IWS algorithm is realized in FORTRAN in form of separate blocks.

The main variables of HBV are: sub-basin and zone areas; soil characteristics. Input variables are: climate data – daily temperature and precipitation data, soil hydrological properties, mean monthly evapotranspiration, discharge in tail gauging stations (to compare simulation with actual data and to calibrate the model). Major output variables are daily and monthly flow amounts per sub-basin and river.

The model HBV-Chirchik implements (with daily step) a well-known hydrological method of mountain river flow generation, which uses elementary transforming reservoir or several linked reservoirs and elementary operator of transformation, which takes account of flow generation zone specificities (unit hydrograph reflecting what time which share of water passes through the outlet of flow generation zone).

In part of flow transformation in the river network, HBV uses Muskingum method. This method has the lowest inaccuracy in case of available linear empirical relationships between the water quantity in river sections and discharge and is true for a river section, where there is no considerable flow off-take. Since HBV produces considerable losses at sites of flow intake and regulation (mountain reservoir places), such sites were excluded in the developed hydrological scheme of the Chirchik-Akhangaran-Keles basin in HBV-Chirchik. It was decided to divide the basin into sub-basins and select some rivers in each sub-basin, while links between the rivers were established in GAMS-model of flow distribution (see section 3.2.1), rather than in HBV-Chirchik, where intakes, disposals of return flow, as well as sites of flow regulation by reservoirs and HEPS were considered.

For model adaptation, we use historic data series from weather stations and measured discharges per river in flow formation zone at outlets, while for future analysis we use climate scenario data.

Adaptation of HBV-Chirchik was performed in order to further use it under the RIVERTWIN project for assessment (not scientific prediction) of mountain river runoff in the Chirchik-Akhangaran-Keles basin for mid- and long-term (scenario computations). River runoff forecasting for a few years is a multifactor problem, which was solved in the region mainly on the basis of relationships between the river runoff series and the variables characterizing regional climate change (analysis of climatic trends and hydrological series of river runoffs, year sequences; assessment of probable deviations from the trends in the future, etc.). At the same time, application of such models as LARSIM/ HBV for assessment of series of natural river runoff for long-term in the region is little-studied.

In HBV-Chirchik structure, three main basins, such as Chirchik, Akhangaran, and Keles are selected. Besides, there are small rivers in the area between the Chirchik river and the Akhangaran river (Parkent district) that now have no direct inflow to these rivers and therefore were selected into separate sub-basin.

In total, 10 sub-basins were selected in the model HBV-Chirchik (five sub-basins in the Chirchik basin, three ones in the Akhangaran basin, one in the Keles basin, and Parkent sub-basin) and then divided into elevation zones with 200 m increment. As the sub-basins are located at an elevation from 400 m to 4000 m above sea level, each sub-basin is divided into 17 zones. There are 170 simulation zones in the model.

Major HBV-Chirchik output is water discharge in the river network nodes of those sub-basins.

Table 4.1. Main entities in HBV-Chirchik – sub-basins and rivers

№	Sub-basins	Main river	Other rivers
1	Pskem	Pskem	Nouvalisai
2	Chatkal	Chatkal	Chimgansai, Yangikurgan
3	Koksu	Koksu	-
4	Ugam	Ugam	Karankulsai, Tashsai
5	Aksagata	Aksagata	Aktash
6	Angren	Akhangaran	Tagan-bashisai
7	Dukent	Dukent	Karabou, Nougarzan, Nishbash, Gushsai
8	Sharkhi	Shavazsai	Almalyksai
9	Keles	Keles	Keles' tributaries
10	Parkent	Parkent	Kyzylsai

The HBV model simulates flow generation in catchment zone, based on certain gauging stations, and its further transformation along the river.

Basic variables:
a) river basin geology;
b) areas of sub-basins and zones;
c) soil thickness and properties.

Input variables:
a) climatic data: daily data on temperature and precipitation;
b) mean monthly temperature per sub-basin;
c) data on soil moisture: field capacity and wilting point;
d) mean monthly evapotranspiration (mm/day)
e) data of gauging stations located in sub-basins;

Simulation time:
One year.

Output variables:

a) daily flow volume per sub-basin;
b) monthly flow volume per sub-basin;
c) evapotranspiration value.

4.2 MODFLOW model

MODFLOW is a 3D groundwater model based on Boussinesq equations and realized in finite element method. MODFLOW includes a main body, which is distributed on free basis, and a number of interface options, most of which are commercial products. For implementation of MODFLOW-Chirchik, non-commercial interface PmWIN was recommended. During joint analysis (together with Roland Barthel) of the Chirchik-Akhangaran-Keles basin topography, the parties agreed that the model MODFLOW-Chirchik may be used only for areas located downstream of Charvak reservoir, from the side of the Chirchik river basin and downstream of Akhangaran reservoir in the Akhangaran river basin. This modeled area has a shape of unequal-sided horseshoe covering spurs of Chatkal mountain range and bordering Kuramin range on the side of the Akhangaran river and Karjantou range on the side of the Chirchik river. The spurs of Chatkal mountain range divide two groundwater lenses that are considered in given section as independent deposits mating through the surface runoff of Chirchik and Akhangaran rivers.

Basic variables:
a) Area of groundwater deposit $\Omega(\mathbf{x})$,
b) Structure of aquifers $k^f(\mathbf{x}, h)$, $\mathbf{x} \in \Omega(\mathbf{x})$,
c) Location of intake wells $\{j(\mathbf{x})\}^g$
d) Water flows throughout the deposit contour $Q(x,t)$, $x \in \partial\Omega(\mathbf{x})$,
Input variables:
a) Climatic data, according to scenarios,
b) Water intake requirements per well cluster $Q_j(t)$, $j \in \{j\}^g$,
c) Forecast values of river discharge, based on HBV results.
Simulation time:
One year,
Output variables:
a) Water intake hydrographs per well cluster $Q_j(t)\ \forall j \in \{j\}^g$
b) Filtration (infiltration) with reservoirs and river sections (functions of conjunction),
c) Groundwater level fluctuation, $z^g(\mathbf{x})$
Model objects:
a) Chirchik groundwater deposit,
b) Akhangaran groundwater deposit.

4.3 HBV-GAMS-Chichik model

The principle tasks of HBV-GAMS-Chirchik is to interlink water requirements from WEAP with water resources, their development and distribution.

Work was aimed at staged development and testing of the GAMS-model of water distribution among water consumers and users in the Chirchik-Akhangaran-Keles basin, which practically includes and links components of a range of models suggested for adaptation (surface water resources, salt fluxes, flow regulation by reservoirs and waterworks facilities, irrigation, hydropower and thermal power stations, groundwater sources, water-supply entities – household, industrial, agricultural consumption).

Staged input of entities in the GAMS-model and their distribution in time and space should be done after their schematization and zoning throughout the basin area. At the same time, the model should be viewed as a part of the integrated model.

Schematization should reflect basin specificity in terms of management and be maximally approximated to existing management entities of the Chirchik-Akhangaran Basin Administration of Irrigation Systems and of the BWO “Syrdarya”. Chirchik-Akhangaran-Keles sub-basin should be considered as a part of the Syrdarya river basin with certain inflow requirements into the latter.

First of all, GAMS-model is to enhance HBV-Chirchik in part of linking of certain sub-basins and rivers in flow formation zone into river systems of Chirchik, Akhangaran, Keles and Parkent rivers, as well as further distribution of river flows among distribution irrigation network and derivation canals, including flow transfers from one sub-basin to another one.

Other important requirements for the GAMS-model are:

- linking of surface and ground waters, assessment and cutting (in case of water shortage) of water supplied to planning zones,
- assessment of water salinity in river and irrigation networks,
- capability to manage surface runoff (regulation by reservoirs, limitations regarding discharge and withdrawals) and environmental constraints in terms of quantity and regime of water discharge into Syrdarya.

The task was to develop a user interface which links the GAMS-model with other models and DB and makes it possible to make and assess simulations for selected scenarios and options.

4.3.1 Model preparation

Initially, for successful adaptation of HBV-IWS to Chirchik-Akhangaran-Keles basin, a special program was developed in GAMS environment and testing simulations were made to link all entities, zones and water and salt fluxes in hydrological scheme-analog of flow formation zone. The program links all zones and waterways of HBV-Chirchik into river systems of Chirchik, Akhangaran, and Keles and stipulates data reading (runoff hydrographs) from HBV-Chirchik.

Then, we developed and tested a scheme of surface runoff distribution network located downstream of flow formation zone and linking the network of rivers and its tributaries in the Chirchik-Akhangaran-Keles basin with the irrigation network, planning zones, drainage (collector, waste) network. Besides, regulation entities (reservoirs), distribution entities (waterworks facilities), and monitoring entities (gauging stations) were incorporated into the scheme. The scheme was realized in GAMS and attached to the GAMS-program of flow formation zone.

Next, hydropower module was developed and tested, and the GAMS-model of flow distribution was supplemented by scheme and algorithm for computation of electric energy generation by Chirchik and Bozsu cascades. There is provision for inputting planned Pskem reservoir and HEPS, as well as existing thermal stations associated with water sources.

Finally, groundwater sources and water-supply entities associated through “Vodokanal” system with water sources and consumers were inputted into the GAMS-model of flow distribution.

Thus, the GAMS- model of flow distribution was developed for major consumers and users of surface and ground waters which allowed runoff management through reservoirs, limitations on discharge and withdrawals, etc.

The GAMS-model was linked with DB through special interface developed in order to ease the model handling.

4.3.2 Model characteristics

The GAMS-model takes into account surface sources in two ways: (i) in form of input information - river runoff hydrographs translated from DB (history, future assessment), (ii) in form of simulation data produced by HBV-Chirchik - on the basis of forecasting of climatic factors and flow formation condition changes. Groundwater sources are selected as separate entities – transects (lines) of wells associated with aquifers and groundwater consumers.

The water distribution system in the GAMS-model is comprised of: river network; irrigation network (conveying water to planning zones); derivation system of canals; water-supply system, which delivers water from surface and ground sources to consumers; control entities – streamflow regulation (reservoirs), distribution entities (waterworks facilities), water delivery entities (off-takes, outlets), and monitoring entities (gauging stations).

Consumers of water resources (surface and ground) are selected as separate entities (cities, industrial centers, thermal stations) and planning zones-entities characterizing water-management areas, mainly, in terms of agricultural land use. The major water user is hydropower represented in form of HEPS cascades in Chirchik and Bozsu routes.

Return flow formation system includes: collector-drainage water from irrigated schemes; industrial sewage; sewage water from settlements and from farms.

4.3.3 Art_reservoir model

Specific part of HBV-GAMS-Chirchik is model of flow regulation in reservoirs. This is a hydrodynamic model simulating functioning of controlled stratified reservoir, based on water intake from various layers (HEPS, surface runoff). The model is based on a system of ordinary differential equations resulting from the mass conservation and medium enthalpy laws and written for three reservoir layers.

Basic variables:

a) Morphology and morphometry of reservoir,
b) Set of hydraulic structures separated according to water intake levels,
c) Technical characteristics of HEPS.

Input variables:

a) Climatic data,
b) Water intake requirements per intake point,
c) Generated electric energy requirements,
d) Requirements from the WAVE model,
e) Inflows, based on HBV-IWS,
f) Filtration (infiltration) functions, based on MODFLOW results

Simulation time:

One period,

Output variables:

a) Inflow hydrographs per intake point $Q_j(t)\ \forall j \in \{j\}^{Art\_reservoir}$,
b) Filtration (infiltration) with groundwater,
c) Water discharge to river channel,
d) Water salinity,
e) Water temperature.

Model objects:

a) Charvak reservoir,
b) Khodjikent reservoir,
c) Galkent reservoir,
d) Akhangaran reservoir,
e) Tashkent reservoir,
f) Pskem reservoir (projected).

4.4 WEAP-Ir_sys model

Irrigation system operation model is a network of canals linked with each other through a set of hydraulic structures equipped with measuring devices and information transmission facilities. The main functions of the **Ir_sys** model are as follows:

- formation of water requirements per selected rayon,
- correction of those requirements, according to technical characteristics of irrigation systems and water limits.

Irrigation system structure is formalized in form of oriented multilinked network, where the arcs are uniform canal sections and nodes are hydraulic structures. The nodes are divided into external and internal ones. The external nodes are planning zone elements sorted per economic sector. Internal nodes, through which water distribution is managed, meet the water mass conservation laws. The irrigation system model has the following data at the input:

Basic variables:

a) Structure of irrigation system, linked with planning zone
b) Set of hydraulic structures,
c) efficiency of canals.

Input variables:

a) Water requirements per economic sector,
b) Inflow to the head of canal from WAVE model,
c) Inflow from wells, based on MODFLOW results,
d) Additional inflows, based on HBV results.

Simulation time:

One period (non-growing, growing),

Output variables:

a) Inflow hydrographs per water consumer $Qj(t)\ \forall j \in \{j\}^{Ir\_sys}$,
b) Discharge in canals,
c) Filtration losses,
d) Outflow to collector-drainage network,
e) Outflow to river network.

Model objects: - Irrigation systems.

Based on principles of WEAP development as applied to the Chirchik river basin, two sub-models, such as irrigation water use model WEAP – Ir_sys model and WEAP – other were constructed. These models consider water use by industry, communal sector, and other economic sectors (including services). It is more difficult to determine water demand of irrigated lands since here we should take into account differences in environmental conditions (climate, soil), cropping patterns, as well as irrigation systems themselves with their complex hierarchical structure.

FAO methodology (publications №24 and №56) was used as a methodical base. The reference evapotranspiration was calculated by Penman-Monteith formula, the effective precipitation was calculated using a method of US Bureau of Reclamation (documentation to CROPWAT program), and groundwater contribution was estimated by Harchenko's formula adapted to FAO classification by Horst M.G.

While calculating, yield damage estimation was validated based on FAO recommendations №№ 33, 56

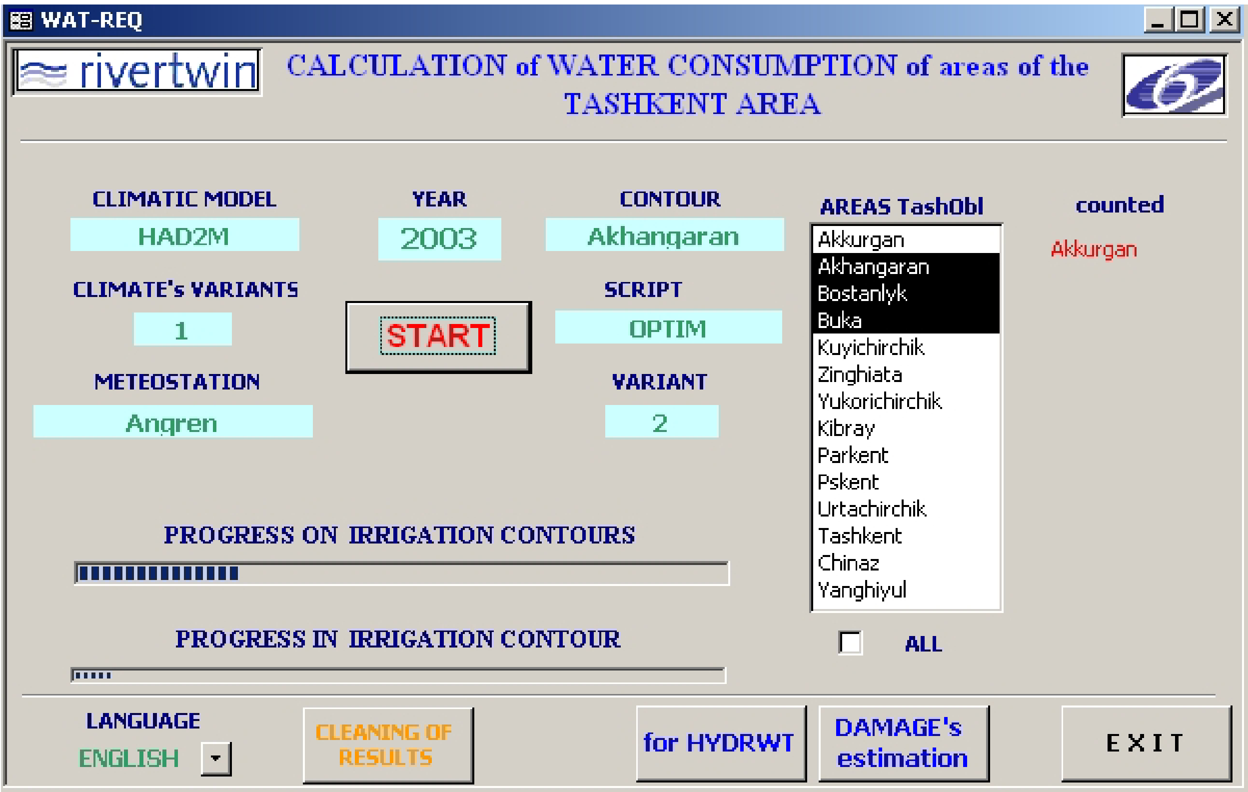
$$\left(1-\frac{Yr}{Yp}\right)=k_c\left(1-\frac{ETr}{ETc}\right) \qquad (4.1)$$

where Yr - actual yield
Yp – potential yield
ETr – actual evapotranspiration

Etc – Potential evapotranspiration
Kc – Crop coefficient

The software implementation was undertaken in ACCESS environment in form of individual DB linked with the project DB. Software component was written in VBA. This block creates text file of climatic data for HBV, text file with irrigation water requirements for program HydRWT, reads out response of HydRWT and computes yield damage due to under-irrigation. The computation results are inputted into the project DB. Moreover, the block contains a tool for inputting and supporting agricultural scenarios.

For implementation purposes, the model interface was developed (Figure. 4.1).



CALCULATION of WATER CONSUMPTION of areas of the TASHKENT AREA

CLIMATIC MODEL: HAD2M
YEAR: 2003
CONTOUR: Akhangaran
CLIMATE's VARIANTS: 1
SCRIPT: OPTIM
METEOSTATION: Angren
VARIANT: 2
AREAS TashObl: Akkurgan, Akhangaran, Bostanlyk, Buka, Kuyichirchik, Zinghiata, Yukorichirchik, Kibray, Parkent, Pskent, Urtachirchik, Tashkent, Chinaz, Yanghiyul
counted: Akkurgan
☐ ALL
LANGUAGE: ENGLISH

Fig. 4.1 Model interface

The block's principle form contains function call buttons.
The model was calibrated for 1994-1996. The calibration results are shown in Table 4.2.

Table 4.2. Summary table of statistical parameters from comparison of actual and simulated water consumption characteristics, using the model WEAP(REQWAT)

Year	Parameters	Akkur gan	Ahan garan	Bost onlyk	Buka	Kuichi rchic	Zengiata	Ukoryc hirchik	Kibray	Parkent	Pskent	Urtac hirchk	Tash kent	Chinaz	Yangiul
1994	Average	392	564	465	268	9	577	473	317	586	510	353	340	386	301
	Dispersion	636	864	756	492	417	838	755	518	780	759	578	562	665	542
	Variation coeff.	62	65	61	55	2	69	63	61	75	67	61	60	58	56
	Correlation coeff.	0,968	0,963	0,965	0,971	0,885	0,836	0,965	0,945	0,983	0,967	0,962	0,907	0,910	0,936
1995	Average	-87	-58	-137	-10	-405	-249	37	-498	226	31	-41	-610	-242	-146
	Dispersion	552	452	369	464	739	497	543	701	224	598	503	797	453	422
	Variation coeff.	-16	-13	-37	-2	-55	-50	7	-71	101	5	-8	-76	-53	-35
	Correlation coeff.	0,898	0,932	0,898	0,926	0,855	0,932	0,891	0,940	0,976	0,862	0,912	0,871	0,935	0,943
1996	Average	452	714	554	251	107	598	684	449	790	572	562	494	464	449
	Dispersion	663	963	809	505	538	792	909	599	907	832	828	668	756	691
	Variation coeff.	68	74	69	50	20	75	75	75	87	69	68	74	61	65
	Correlation coeff.	0,974	0,945	0,941	0,946	0,833	0,932	0,960	0,907	0,950	0,949	0,975	0,896	0,887	0,911
2000	Average	161	-501	48	23	-457	-266	145	-158	81	-42	233	-612	-248	-298
	Dispersion	734	629	484	787	729	696	711	377	196	843	834	549	820	588
	Variation coeff.	22	-80	10	3	-63	-38	20	-42	41	-5	28	-112	-30	-51
	Correlation coeff.	0,857	0,850	0,808	0,791	0,814	0,850	0,896	0,939	0,980	0,753	0,807	0,888	0,774	0,878
2001	Average	253	-486	33	89	-278	-230	-18	-538	29	258	181	-875	-159	-104
	Dispersion	676	644	319	649	665	581	627	476	92	775	591	716	841	528
	Variation coeff.	37	-75	10	14	-42	-40	-3	-113	31	33	31	-122	-19	-20
	Correlation coeff.	0,919	0,857	0,933	0,882	0,854	0,908	0,907	0,936	0,996	0,806	0,926	0,804	0,770	0,910
2002	Average	398	-532	-192	86	-84	-222	21	-101	-96	421	200	-334	1	-104
	Dispersion	664	763	223	540	558	500	503	340	263	680	422	613	781	443
	Variation coeff.	60	-70	-86	16	-15	-44	4	-30	-37	62	47	-54	0	-23
	Correlation coeff.	0,976	0,836	0,973	0,915	0,905	0,921	0,927	0,952	0,965	0,927	0,975	0,781	0,798	0,935
2003	Average	344	-214	-210	74	189	-74	210	2	14	173	243	-195	7	-235
	Dispersion	520	507	426	317	510	416	376	258	333	269	365	406	424	639
	Variation coeff.	66	-42	-49	23	37	-18	56	1	4	64	67	-48	2	-37
	Correlation coeff.	0,988	0,933	0,956	0,969	0,925	0,953	0,973	0,974	0,964	0,992	0,989	0,941	0,940	0,919

Notes:

1. AVERAGE - Average deviation of actual from simulated data, annual (del_FC) - m3/ha
2. DISPERSION - Dispersion for monthly deviations of actual from simulated data (one year) - m3/ha
3. VARIATION COEFF. - Variation coefficient of actual data deviation from simulated data (one year) - %
4. CORRELATION COEFF. - Coefficient of correlation between actual and simulated data (one year) - unit fraction

5 ECOLOGICAL BLOCK

Models in this block (Qual- Circhik**,** collector-drainage network model, MONERIS-Circhik) use the information collections from the Climatic and Hydrological blocks plus additional data on inflow of chemical and biological pollutants. As a result of block operation, a new infomedia, which, similarly to previous one, can be referred to as ecological infomedia. A group of indicators is also selected from this information for visualization of ecological block output.

5.1 QUAL- Circhik model

QUAL is a model that describes changes in water quality in river sections and reservoirs under influence of temperature and hydrodynamic factors. According to the protocol of February 5, 2005, specific QUAL-Circhik is needed in order to meet actually available data and general composition of the models from Hydrological block. The QUAL-Circhik is based on solutions of the WAVE model in part of hydrodynamic parameters and salinity. Besides, algorithm for calculation of temperature fields along the stream length was changed in QUAL-Circhik in order to consider stream movement in dry channel. Moreover, additional algorithm was included for linking time series of inflow, temperature, rainfall and evaporation function from climatic block. QUAL-Circhik uses interface of WAVE.

Basic variables:

a) Morphology and morphometry of river channel,
b) Set of hydraulic structures.

Input variables:

a) Climatic data,
b) Hydroodynamic parameters of flow from Wave-Larsim,
c) Temperature of inflows, based on Art_reservoir results,
d) Collector-drainage flow, based on MONERIS – Chirchik results.

Simulation time:

One year.

Output variables:

a) Water salinity along the river channel, broken down into components,
b) Flow temperature along the river channel,
c) Flow oxygenation
d) Biogenic element saturation (for individual sections)

Model objects:

b) Chirchik river,
c) Akhangaran river,
d) Keles river.

Specific part of this model is WAVE sub-model.

5.2 WAVE sub-model

Hydrodynamic model, which simulates stream moving in open channels. The model is based on a system of partial differential equations derived from two-phase liquid mass and momentum conservation law, with assumption that the volume of solid phase (this case - salinity) is quite small and only forms medium ecology, while momentum conservation equations are written as for homogeneous liquid with variable density. The boundary conditions for the model are formed by outputs of **HBV-CHIRCHIK, MODFLOW, Art_reservoir** and by physical and climatic characteristics of given year. Raw data for the hydrodynamic model include: topographic map of relief; graphical layout of supply and discharge canals and collectors; time series of inflow with salinity and temperature values; graphs of temperature fluctuations and evaporation function. Modeling results are the series of tables representing stream parameters for a river section, the values of water-surface elevation and salinity, depending on state of the object and water inflow. The model operates in hydrological mode (together with the **Art_reservoir** model) and in ecological regime (together with **QUAL-CHIRCHIK**)

Basic variables:

a) Morphology and morphometry of river channel,
b) Set of hydraulic structures.

Input variables:

b) Climatic data,
c) Water intake requirements per intake point,
d) Inflows, based on Art_reservoir results.
e) Inflows, based on HBV results.
f) Filtration (infiltration) functions, based on MODFLOW results.
g) Collector-drainage flow, based on MONERIS – Chirchik results.

Simulation time:

One year.

Output variables:

a) Inflow hydrographs per intake point $Qj(t)\ \forall j \in \{j\}^{WAVE}$,
b) Filtration (infiltration) with groundwater,
c) Water discharge and level along the river channel,
d) Water salinity along the river channel,
e) Discharge into the Syrdarya river (tail section line).

Model objects:

a) Chirchik river,
b) Akhangaran river,
c) Keles river.

5.3 MONERIS model

MONERIS is a model describing nitrate and phosphorus emissions in river systems. The model is based on a number of regression-type equations derived from processing of field data on various areas and river systems in Germany. Direct application of those equations for conditions of the Chirchik-Akhangaran-Keles basin is impossible. Therefore, it was decided (protocol of February 5, 2005) to consider a possibility of applying this model for new conditions. Collector-drainage systems play the key role in accumulation and transfer of pollutants in the Chirchik-Akhangaran-Keles basin. Those systems are comprised of a network of collectors beginning in rayons (planning zones) and ending by waste discharge sites into a river or outside the project area. Information on wastewater quality is mainly linked to tail parts of collectors. Therefore, the MONERIS – Chirchik was decided to transform into a model of collector-drainage network which simulates inflow of chemical and biogenic elements from planning zones to discharge sites into a river or outside the project area. Distribution of pollutants in river network is simulated by the QUAL-Chirchik model.

Basic variables:

a) Collector-drainage network,
b) Set of treatment plants.

Input variables:

a) Climatic data,
b) Collector-drainage flow, based on “Planning Zone” results,
c) Wastes from thermal power stations,
d) Wastes from urban areas, including industrial production.

Simulation time:

One year.

Output variables:

a) Collector-drainage flow volumes in discharge points,
b) Biogenic element saturation of waste flows.

Model objects: Collector-drainage network.

6 ALGORITHMS

6.1 Data formatting

One of the procedures required for coupling of various models is a procedure for formatting of data received from any model or the Database to another model. Such procedures would be symbolized as “ ***F*** ” as derived from usually used term «formatting» but with wider meaning. Full ***F*** – formatting of data between the models consists of the following stages:

- matching of dimensions,
- spatial interpolation,
- temporal interpolation (or modeling!),
- adjustment of data values to a value area acceptable for given model,
- adjustment of data to model format.

The first stage and the fifth stage are described in details in the technical literature and do not need explanation. Programmer of the Database can be directly entrusted with execution of those stages. However, the second, third, and fourth stages are not trivial and need consultations with model developers. Let’s start from the analysis of the second stage.

Spatial interpolation is made on the basis of GIS tools and by using information on physical properties of the interpolated object – it would be mainly a question of climatic parameters of the Chirchik-Akhangaran-Keles basin. For the Neckar river basin, it is not a problem since quantity of weather stations is quite large and they densely cover the whole project area. Besides, fluctuations of elevations are within 1000 m and this allows linear approximation for the temperature (every 100 m of increment in elevation accounts for 0.6 ^{o}C decrease in temperature), which well holds true within the elevation limits of up to 2500 m. For the Chirchik-Akhangaran-Keles basin, these conditions are quite different: first, number of involved weather stations (7 stations) is not sufficient to address the whole project area; and, second, maximum terrain elevations are 4500 m. Climatic parameters of the flow formation zone are much uncertain (**HBV** model operation area). Hence, special algorithms for extrapolation of climatic characteristics for flow formation zones or any other ways for calibration of model parameters that differ from those used in the Neckar river basin are needed for correct adaptation of the HBV model.

Temporal interpolation. The real calculation process of variable values for specific time series is implemented by writing the values in a sequence determined by algorithm of particular model (let refer it as $\mathbf{M^1}$). Next, model M_2 starts to operate; time is considered as continuous variable and, as a result, variable values in sequence intervals for the model $\mathbf{M^2}$ can be obtained through ordinary (linear or non-linear) interpolation. Such assumption holds true where time intervals in sequences of the models $[t]^{M1}$ and $[t]^{M2}$ are within a factor of ten; otherwise, it is not true. If time step in sequence $[t]^{M2}$ is much larger than similar time step in sequence $[t]^{M1}$, then averaging is needed (standard procedure that does not require explanation). Transition from larger time step to smaller one is more difficult. This case we do not have standard algorithms, and this procedure is defined by physics (or technique) of given process modeled within the model M_2. For example, the model **Qual-Chirchik** uses time sequences for climatic parameters with hourly interval, while the Database contains mean monthly or mean ten-day values of these variables. Climatic characteristics are formed using GIS tools; however, formation of hourly sequences by GIS makes the task technologically unsolvable. Therefore, special algorithms are needed in such situations in order to adjust operation of models (as described in section below).

The last stage - ***adjustment of data values to a value range acceptable for given model*** – concerns algorithm of model only. Assumptions on the character of approximation of equations used and the robustness of methods of their numerical implementation are not always clear even after completion of work on model. Here, it is important for model developer to specify, at most, a value range, in which the model was tested and adapted. By considering this area as acceptable one, variables are continuously checked if they belong to this area and, if necessary, corrected.

Existence of algorithmically unsolvable tasks and formally unproved truths is one of fundamental discoveries of the theory of calculability. By coupling various algorithms, permanently we would be on the verge of “unsolvability”, and, the essence is to make well something that, theoretically, can be made.

6.2 Algorithms for conjugation of time series

This section describes the algorithms for conjugation of time series, based on available information on their mean values for certain large time horizon. These algorithms are based on the fuzzy-set theory. Those can be used separately or in combinations. However, as the algorithms are of semi- heuristic nature, received results should be checked thoroughly. All the algorithms rest on series-analogs used by researcher. Usually, these series relate to past time horizons or directly to given time moment or to period close to the latter in any of parameters. For example, let us consider hydrological problem on finding monthly distribution of flow, based on its mean annual distribution in particular river section line. Let series of past time observations [t] is available,

$$\|Q_{t,\tau}\| \quad = \quad \begin{array}{llllll} Q_{1,1} & Q_{1,2} & \ldots Q_{1,\tau} & \ldots Q_{1,12} & & Q_1^{m} \\ Q_{2,1} & Q_{2,2} & \ldots Q_{2,\tau} & \ldots Q_{2,12} & & Q_2^{m} \\ \ldots & \ldots & \ldots & \ldots & & . \\ Q_{t,1} & Q_{t,2} & \ldots Q_{t,\tau} & \ldots Q_{t,12} & & Q_t^{m} \end{array} \qquad (2.2)$$

Here $Q_{t,\tau}$ – mean monthly discharge of year “t” in month “τ”, Q_t^{m} – mean value of line $Q_{t,\tau}$ on “τ”. There is mean annual value Q^* , according to which a new vector – line Q_τ^* corresponding to mean monthly discharge should be formed. General solution of the problem can be written as:

$$Q_\tau^* = \frac{Q^*}{\sum\limits_{t\in[t]}\mu_t}\sum_{t\in[t]}\mu_t\frac{Q_{t,\tau}}{Q_t^m}\ ;\ \forall\tau\in[\tau] \qquad (2.3)$$

In this formula, contribution of particular series “t” is determined by value “μ_t”. If we take the same values for all μ_t, for instance, $\mu_t = 1$, we will get ordinary formula for weighted average values. However, it is known from hydrology that distribution of monthly flows within a year usually replicates (in some approximation) only those years that are close in terms of flow probability. Taking into account the above-mentioned, the following formula can be derived for μ_t:

$$\mu_t = \frac{1}{1+\left(\frac{Q_t^m - Q^*}{Q^*}\right)^n}\ ;\ \forall\ t\in[t] \qquad (2.4)$$

where n = [0, 2, 4, ..] is even exponent ensuring that denominator and selection interval width are positive. The larger “n”, the narrower selecting band and vice versa. Further modifications for calculation of “μ_t” are related with a possibility to use additional information; for example, if, in addition to mean annual value Q^*, researcher knows discharge Q_τ^* in particular month “τ”, selectability of “μ_t” can be modernized by including additional information in formula (4):

$$\mu_t = \frac{1}{1+\left(\frac{Q_t^m - Q^*}{Q^*}\right)^n + \left(\frac{Q_{t,\tau} - Q_\tau^*}{Q_\tau^*}\right)^n}\ ;\ \forall\ t\in[t] \qquad (2.5)$$

Number of modification options for calculation of “μ_t” is not limited, and it is important that the general equation (3) keeps making sense. If the function is alternating, its values just can be shifted to positive area in order to use those algorithms and then, after calculation of series shifted back (linear transformation). It should be noted that application of the algorithms (3) –

(5) requires some thoroughness. For example, if mean annual values of variables are known and hourly series are needed, such transformation should be made in a few stages:

Year $\boldsymbol{F} \Rightarrow$ (periods, months);
Period $\boldsymbol{F} \Rightarrow$ (months, ten days);
(month, ten day) $\boldsymbol{F} \Rightarrow$ days;
days $\boldsymbol{F} \Rightarrow$ hours.

Here, periods mean growing and non-growing periods.

6.3 Indicators and criteria for basin development assessment

Assessment of basin development in time assumes that criterion (or criteria) quantified through parameters of basin elements is available. Depending on objective to be achieved and formulated, criteria can include economic, technological, and ecological basic characteristics in various combinations. Criteria of basin development optimality can be different but they all represent, necessarily in numerical values, trade-offs between “good” and “bad” as we see now.

More frequently used criteria in such problems are formed on the basis of difference between benefits and costs. Particularly, such criterion is maximizing net benefit in all rayons in given basin over certain period of time, under various natural, technological and economic restrictions. This criterion reflects basin internal well-being and forms system trajectory on the basis of maximum external resources allocated to the basin by the Government.

Variants of this criterion are those resulting from maximizing (or minimizing) of relative economic indicators of each rayon, such as

- achieving maximum productivity per unit investments,
- achieving maximum productivity per unit agricultural land,
- achieving maximum net benefit per unit water use, under restrictions same as for criteria of the first type. These types of criteria form the so called economic trajectories relating to parameter which appears in denominator.

Next variant of criteria occurs when radical changes are needed in the basin over certain, limited period of time. In this case, as a rule, ultimate (desirable) basin parameters are known, and one needs to find an optimal system trajectory, in terms of minimum costs, in order to transform the system from one state to another one. These problems relate to optimal control problems, where production of optimal trajectory is the first stage only. The second stage, which is equally important and more complicate, is a synthesis problem, where probable deviations in the system from programmed trajectory and control stability conditions are evaluated.

Besides the above-mentioned global criteria for assessment of basin functioning and development, there is a number of so called technological optimization criteria that form optimal parameters of basin elements. For example, irrigation and collector-drainage system structures, cropping patterns in various rayons, water distribution between crops under water shortage, etc.

Within the framework of the long-term basin development research, solution of local optimization problems is senseless since uncertainty of raw information is of the same order as deviations of target function values in the local problems. Therefore, enlarged indicators based on data about current state of basin elements and reflecting their integrated characteristics would be used during analysis of basin functioning and development in the long term.

7 CALIBRATION OF HYDROLOGICAL MODELS[*]

Calibration results of the main hydrological models are given below.

7.1 Calibration of HBV – Chirchik model

The testing objective is to select calibration coefficients for HBV-Chirchik that meet the condition of maximum approximation of simulation flow hydrographs to actual (observed) ones.

We compared discharges for typical periods selected, from simulation series for daily, mean monthly, and maximum flow values:

- Akhangaran river and its tributaries at sub-basin outlets - (i) inflow to Akhangaran reservoir, (ii) lateral inflow at the section from Akhangaran reservoir to Sharkhi waterworks facility, (iii) sais downstream of Sharkhi waterworks facility.
- rivers in Chirchik basin at sub-basin outlets (Pskem, Chatkal, Koksu, Ugam, Aksagata).

For model calibration we used climatic data and daily runoff quantities over 1980-1982. Input data were prepared on the basis of information from the Project's DB and A.Gafurov's thesis.

Table 7.1.1 shows the analysis results of simulated runoff generated from model calibration. It follows from those data that correlation value is within 0.74 – 0.99. The error of annual runoff simulation is less then 39%. The highest error of monthly runoff simulation refers to Akhangaran river.

Table 7.1.1

Calibration of runoff simulation results

Subcatchment	Correlation			Mean error of monthly runoff simulation, %			Error of annual runoff simulation, %		
	1980	1981	1982	1980	1981	1982	1980	1981	1982
Ahangaran, subcatchment 1	0.912	0.989	0.983	51.6	39.9	46.1	13.6	38.7	7.3
Ahangaran, subcatchment 2	0.997	0.931	0.746	16.1	22.3	35.3	5.1	23.0	25.9
Ahangaran, subcatchment 3	0.995	0.968	0.895	19.0	25.7	34.5	8.4	22.4	35.8
Ugam	0.986	0.942	0.746	15.4	19.3	28.9	6.4	3.6	20.8
Pskem	0.993	0.975	0.848	15.2	21.2	27.4	1.7	7.4	0.5
Koksu	0.989	0.988	0.898	18.7	19.9	38.6	17.6	1.5	3.6
Chatkal	0.998	0.950	0.818	12.1	32.3	31.0	4.9	13.6	9.5
Aksagata	0.987	0.945	0.831	18.4	21.7	32.5	0.6	2.3	0.9

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[*] Calibration of socio-economic models, including agricultural block ones, is described in the Report D-27.

Keles	0.990	0.951	0.935	17.1	16.6	24.8	0.3	9.1	22.5
Says of Parkent	0.996	0.968	0.901	21.1	21.3	25.5	15.5	1.8	18.8

Table 7.1.2 shows analysis results of runoff simulation as derived from testing of calibrated model using data for 1984-1985.

Table 7.1.2

Results of calibrated model testing

Subcatchment	Correlation		Mean error of monthly runoff simulation, %		Error of annual runoff simulation, %	
	1984	1985	1984	1985	1984	1985
Ahangaran, subcatchment 1	0.952	0.948	46.7	51.9	26.2	24.9
Ahangaran, subcatchment 2	0.998	0.957	19.2	25.6	13.2	33.3
Ahangaran, subcatchment 3	0.986	0.988	19.2	24.9	9.7	29.9
Ugam	0.986	0.987	17.3	14.2	1.0	5.8
Pskem	0.966	0.993	22.6	16.8	13.8	5.6
Koksu	0.960	0.992	23.8	20.8	21.1	5.1
Chatkal	0.966	0.994	26.7	22.7	23.4	19.7
Aksagata	0.964	0.966	22.3	25.3	1.3	22.9
Keles	0.982	0.972	22.0	23.7	7.4	24.4
Says of Parkent	0.987	0.979	14.7	24.3	17.8	12.7

7.2 Calibration of HBV-GAMS model

The model was tested by using actual data of 1994.

In general, the model gave quite satisfactory results for a year for the basin.

Imbalance (difference between simulated and measured runoff volumes) was mainly caused by lack of appropriate monitoring network and by impossibility, in the algorithm, to fully take into account all specificities of flow distribution and use zone, where instead of flow concentration in main channels (as occurred in flow formation zone), the flow is derived from the main channels, with its partial return after water use and consumption, with flow losses and discharge, where some canals have a form and nature of natural waterways, and surface runoff in many waterways is a mixture of natural runoff and return water, intake of which leads to re-use of already mixed flow.

Deviation of total simulated annual water withdrawal to planning zones from actual one (as measured by water distribution monitoring system) is about 3 %. Statistical comparison of simulated and actual withdrawal series for planning zones (15 zones) shows correlation coefficient of 0.99. Similar indicators regarding simulated and actual outflow outside the basin show values of 2 % and 0.98, respectively (Table 7.2.1).

The figures below show relationships between actual and simulated data on water outflow along the rivers Chirchik and Akhangaran and Bozsu canal outside the Chirchi-Akhangaran sub-basin (Fig. 7.1) and intakes to planning zones (Fig. 7.2).

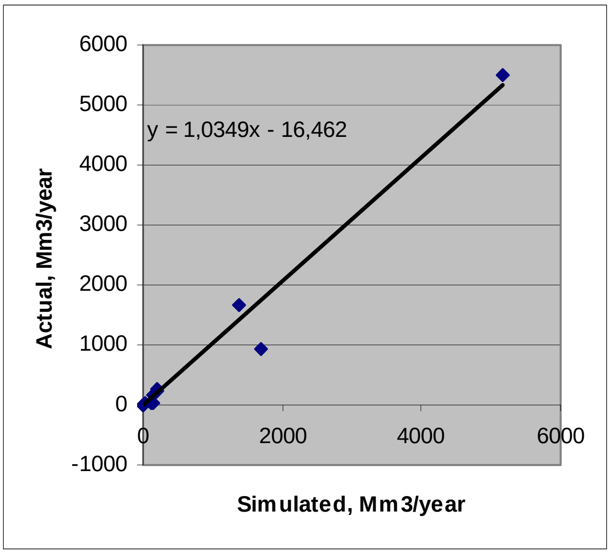


Fig.7.1. Outflow from basin

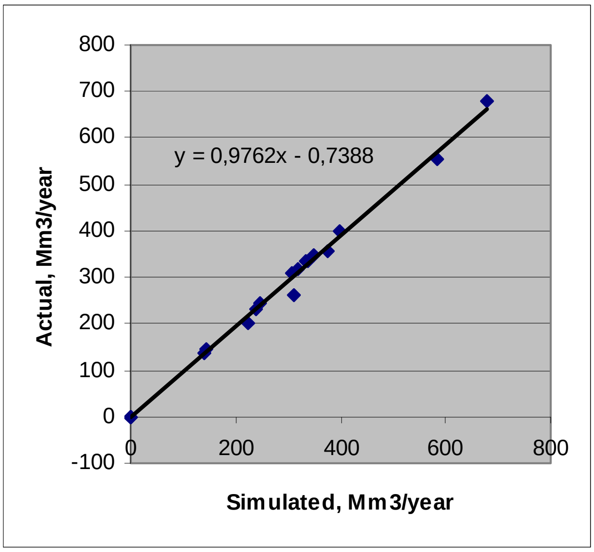


Fig.7.2. Intake to PZ

Table 7.2.1 Comparison of simulated (GAMS-model) and actual annual withdrawals for planning zones and outflows outside the basin (outlets), 1994.

Balance elements	Calculation, mln.m3/year	Fact, mln.m3/year	D = Calc – Fact, mln.m3/year	100D/Fact %
1.Intake in PZ	4844	4984	- 140	- 3
including:				
- Bostanlik	145	145	0	0
- Kibray	356	377	- 21	- 6
- Tashkent	346	348	- 2	- 1
- Zangiata	201	223	- 22	- 10
- Yangiul	334	338	- 3	- 1
- Chinaz	232	238	- 5	- 2
- Parkent	135	140	- 5	- 3
- Ahangaran	308	308	0	0
- Yukachirchik	333	333	0	0
- Urtachirchik	262	311	- 50	- 16
- Pskent	245	245	0	0
- Kuyichirchik	554	583	- 29	- 5
- Akkurgan	317	320	- 3	- 1
- Buka	398	398	0	0
- Keles	678	678	0	0
2.Outflow	8901	9077	176	- 2
oncluding:				
- Chirchik/Chinaz	5516	5159	357	7
- Bozsu/issue	943	1701	- 758	- 45
- Keles/issue	181	149	32	22

- Ahangaran/Soldatskoe	1677	1390	287	21
- Gedjigen/issue	26	136	- 110	- 81
- Tashcanal/Bektemir	19	107	- 88	- 82
- Sarisuv 1 / in Syrdarya	25	25	0	1
- Sarisuv 2 / in Syrdarya	231	205	26	13
- Karasu 2 /in Syrdarya	282	205	77	37

The total basin water balance (as simulated in the model) is shown in the Table 7.2.2, while its distribution between major components is shown in Figures 7.3, 7.4, 7.5.

Table 7.2.2 Annual water balance of the Chirchik-Akhangaran-Keles basin (GAMS-model simulation, 1994)

#	Balance elements	Mm3/year
1	Rivers resource	11661
2	Groundwater	555
3	Return flow	2917
4	Reservoir draw-off	46
	Including:	
	- Charvak	53
	- Ahangaran	- 9
	- Tashkent	2
5	Total inflow: 1+2+3+4	15179
6	Intake	5943
7	Outflow from basin	8901
8	Losses	335
9	Total outflow: 6+7+8	15179

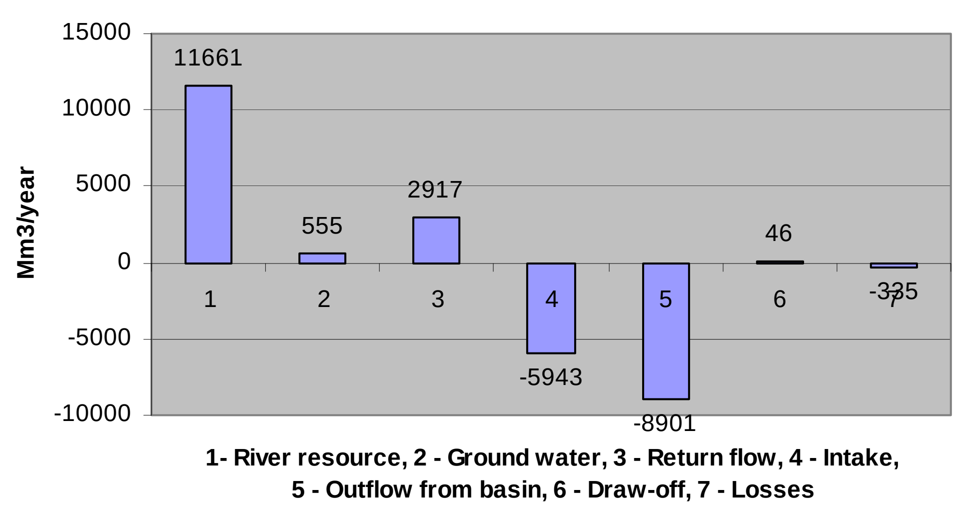


Fig. 7.3 Water balance elements

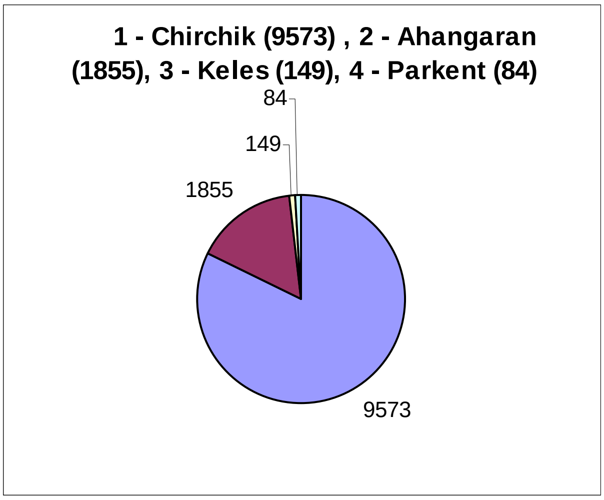


Fig. 7.4 River resources

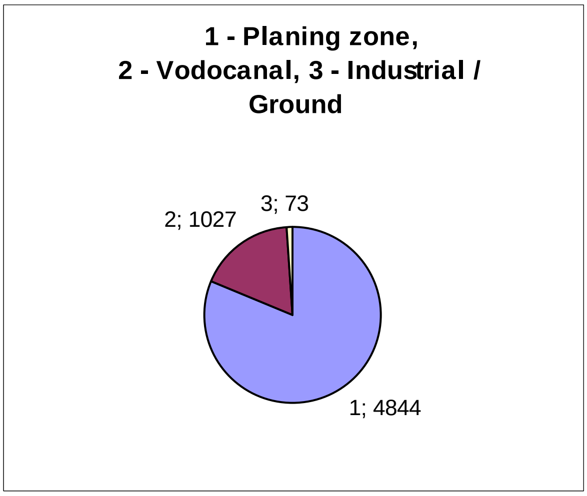


Fig. 7.5 Intake

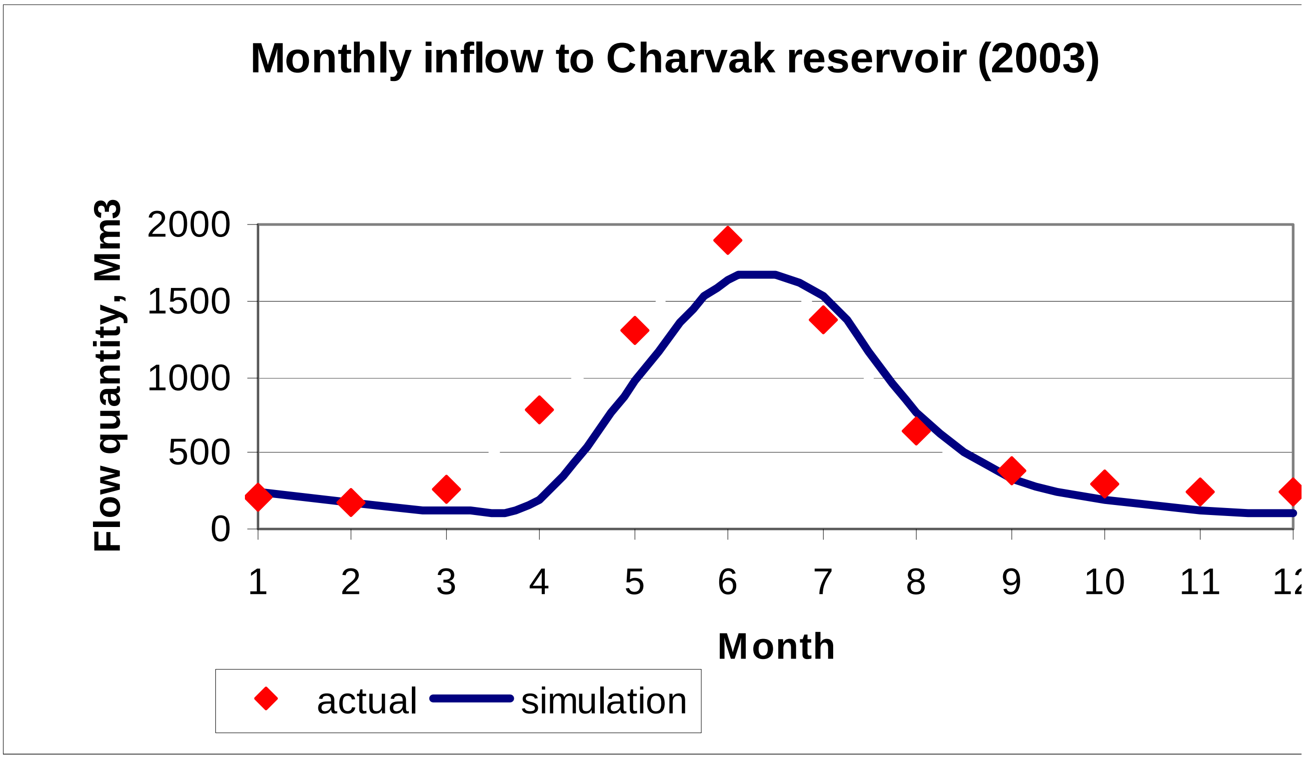
Figure 7.4 shows the constituents of flow in the Chirchik-Akhangaran-Keles sub-basin, in absolute values (Mm^3/year) and in unit fractions (of pie chart); Figure 7.5 – the constituents of intake, in the same units, for agricultural, drinking water supply (Vodocanal), and industrial needs.

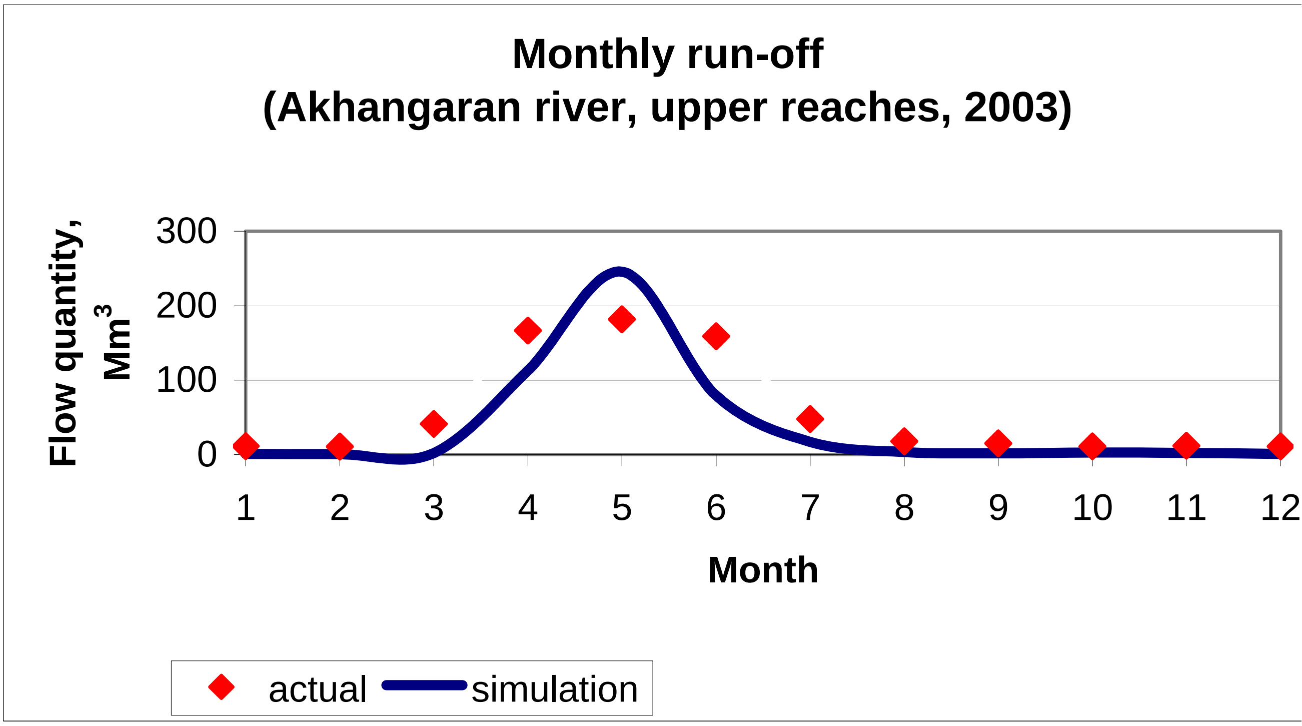
7.3 Testing of HBV-IWS model

The model HBV-IWS is linked with DB through text files, such as meteopre.txt, precipitation.txt, meteotemp.txt and temperature.txt that are generated from the general project interface on the basis of data from DB. Run-offs calculated by HBV-IWS are inputted into HydRWT from the file surface.txt, which is generated by clicking on the button “Start” of data generation block in water-distribution model.

The model HBV-IWS within the integrated model was tested using climatic data of 2003. HBV-IWS testing results are shown in Figure 7.6. Analysis of simulation results has shown the following: 1) correlation of simulated inflow to Charvak reservoir and actual data is 0.936, the calculation error of annual run-off is 18%; 2) calculation of run-off in Akhangaran river: correlation - 0.891; calculation error of annual run-off - 32 %; 3) calculation of run-off in Ugam river: correlation - 0.904; calculation error of annual run-off -15 %.

The results of HBV model linking with the project DB and coupling with water-distribution model showed that the forecast version of HBV-IWS operated without fail and output of simulation results is in conformity with requirements of the database and the water-distribution model.


Monthly inflow to Charvak reservoir (2003)
Flow quantity, Mm3
2000
1500
1000
500
0
1
2
3
4
5
6
7
8
9
10
11
Month
actual
simulation


Monthly run-off
(Akhangaran river, upper reaches, 2003)
Flow quantity, Mm3
300
200
100
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
actual
simulation

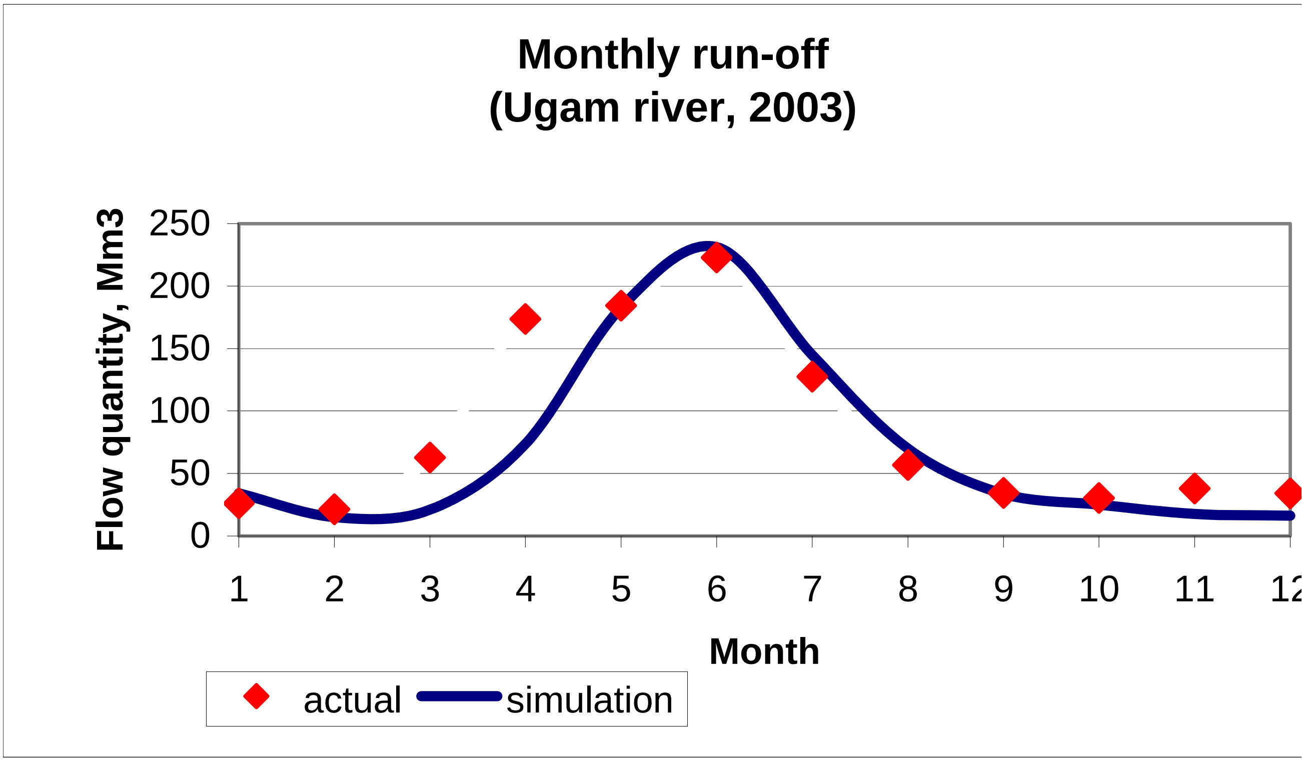


Fig.7.6 HBV-IWS testing results within the integrated model, climatic data of 2003

7.4 WEAP model and aggregated hydrological block

Testing of WEAP model and aggregated hydrological block was described in Report D-24 while comparing simulated and physical data on water consumption per district in the province over 2000 – 2003.

Using the year of 2003, we tested the general hydrology of modeling complex: HBV-Chirchik, HBV-GAMS-Chirchik, and WEAP by comparing the aggregated river water balance, comparing outflow from the basin by rivers (observed-simulated), between planning zones (observed-simulated). The testing results are shown in Tables 7.4.1 – 7.4.3:

- total error in basin water balance has admissible value (less than 10 %) – actually 3,74% (Table 7.4.1);
- total difference in the outflow by comparing simulated and observed values on the basin is 5,1%, but error is enough big by different rivers (Table 7.4.2). It requires additional investigation on the reasons of such incorrect allocation of water between rivers and use of optimization model for correcting allocation. It should be done in the final report;
- comparison between simulated volume of water by HBW-GAMS-Chirchik and observed one gave enough good result – error 9,1 %. But deviation is from -23.3 up to 45.0 % in relation to water requirements on different zones. The reason may be laying in difference in water resources distribution between rivers (Table 7.4.3).

Table 7.4.1. BASIN WATER BALANCE

```
 ------------------------------
  Balance elements  (mln.m3)
 ------------------------------
  1.RIVERS RESOURS       10368
    Including:
  - Chirchik basin        8978
  - Ahangaran basin        980
  - Keles                  243
  - Parkent rivers         167
 ------------------------------
  2.GROUND WATER          571
    Including:
  - Chirchik basin        394
  - Ahangaran basin       176
 ------------------------------
  3.RETURN FLOW           2610
    Including:
  - irrigation            1271
  - other                 1339
 ------------------------------
  4.TOTAL INFLOW: 1+2+3  13549
 ------------------------------
  5.INTAKE               3987
    Including to:
  - Planning zones
    (agriculture)        2969
  - Communal water        938
  - Industrial             80
 ------------------------------
  6.OUTFLOW FROM BASIN    8813
    Including:
  - Chirchik/Chinaz       3647
  - Bozsu/issue           1113
  - Keles/issue            279
  - Ahangaran/Soldatskoe  3242
  - Gedjigen/issue          23
  - Tashkanal/Bektemir      24
  - Sarisuv 1               22
  - Sarisuv 1              223
  - Karasu 2               241
 ------------------------------
  7.REGULATION FLOW        261
    Including:
  - Charvak reservoir      231
  - Ahangaran reservoir      0
  - Tashkent reservoir      30
 ------------------------------
  8.TOTAL OUTFLOW: 5+6+7 13060
 ------------------------------
  9.BALANS: 8-4           -488
 10.Error %:              3.74
 ------------------------------
```

Table 7.4.2. COMPARISON OF OUTFLOWS FROM BASIN

```
 ----------------------------------------------------------------
  Balance elements (mln.m3)  Estimated Actually Difference     %
 ----------------------------------------------------------------
  - Chirchik/Chinaz              3647      4936      -1289    -26
  - Bozsu/issue                  1113      1595       -482    -30
  - Ahangaran/Soldatskoe         3242      1901       1341     71
 ----------------------------------------------------------------
  Total:                         8002      8432       -430   -5.1
 ----------------------------------------------------------------
```

Table 7.4.3. COMPARISON OF WATER ALLOCATION BETWEEN PLANNIG ZONES

```
 ----------------------------------------------------------------
  Balance elements (mln.m3) Estimated  Actually Difference     %
 ----------------------------------------------------------------
  INTAKE IN PLANNIG ZONES       2567     2352        215     9.1
```

```
   Including:
 - Bostanlik                    115       83         32    38.6
 - Kibray                       168      161          7     4.3
 - Tashkent                     120      134        -14   -10.4
 - Zangiata                     192      134         58    43.3
 - Yangiul                      173      186        -13    -7.0
 - Chinaz                       164      175        -11     5.8
 - Parkent                      155       87         68    44.9
 - Ahangaran                    248      171         77    45.0
 - Yukachirchik                 231      181         50    27.6
 - Urtachirchik                 194      174         20    11.5
 - Pskent                       194      169         25    14.8
 - Kuyichirchik                 201      250        -49   -19.6
 - Akkurgan                     205      177         28    15.8
 - Buka                         207      270        -63   -23.3
----------------------------------------------------------------
 Balance elements          Estimated  Actually Difference     %
----------------------------------------------------------------
   RIVERS RESOURS              10125    10609       -484    -4.6
   Including:
 - Chirchik basin               8978     9122       -144    -1.6
 - Ahangaran basin               980     1317       -337   -25.6
 - Parkent rivers                167      170         -3    -1.8
```

8 INTEGRATION OF MODELS

Model interlinking is made through user interface and database. Printouts of the main interface forms are given below.

The main form of the GAMS-model's user interface is a dialog box, which has several functional buttons:

- model setup,
- input of initial conditions and restrictions,
- access to simulation block,
- access to simulated information.

Model setup implies setting of information link between the GAMS-model and other models and DB. At present, the links were established with HBV and with agricultural module.

Input of initial conditions and restrictions involves the following:

- connection (or disconnection) to hydrological scheme of Pskem reservoir model,
- setting of volumes in reservoirs at the beginning of simulation period,
- setting of environmental releases (maximum, minimum) at river and canal nodes.

Each of those parameters can be imported from DB, corrected or again inputted at user's discretion through the dialog box, as well as saved for further use in model simulations for selected scenario or actual year.

The simulation block allows the user:

- select simulation year,
- select scenario,
- input initial data,
- run model,
- output simulation results – export to DB and to intermediate files for other models.

In "Simulated information" area the user can:

- look through simulation results in form of graphs, tables, and diagrams,
- look through results in form of reports.

The recommended interface handling order:

- Model setup,
- Selection of simulation year,
- Selection of scenario,
- Input, review and correction of initial information,
- Model run,
- Looking through results (graphs, reports).

The interface (Figure 8.1.) has been developed in accordance with the requirements specified by the Terms of Reference. Development environment is Visual Basic Pro. The main purpose of the user interface (as well as of another one) is to effectively integrate functional components into a single whole system and organize fulfilling functions so that user could draw all his attention to necessary analytical work, not programs, using which this work is done.

The user interface is a system of blocks (DB block, GIS block, forms for information input and output) designed for user servicing: input, adjustment, update and analysis of information available in the database.

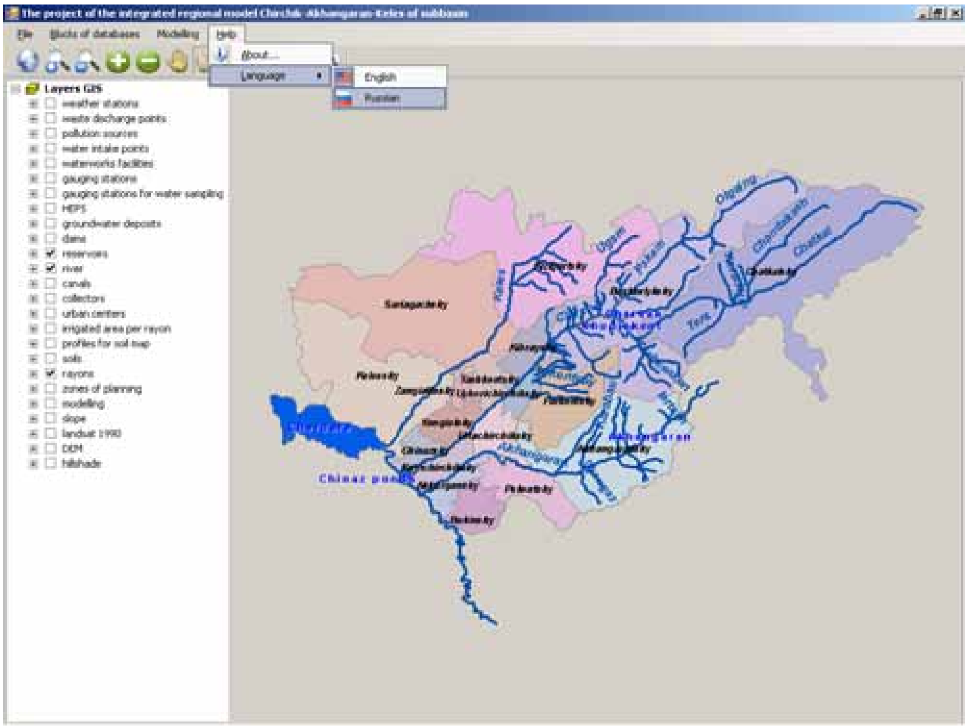


Figure 8.1. Main form of interface

The following models were linked with DB (Fig. 8.2.) and coupled with each other through the interface:

- HBV-Chirchik,
- WEAP,
- HydRWT (GAMS),
- SEM,
- QUAL-Chirchik

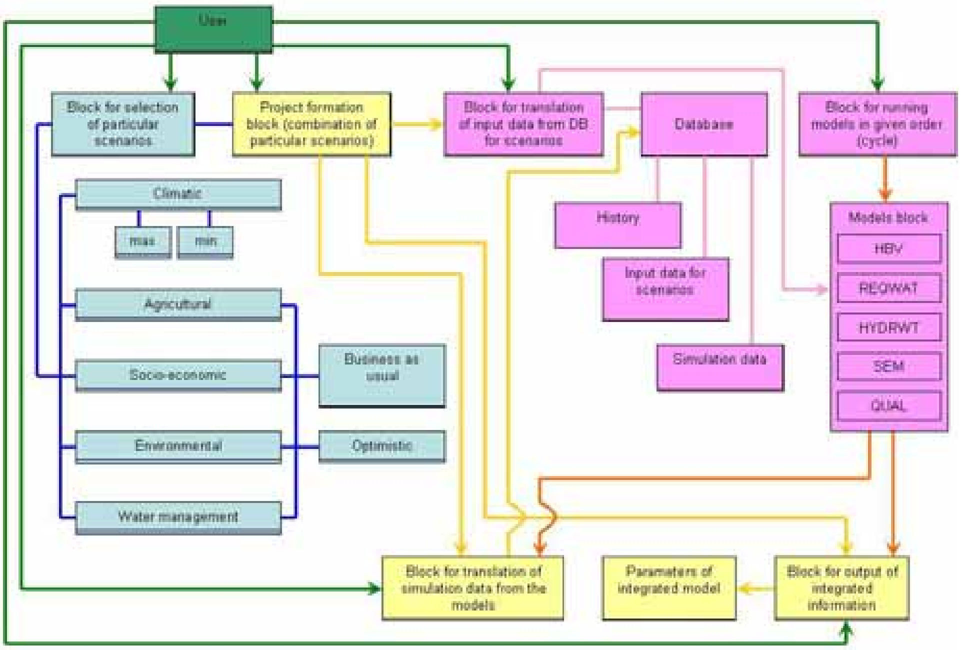


Figure 8.2. Diagram of model coupling through interface

The accepted **levels of coupling** of separate models and modules into the **integrated model**:

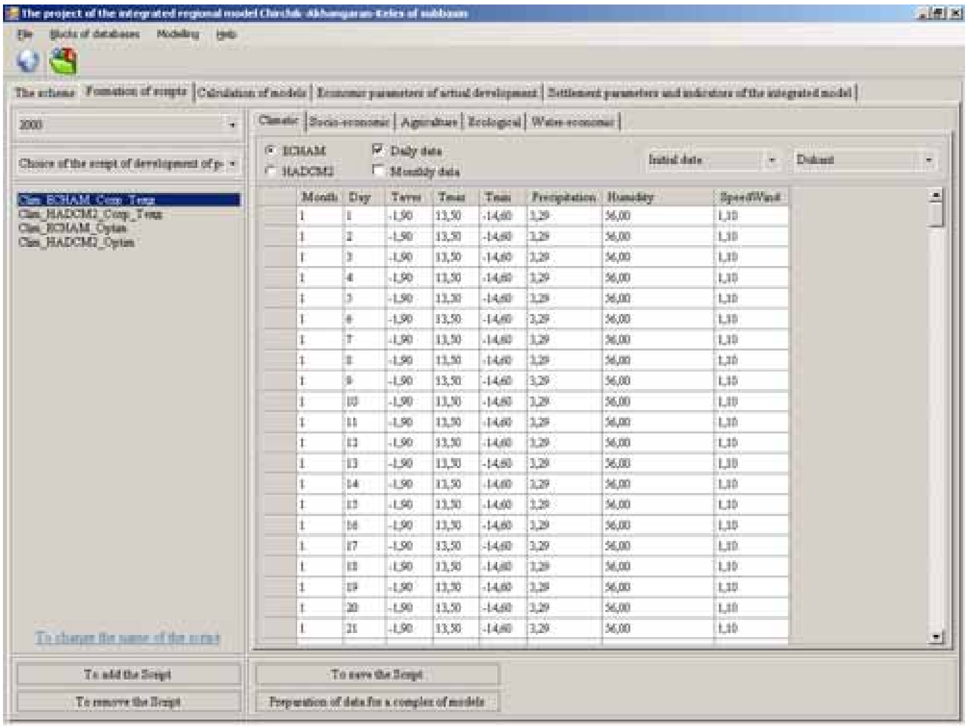
- **Program** – coupling of models and modules with each other and with database (DB) through user interface for joint operation, including: (i) development of scenarios, (ii) inputing data into the models from DB on scenarios, (iii) cycles of model running (scenario simulations) and translation of simulation data between the models in a certain order, (iv) outputting simulation data through user interface and their translation into DB.
- **Through DB** – interpretation of model and module simulation results through DB according to the developed system of integrated parameters and indicators.

The following information is collected and stored in **DB**:

- Basic data for modeling, classified and stored in separate blocks, depending on **type of individual scenarios** and translated on appropriate requests (model- scenario),
- Simulation data (model outputs) – integrated parameters and indicators stored in separate blocks with indication of a **number (name) of combination of individual scenarios**, accepted for simulations.

Types of individual scenarios (Fig. 8.3.):

- Climatic,
- Socio-economic,
- Agricultural,
- Ecological,
- Water-sector.



2000

Choice of the script of development of p

Clim_ECHAM_Comp_Temp
Clim_HADCM2_Comp_Temp
Clim_ECHAM_Optim
Clim_HADCM2_Optim

● ECHAM ☑ Daily data
○ HADCM2 ☐ Monthly data

Initial data

Dukant

Month	Day	Taver	Tmax	Tmin	Precipitation	Humidity	SpeedWind
1	1	-1,90	13,50	-14,60	3,29	56,00	1,10
1	2	-1,90	13,50	-14,60	3,29	56,00	1,10
1	3	-1,90	13,50	-14,60	3,29	56,00	1,10
1	4	-1,90	13,50	-14,60	3,29	56,00	1,10
1	5	-1,90	13,50	-14,60	3,29	56,00	1,10
1	6	-1,90	13,50	-14,60	3,29	56,00	1,10
1	7	-1,90	13,50	-14,60	3,29	56,00	1,10
1	8	-1,90	13,50	-14,60	3,29	56,00	1,10
1	9	-1,90	13,50	-14,60	3,29	56,00	1,10
1	10	-1,90	13,50	-14,60	3,29	56,00	1,10
1	11	-1,90	13,50	-14,60	3,29	56,00	1,10
1	12	-1,90	13,50	-14,60	3,29	56,00	1,10
1	13	-1,90	13,50	-14,60	3,29	56,00	1,10
1	14	-1,90	13,50	-14,60	3,29	56,00	1,10
1	15	-1,90	13,50	-14,60	3,29	56,00	1,10
1	16	-1,90	13,50	-14,60	3,29	56,00	1,10
1	17	-1,90	13,50	-14,60	3,29	56,00	1,10
1	18	-1,90	13,50	-14,60	3,29	56,00	1,10
1	19	-1,90	13,50	-14,60	3,29	56,00	1,10
1	20	-1,90	13,50	-14,60	3,29	56,00	1,10
1	21	-1,90	13,50	-14,60	3,29	56,00	1,10

Figure 8.3. Form for selection of modeling scenario

For each type of individual scenario, DB stores input information on a number of parameters for two extreme cases: (i) **“MAX”**, (ii) **“MIN”** (maximum and minimum climate impact)[2] or (i) **“Business as Usual”**, (ii) **“Optimistic”** (for other scenario types). Construction of the option "BAU" is based on prolongation of all trends, even if these trends lead to abrupt changes and declines, with account of their interlinking and

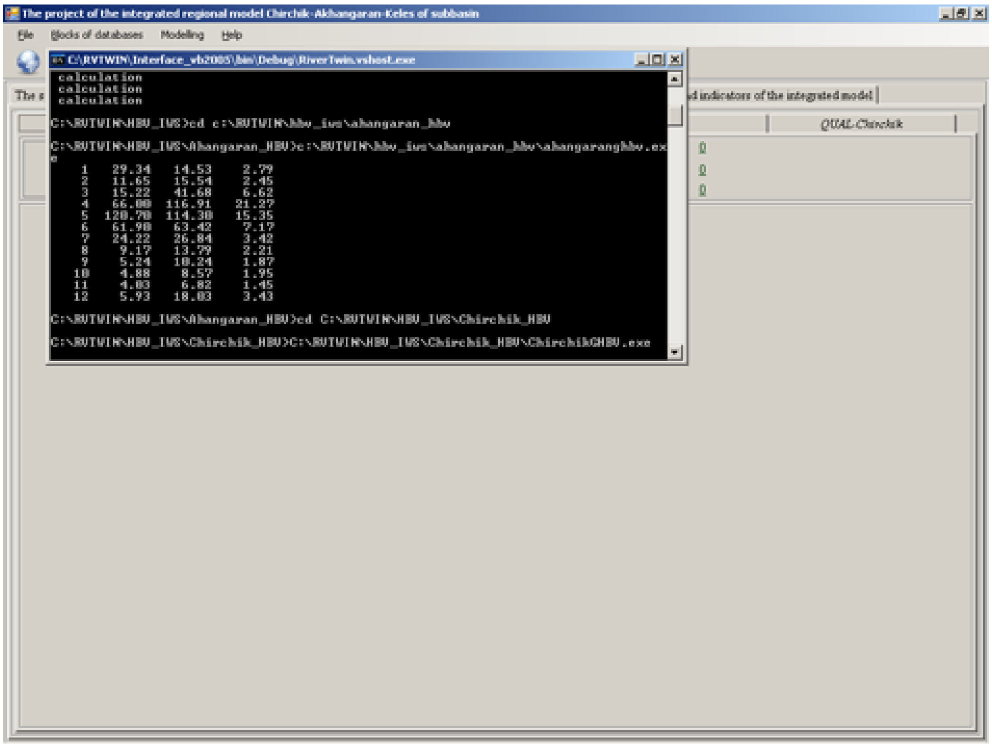
---

[2] HadCM2 (UK, Hadley Centre) is taken as maximum scenario and ECHAM4 (Germany, Max Planck Institute) as minimum scenario. Both these scenarios were laid in the base of all our estimations, taking into account their good validation with regional trends. Comparison with the last version of Wei’s modeling show their enough close fitting.

interaction. "Optimistic option" considers possibilities of complete (or close to complete) use of available potential of industries, natural mineral resources, desirable demographic level. Needed capital investments and other necessary resources (related material, human, etc.) are determined for this.

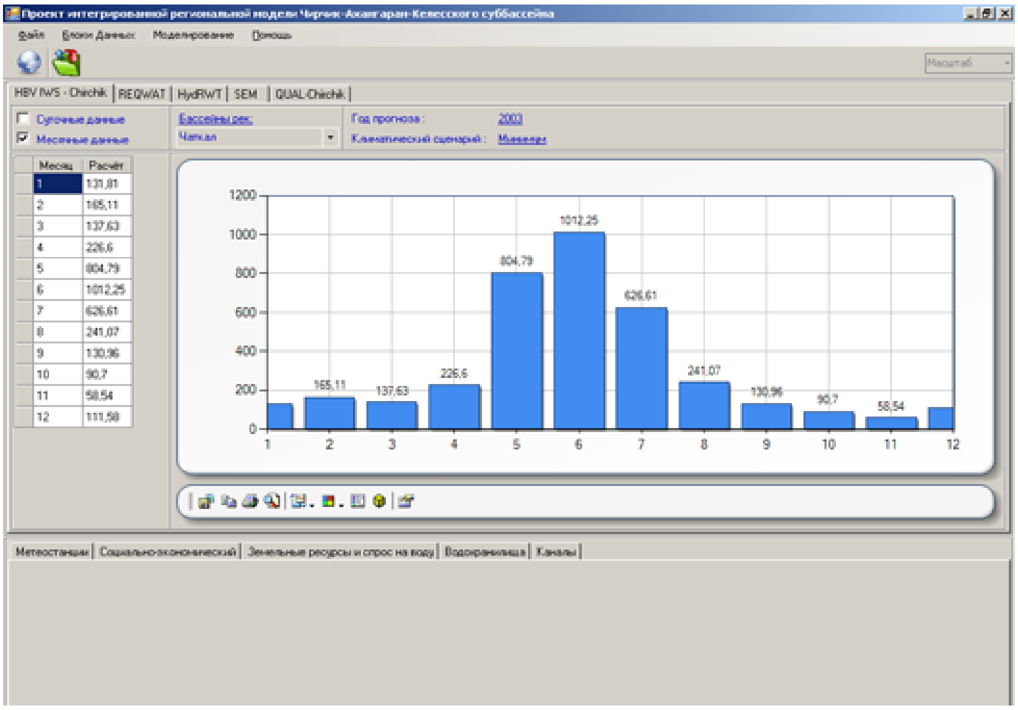
Basic data collected per scenario (**basic list**):

- Climatic (for HBV-Chirchik (Figures 8.4. - 8.5.), WEAP (Figure 8.6.), HydRWT, SEM, QUAL-Chirchik) – precipitation, evaporation, temperature with reference to weather stations,
- Socio-economic (for SEM, HydRWT) – trends of population growth, required power consumption (hydro and heat power plants), groundwater use volumes, unit water supply to non-irrigation consumers (household-drinking and industrial), macroeconomic indicators, prices, investments in development and their distribution among purposes,
- Agricultural (for WEAP, SEM) - change in irrigated lands, cropping patterns, fertilizers,
- Ecological (for HydRWT, QUAL-Chirchik) – sanitation and environmental flows, standard water quality indicators, dynamics of return water treatment (with reference to waste-water network),
- Water management (for HydRWT, SEM) – inputting new hydraulic structures (Pskem reservoir), flow regulation and transfer regimes (Syrdarya river basin, Bekabad district), Kazakhstan's water demand, water conservation and hydraulic infrastructure development indications (through efficiency coefficient).



```
 calculation
 calculation
 calculation

C:\RVTWIN\HBV_IWS>cd c:\RVTWIN\hbv_iws\ahangaran_hbv

C:\RVTWIN\HBV_IWS\Ahangaran_HBV>c:\RVTWIN\hbv_iws\ahangaran_hbv\ahangaranghbv.ex
e
    1    29.34    14.53     2.79
    2    11.65    15.54     2.45
    3    15.22    41.68     6.62
    4    66.00   116.91    21.27
    5   120.70   114.30    15.35
    6    61.90    63.42     7.17
    7    24.22    26.84     3.42
    8     9.17    13.79     2.21
    9     5.24    10.24     1.87
   10     4.88     8.57     1.95
   11     4.03     6.82     1.45
   12     5.93    18.03     3.43

C:\RVTWIN\HBV_IWS\Ahangaran_HBV>cd C:\RVTWIN\HBV_IWS\Chirchik_HBV

C:\RVTWIN\HBV_IWS\Chirchik_HBV>C:\RVTWIN\HBV_IWS\Chirchik_HBV\ChirchikGHBV.exe
```

Figure 8.4. Form for view and correction of input data for the model HBV IWS - Chirchik



☐ Суточные данные
☑ Месячные данные

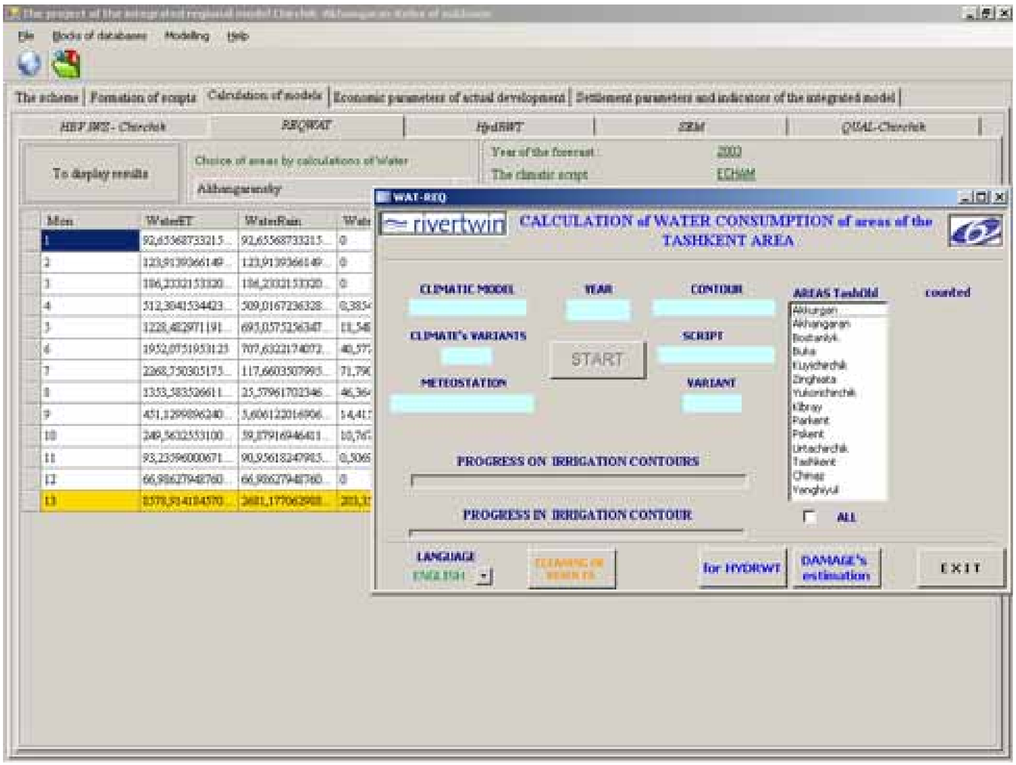
Бассейны рек: Чаткал

Год прогноза : 2003

Климатический сценарий :

Месяц	Расчёт
1	131,81
2	165,11
3	137,63
4	226,6
5	804,79
6	1012,25
7	626,61
8	241,07
9	130,96
10	90,7
11	58,54
12	111,58

Figure 8.5. Form for view and correction of input data for the model HBV IWS - Chirchik



Choice of areas by calculations of Water: Akhangaransky

Year of the forecast: 2003

The climatic script: ECHAM

Mon	WaterET	WaterRain	Wat
1	92,65568733215...	92,65568733215...	0
2	123,9139366149...	123,9139366149...	0
3	186,2332153320...	186,2332153320...	0
4	512,3041534423...	509,0167236328...	0,385
5	1228,482971191...	693,0575256347...	11,54
6	1952,0751953123	707,6322174072...	40,57
7	2268,750305175...	117,6603507995...	71,79
8	1353,583526611...	25,57961702346...	46,36
9	451,1299896240...	5,606122016906...	14,41
10	249,5632553100...	59,07916946411...	10,76
11	93,23396000671...	90,95618247983...	0,506
12	66,98627948760...	66,98627948760...	0
13	2378,914184570...	2681,177062988...	203,3

CALCULATION of WATER CONSUMPTION of areas of the TASHKENT AREA

CLIMATIC MODEL | YEAR | CONTOUR | CLIMATE's VARIANTS | SCRIPT | METEOSTATION | VARIANT

PROGRESS ON IRRIGATION CONTOURS

PROGRESS IN IRRIGATION CONTOUR

AREAS TashObl: Akkurgan, Akhangaran, Bostanlyk, Buka, Kuyichirchik, Zanghiata, Yukorichirchik, Kibray, Parkent, Pskent, Urtachirchik, Tashkent, Chinaz, Yanghiyul

counted

☐ ALL

LANGUAGE: ENGLISH

Figure 8.6. Form for view and correction of input data for the model WEAP

By present, coupling of three models (HBV-Chirchik, HydRWT (GAMS) and WEAP? and DB through the user interface have been completed using data of the year 2003.

Socio-economic model (SEM) was also linked to interface, and now the QUAL-Chirchik model is being integrated.

A block was developed to output the integrated indicators as a result of operation of the modeling set (this information is stored in DB and displayed upon user request).

In particular, from coupled HydRWT (GAMS) and agricultural module WEAP (CROPWAT) we estimate the following:

- water requirements (this information is transmitted from agricultural module to GAMS-model),
- water supply in districts (information is transmitted from GAMS-model to agricultural module).

We identified and programmed flows of data transmitted between HBV-Chirchik and GAMS-model.

Integrated model indicators (Figures 8.7.- 8.9.) derived via DB (**basic list**)**:**

- Water supply of irrigated agriculture (%) per planning zone (simulation data from HydRWT),
- Agricultural development indicators – area changes, crop yields, production volumes and incomes in irrigated agriculture per planning zone (simulation data from WEAP , SEM),
- Hydropower generation and deficit per cascade and individual HEPS (simulation data from HydRWT),
- Deficit of environmental releases in control section lines of river network (simulation data from HydRWT),
- Deviation of simulated surface water quality figures from standard indicators (permissible water salinity for drinking water supply, agriculture and fishery) in control section lines of river network (simulation data from QUAL-Chirchik),
- Aggregate regional water balance (simulation data from HydRWT),
- Socio-economical development indicators – demography, macroeconomic indicators, investments, food provision (input data and simulated data from SEM).

Indicators of socio-economic model outputted through the interface:

- population (urban and rural),
- number of workable population (urban and rural),
- number of work places,
- water availability of communal sector,
- water availability of industry,
- gross production volumes per sector,
- gross domestic income of the province GDP,
- personal income, urban and rural,
- food supply,
- employment.

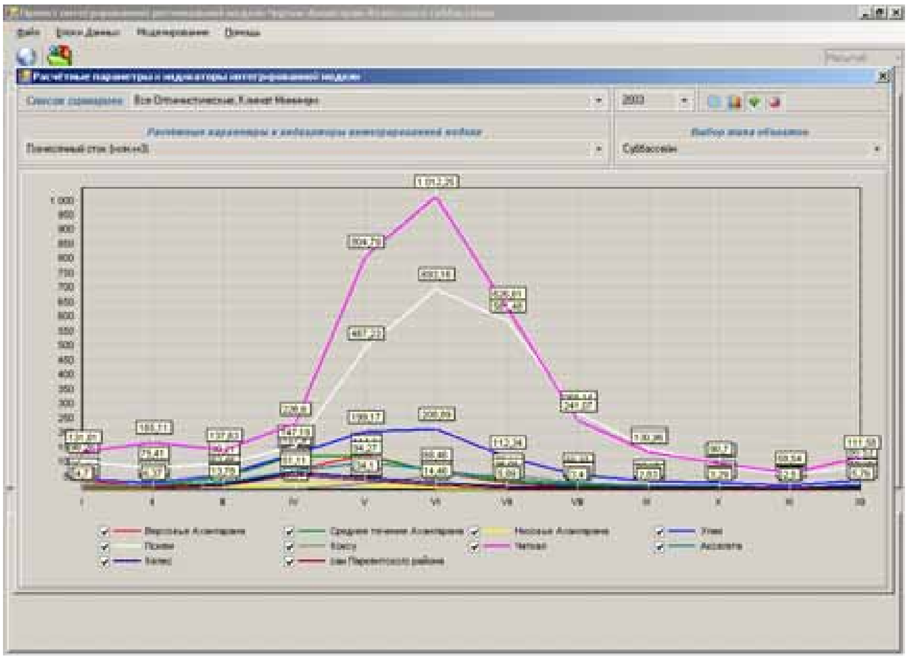


Figure 8.7. Form for view of simulated parameters and indicators

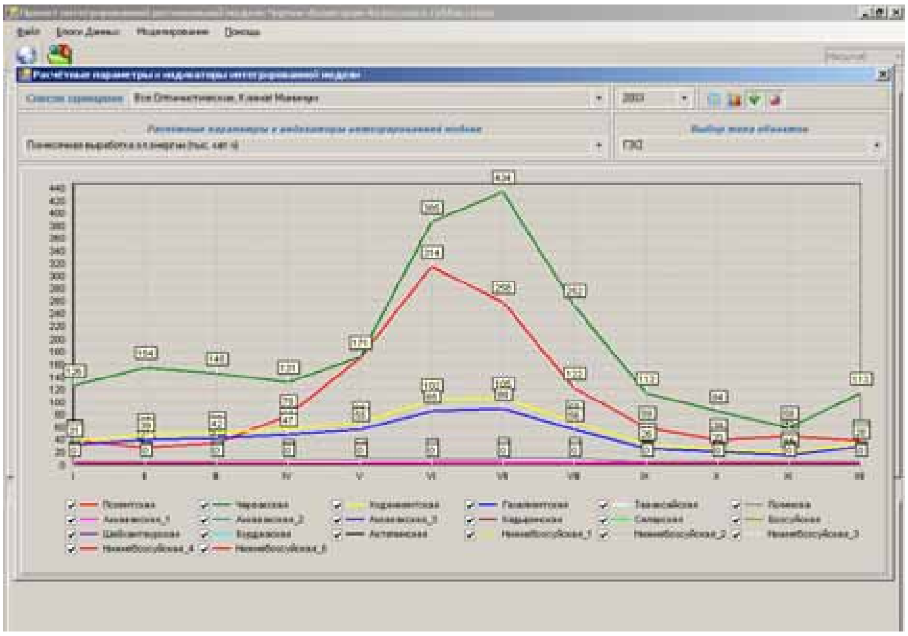


Figure 8.8. Form for view of simulated parameters and indicators

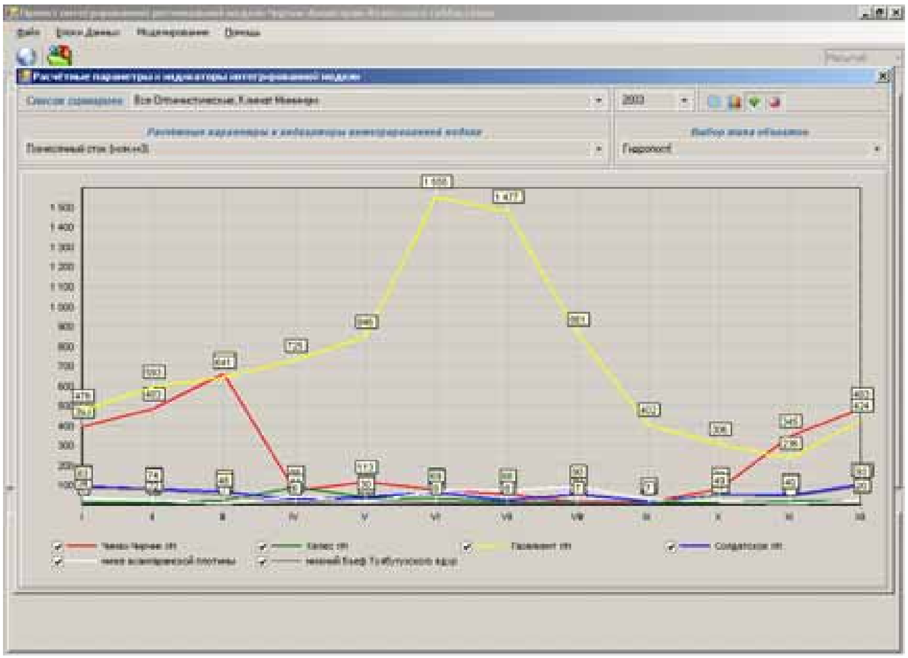


Figure 8.9. Form for view of simulated parameters and indicators

The set of HBV-GAMS- WEAP -SEM is adjusted to simulation of scenarios:

- climatic - to determine an impact of future climate changes on flow quantity and regime; these scenarios are played first in HBV-Chirchik and agricultural module (climate impact on required water consumption),
- socio-economic and agricultural – to determine future water demands; these scenarios are played first in agricultural module and socio-economic model and transmitted to GAMS-model of water distribution, with back data transfer (after comparison of demand and available resource),
- flow regulation by reservoirs and HEPS (introduction of Pskem waterworks facility, etc.) and environmental limitations (discharge into the Syrdarya river, etc.); first played in GAMS model of water distribution; these scenarios influence on water availability of irrigated schemes, water-supply entities and energy sector,

Further interface improvement would allow selection and comparison of options based on criteria, restrictions, and integrated assessments and search form rational, optimization solutions through dialogue with user (input of scenarios by user).

The user interface has been constructed, based on the following system principles: dialogue controlled by system, i.e. inflexible “rules of play” are established in working with system such as what functional components can be handled, what forms of information display can be used, what key parameters should be set to process any information object; mixed structure of dialogue that enables to simultaneously use a number of different elements of dialogue on the screen, edit data fields before input. In other words, user has an opportunity to work with the form until he presses appropriate button that means, for example, exit from the form and so on. Moreover, while developing a user interface, numerous requirements that are usually set to modern software products were fulfilled.

The suggested **order of integrated model operation:**

1. **Selection of scenarios** (2006…2030) from the suggested list of specific scenarios, with indication of code – number, title of their combination (project); This code **(project)** will be used for recording and saving simulation data in DB,

2. Translation of input data on selected combination of scenarios (project) into models and review of data (from translation files through interface); in case of formation of new user scenario, input data are edited (changed) and saved in new project,

3. **Running of the set of models in cycles** (25 **cycles,** time **step** - 1 year, possible **a few iterations** in one cycle until set model parameters are achieved and restrictions are met):

- Running HBV-Chirchik and translating simulation data from HBV-Chirchik into HydRWT,
- Running WEAP and translating simulation data from WEAP into SEM and HydRWT,
- Running SEM and translating simulation data from SEM to HydRWT,
- Running HydRWT and translating simulation data from HydRWT into WEAP, SEM and QUAL-Chirchik ,
- Running WEAP and translating simulation data from WEAP into SEM,
- Running QUAL-Chirchik,

4. Translation of simulation data from the models into DB and their review, printing, etc. with reference to integrated indicators; if necessary, opening special interfaces and outputting simulation results in extended list (supplement to integrated indicators).

5. After completing series of simulations (25 cycles), simulation results (see Figures 8.7-8.9) are outputted via DB, showing their dynamics and their comparison.

The “Rivertwin” DB interface adequately takes into account the basic requirements to the interface of modern software products, namely:

1. Uniformity of main dialogue forms and data processing forms: appearance, sequence of data placing and display on the screen.
2. Naturalness of dialogue: conducting dialogue in native language (in our case it is Russian, later English as well). The procedure for information input is extremely approximated to that procedure, in which user generally processes information.
3. No redundancy (conciseness): input of minimum information necessary for fulfilling any function. One cannot input information, which can be formed automatically or which was inputted before. This enables to make the dialogue fast and simple, and reduce the number of possible errors. Broad use of icons (menu button) instead of text to mark frequently used functions. At the same time, if user does not understand destination of the icon, then he can see a brief text explanation of its destination beside it, having placed the mouse pointer on this icon.
4. User-friendly support: it gives an opportunity to receive general or context-dependent information (assistance), giving user reports on any events (actions), for example, lack of information on object for given key parameters in the table.

User interacts with the system on the basis of dialogue forms by using a keyboard and mouse. As a rule, using a keyboard, data are inputted and updated. Using a mouse, different elements of dialogue forms (functional buttons, selecting menu items, finding objects in GIS and so on) are selected and activated.

9 TESTING AND OUTPUTS OF THE SET OF MODELS

In accordance with the Terms of Reference, BWO “Syrdarya” in association with SIC ICWC provided a trial test of GAMS-Model for water resources distribution in Chirchik-Akhangaran-Keles Basin.

The tested model is a balance model that describes in detail the following components: (i) river network in the basin with all reservoirs, hydro power plants and gauging stations located within it; (ii) irrigation systems including canals, waterworks facilities, water intakes, escapes, water-measurement points; (iii) “Vodokanal” system that uses water from surface and groundwater sources; (iv) collector and waste-disposal network.

It includes all entities managed and controlled by BWO “Syrdarya”, in particular those of interstate importance, which ensure water supply to users in neighboring Kazakhstan.

The model makes it possible to establish restrictions on supply (discharge) to the Syrdarya river, but concrete numerical values for these restrictions have not been defined. Moreover, the model enables to calculate salt balance for rivers, reservoirs and canals, along with water balance.

In testing, the year 1994 was selected as a modeling year, which can be referred to years with above average water availability for the considered basin. Based on archival data available in the BWO for the mentioned year, the model established actual water requirements (limits) by setting average monthly water discharges for all water supply points, side inflow, and limitations on waste discharges and other components characterizing surface water resources in the basin.

The calculations of surface runoff regimes under given conditions and limitations in 1994 made it possible to derive simulation data on these components: (i) operation modes of reservoirs in the form of filling/drawdown schedules; (ii) average monthly water discharges and salinity for all the main sections of river and distribution network, including waterworks facilities, water intakes, disposals; (iii) timetables for head pressure, releases and power generation at instream (Chirchik) and derivation (Bozsu) hydro power plants.

Based on simulation, monthly channel balances were identified for specific sites in the basin, and compared with available actual balances. The analysis of the results enabled to draw the following conclusions and set some tasks for the next work stage.

1. The model showed good fitting (within a reasonable error in water balance of 5-6%) of actual and simulation results regarding operation modes of reservoirs and hydro power plants, and water supply over outlets from irrigation network to districts.

As water outlets approach bottom up to river channel, the error in computation of water discharges increases. Similarly, the error in computations of discharges along Chirchik and Akhangaran river channels rises while moving from upper reaches to mouth. Here, in particular months the errors exceed reasonable values 1.5 to 2 times. However, yearly imbalances are within reasonable error and quite small in comparison with overall balance for the basin, when the comparison is made not for individual objects, but for the whole basin (total resources, withdrawal, losses, outflow from the basin). Discrepancy in simulated and actual values of imbalance in some sites and entities can also be due to that the model, in comparison with balance calculations of the BWO, operates with a great deal of influencing factors, and optimizes water distribution among streams, the direction and size of which can differ from the actual ones. To reduce the error, special additional numerical simulation experiments may be conducted using available information of the BWO.

2. While testing the model, comparison of simulated and actual water delivery from the Chirchik river to the Syrdarya river was made. The amount of such discharge should be considered in the model as environmental requirement in simulations by different scenarios. The model considers such limitation as a variable that requires expert evaluation depending on flow probability in the Chirchik river and water situation in the entire Syrdarya river basin. Preliminary, the minimum discharge along the Chirchik river channel to the Syrdarya river for

environmental requirements in the vegetation period can be estimated no less than 30 m^3/sec, and the maximum one should not exceed the value, which (with account of inflow along the Syrdarya river channel and accumulation) ensures release from the Chardara reservoir of no more than 1200 m^3/sec, based on limits of Syrdarya river channel's flow capacity. In the next work stage, the BWO will present numerical values of minimum and maximum requirements to releases to the Syrdarya river for several management scenarios to be included in the model.

3. The testing of the presented model version showed its efficiency and, in general, acceptable accuracy of computations. The model may be used for variant calculations and development of proposals for long-term water resources management in the Chirchik-Akhangaran-Keles basin, with account of limitations and requirements to the whole Syrdarya river basin.

4. The calibration and testing of SEM (including agricultural block) was presented in the report D-27 on the example of the same years (2000-2003) as for hydrological block. In model calibration we used data over 1975-1990, while model validation was based on comparison of simulated data with observed data over 2000-2003 (Table 9.1). For calibration of indicators in other blocks we used statistical data over 1995-2002, and validation was based on comparison with economic results of the same years, particularly 2003, when economic trends slightly stabilized. Equation parameters were determined through processing of trends for respective indicators as collected in the database on Tashkent province, with division into districts (project report D-24). Calibration of indicators was made on the basis of analysis of statistical data on Tashkent province. As a result of cumulative estimation of major indicators of sub-basin development within Tashkent province, we derived cost indicators of gross production volume and GDP per main economic sectors and compared them with official macro-economic indicators (Tables 9.2).

5. Interface as a tool for integration has created a possibility to build up the forecast of future development and to try to assess feasibility of different scenarios for complex development in the Chirchik-Akhangaran-Keles basin.

Table 9.1 Comparison of simulated and statistical economic indicators in the agricultural sector

2000

Tashkent province (2000)	Simulation			Statistics		
	Gross volume ($)	Profit ($)	GDP ($)	Gross volume ($)	Profit ($)	GDP ($)
irrigated area	163 523 621	26 541 780	151 263 428	165 248 731	24 651 251	*
dry land	1 945 796	985 643	1 453 215	1 792 534	879 562	
homestead plots	52 698 741	16 372 520	16 372 520	53 682 428	13 658 792	
TOTAL for crop production	218 168 158	43 899 943	169 089 163	220 723 693	39 189 605	
TOTAL for livestock-breeding	240 285 058	48 660 298	170 164 328	183 158 883	49 866 740	
TOTAL for agriculture	458 453 216	92 560 241	339 253 491	403 882 576	89 056 345	298 870 000

2001

Tashkent province (2001)	Simulation			Statistics		
	Gross volume ($)	Profit ($)	GDP ($)	Gross volume ($)	Profit ($)	GDP ($)
irrigated area	166 364 521	28 624 571	152 651 471	165 489 231	29 352 671	*
dry land	3 216 450	1 894 567	2 306 504	2 958 451	2 160 351	
homestead plots	54 216 320	14 568 321	14 568 321	55 489 682	13 896 571	
TOTAL for crop production	223 797 291	45 087 459	169 526 296	223 937 364	45 409 593	

TOTAL for livestock-breeding	231 995 363	49 157 861	167 756 495	240 124 767	45 841 049	
TOTAL for agriculture	455 792 654	94 245 320	337 282 791	464 062 131	91 250 642	343 400 583

2002

Tashkent province (2002)	Simulation			Statistics		
	Gross volume ($)	Profit ($)	GDP ($)	Gross volume ($)	Profit ($)	GDP ($)
irrigated area	162 358 741	26 548 720	153 642 897	163 546 581	25 671 421	*
dry land	2 345 872	1 056 345	2 036 891	2 248 972	1 125 632	
homestead plots	56 324 781	14 532 684	14 532 684	55 648 923	17 830 900	
TOTAL for crop production	221 029 394	42 137 749	170 212 472	221 444 476	44 627 953	
TOTAL for livestock-breeding	233 564 280	51 019 126	166 190 279	259 788 095	54 735 347	
TOTAL for agriculture	454 593 674	93 156 875	336 402 751	481 232 571	99 363 300	356 113 264

2003

Tashkent province (2003)	Simulation			Statistics		
	Gross volume ($)	Profit ($)	GDP ($)	Gross volume ($)	Profit ($)	GDP ($)
irrigated area	165 352 840	27 640 842	154 492 972	161 537 800	27 045 000	*
dry land	2 588 561	1 178 278	2 306 504	2 427 600	927 800	
homestead plots	58 717 113	15 627 113	15 627 113	58 402 000	17 830 900	
TOTAL for crop production	226 658 514	44 446 232	172 426 589	222 367 400	45 803 700	
TOTAL for livestock-breeding	231 510 349	49 960 719	176 116 129	263 675 168	53 559 600	
TOTAL for agriculture	458 168 863	94 406 951	348 542 718	486 042 568	99 363 300	359 674 257

* Official reports give only statistical data on GDP for agriculture in general, without division into separate areas.

Table 9.2 Comparison of cost indicators of gross production volume and GDP per main economic sectors with official macro-economic indicators

(GV – gross production volume; GDP – gross domestic product)

	Industry					AgroIndustry			
	Simulation		Statistics			Simulation		Statistics	
	GV	GDP	GV	GDP		GV	GDP	GV	GDP
	million$	million$	million$	million$		million$	million$	million$	million$
1995	1327.32	278.74	1285.01	269.85		508.06	177.82	224.99	78.75
2000	980.20	205.84	998.43	209.67		288.04	100.81	313.57	109.75
2001	851.73	178.86	847.08	177.89		278.72	97.55	288.42	100.95
2002	702.87	147.60	716.53	150.47		273.90	95.86	263.67	92.29
2003	712.51	149.63	718.66	150.92		271.20	94.92	260.44	91.15

	Agriculture					Service			
	Simulation		Statistics			Simulation		Statistics	
	GV	GDP	GV	GDP		GV	GDP	GV	GDP

	million$	million$	million$	million$		million$	million$	million$	million$
1995	488.29	361.34	430.40	318.50		718.11	617.57	530.36	456.11
2000	458.45	339.25	403.88	298.87		514.85	442.77	568.81	489.18
2001	455.79	337.28	464.06	343.40		525.86	452.24	480.13	412.91
2002	454.59	336.40	481.23	356.11		549.06	472.19	423.86	364.52
2003	454.24	336.13	486.04	359.67		579.51	498.38	420.00	361.20

	Region			
	Simulation		Statistics	
	GV	GDP	GV	GDP
	million$	million$	million$	million$
1995	3041.78	1435.47	2470.76	1123.20
2000	2241.54	1088.68	2284.69	1107.47
2001	2112.09	1065.93	2079.68	1035.14
2002	1980.42	1052.06	1885.29	963.39
2003	2017.46	1079.06	1885.14	962.94

ANNEX 1

Comparison of simulated and observed monthly runoff and environmental requirements in Chinaz-Chirchik section (2003)

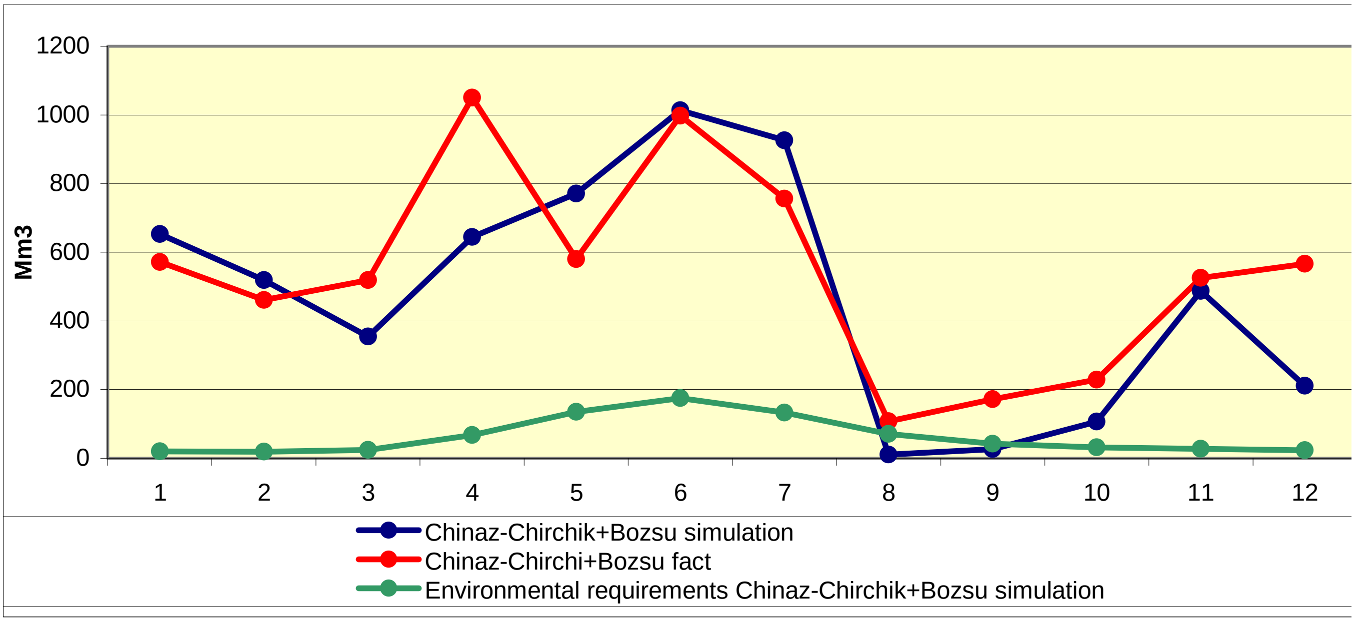
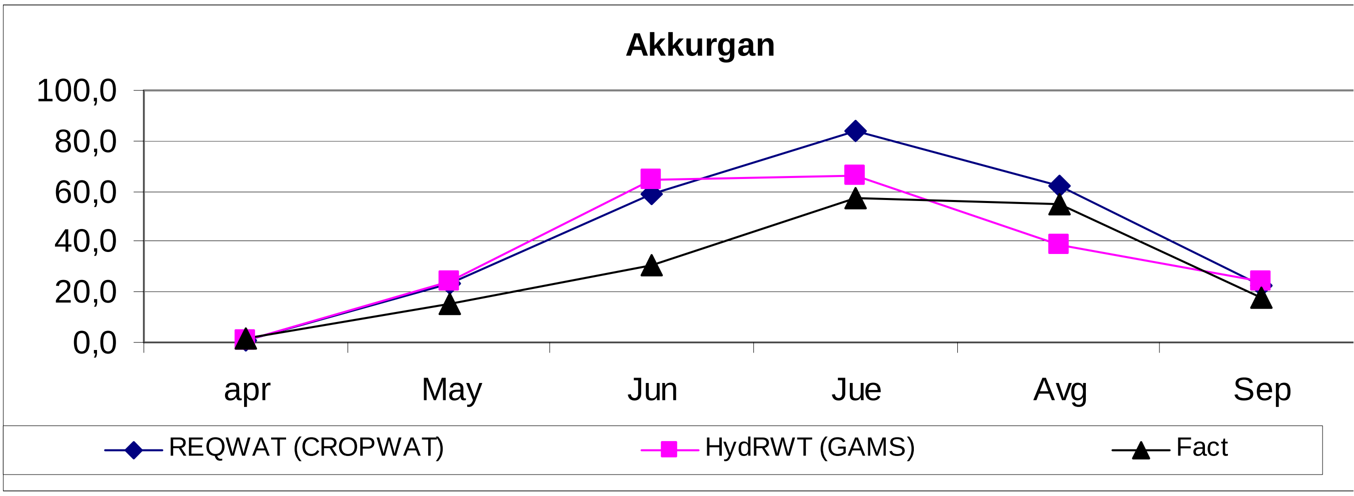


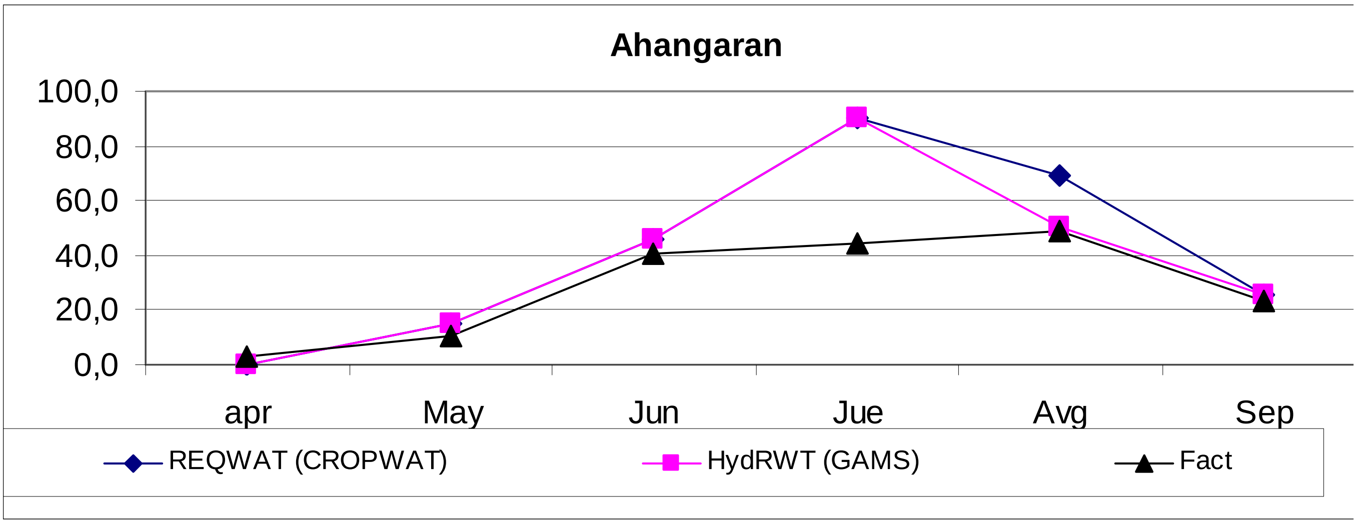
Table 1. Comparison of estimated data by WEAP, HydRWT with actual data on each PZ

Rayon	ω	Year	Month	WEAP (CROPWAT)	HydRWT (GAMS)	Actual
Akkurgan	29,5	2003	apr	0,8	0,9	2,0
	29,5	2003	May	23,2	24,0	15,0
	29,5	2003	Jun	59,0	64,4	30,6
	29,5	2003	Jue	83,8	66,3	57,0
	29,5	2003	Avg	62,0	38,4	55,0
	29,5	2003	Sep	22,5	24,5	17,6
				251,4	**218,5**	**177,2**

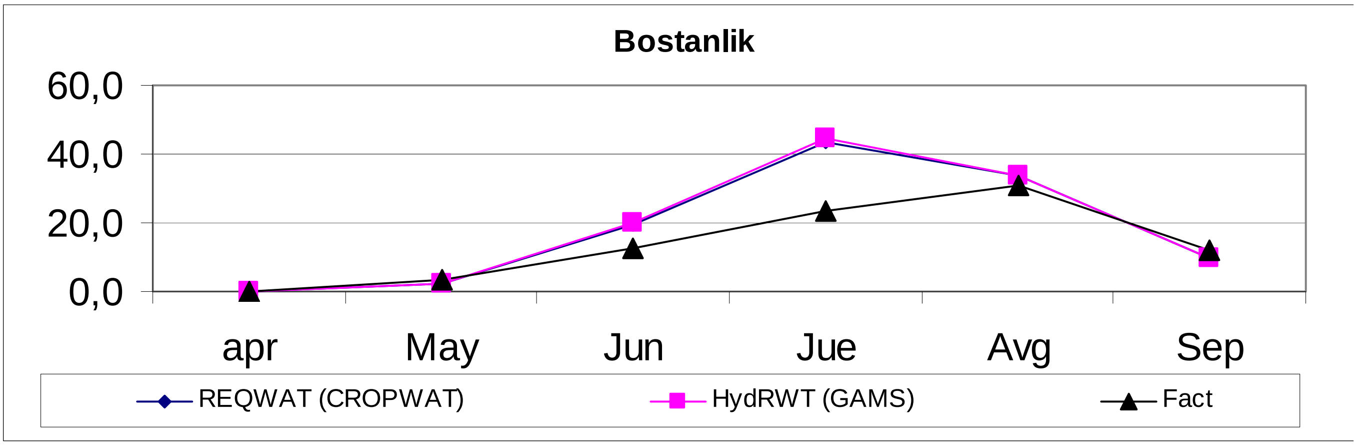


Ahangaran	25,9	2003	apr	0,1	0,0	3,1
	25,9	2003	May	15,2	15,2	10,4

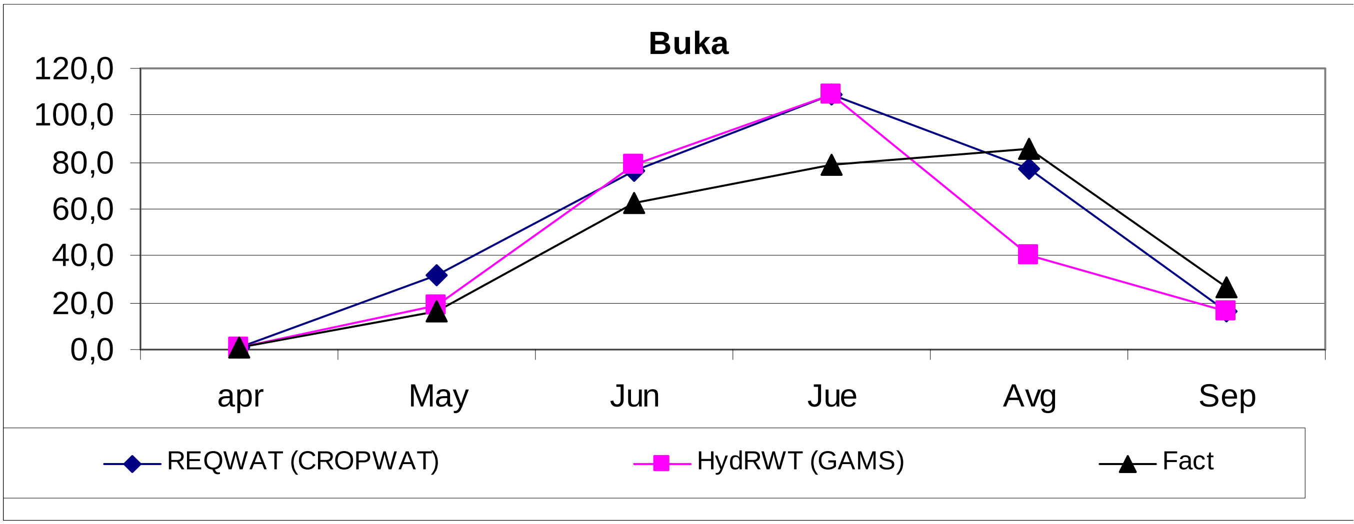
	25,9	2003	Jun	45,5	45,5	40,5
	25,9	2003	Jue	90,0	90,1	44,7
	25,9	2003	Avg	69,3	50,3	48,7
	25,9	2003	Sep	25,2	25,2	23,4
				245,4	**226,3**	**170,8**



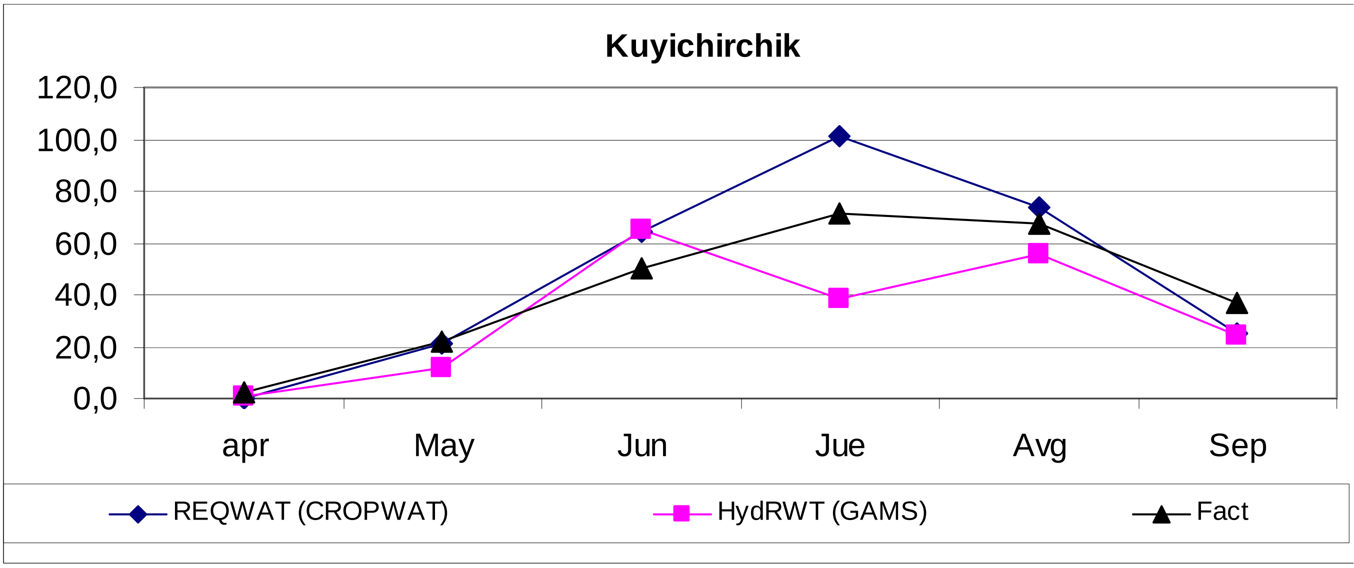
Bostanlik	15	2003	apr	0,0	0,0	0,0
	15	2003	May	2,0	2,1	3,3
	15	2003	Jun	19,5	19,8	12,8
	15	2003	Jue	43,7	44,5	23,7
	15	2003	Avg	33,5	34,0	31,0
	15	2003	Sep	9,8	9,9	11,9
				108,5	**110,3**	**82,7**



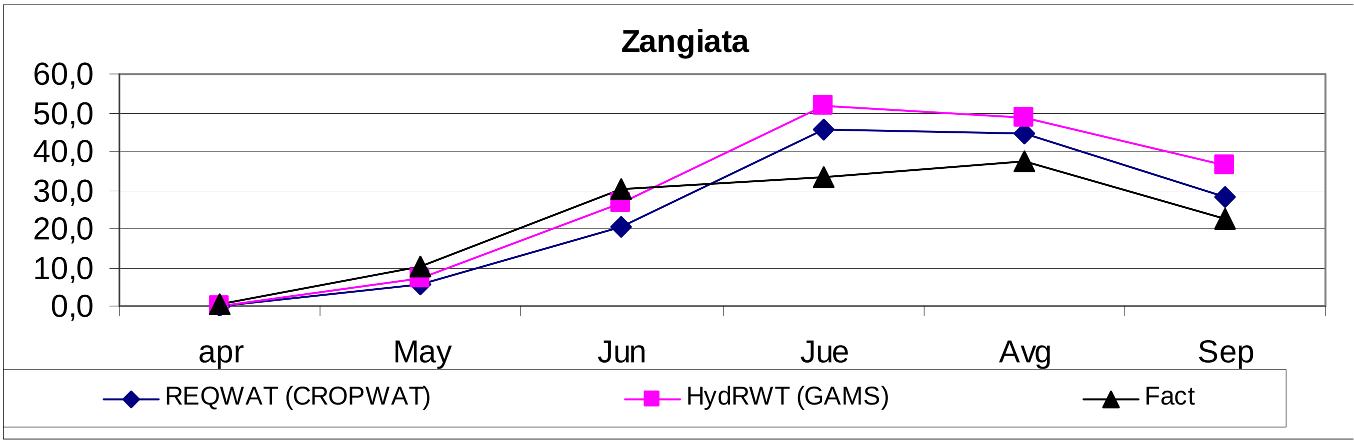
Rayon	ω	Year	Month	WEAP (CROPWAT)	HydRWT (GAMS)	Actual
Buka	38,6	2003	apr	0,8	0,7	0,7
	38,6	2003	May	31,7	18,5	16,1
	38,6	2003	Jun	76,5	79,0	62,3
	38,6	2003	Jue	108,4	109,2	78,8
	38,6	2003	Avg	77,0	40,2	85,8
	38,6	2003	Sep	16,4	16,6	26,4
				311,0	**264,2**	**270,2**



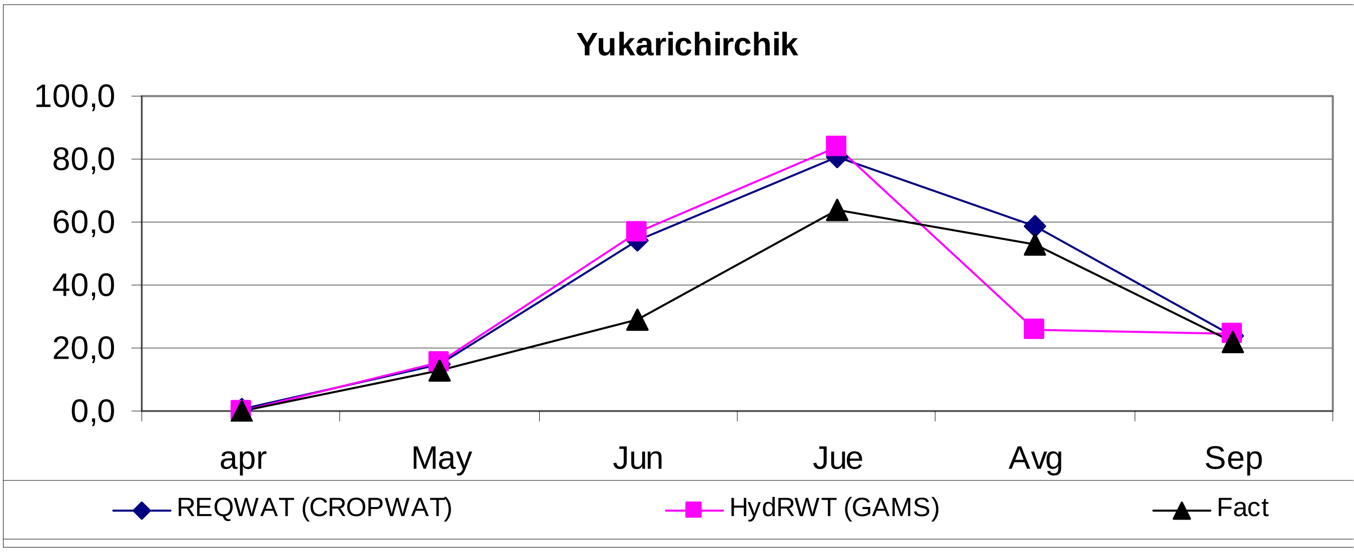
Kuyichirchik	39,4	2003	apr	0,4	0,4	2,2
	39,4	2003	May	21,0	12,0	21,6
	39,4	2003	Jun	63,9	65,3	50,2
	39,4	2003	Jue	101,2	38,5	71,3
	39,4	2003	Avg	73,9	55,3	67,5
	39,4	2003	Sep	24,9	24,4	37,0
				285,3	**195,9**	**249,8**



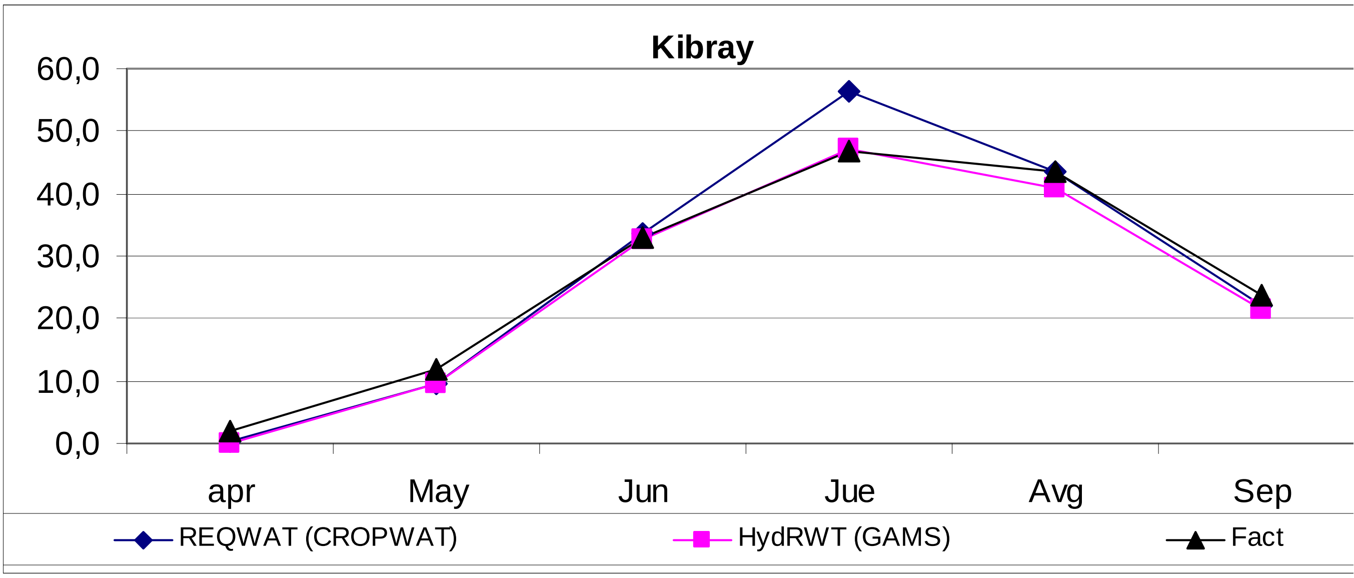
Rayon	ω	Year	Month	WEAP (CROPWAT)	HydRWT (GAMS)	Actual
Zangiata	12,6	2003	apr	0,1	0,0	0,4
	12,6	2003	May	5,5	7,0	10,2
	12,6	2003	Jun	20,6	26,5	30,1
	12,6	2003	Jue	45,5	51,7	33,5
	12,6	2003	Avg	44,8	48,6	37,2
	12,6	2003	Sep	28,3	36,5	22,6
				144,7	**170,3**	**134,0**



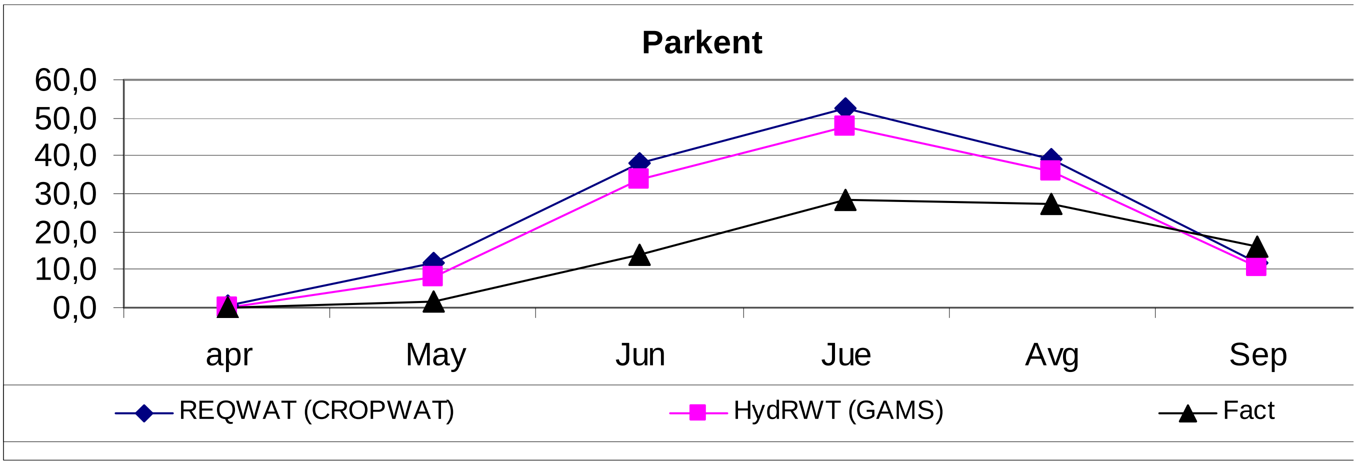
Yukarichirchik	26,2	2003	apr	0,4	0,3	0,2
	26,2	2003	May	14,6	15,2	12,7
	26,2	2003	Jun	54,1	56,5	28,8
	26,2	2003	Jue	80,6	84,0	64,1
	26,2	2003	Avg	58,6	25,7	53,0
	26,2	2003	Sep	23,8	24,7	22,1
				232,1	**206,4**	**180,9**



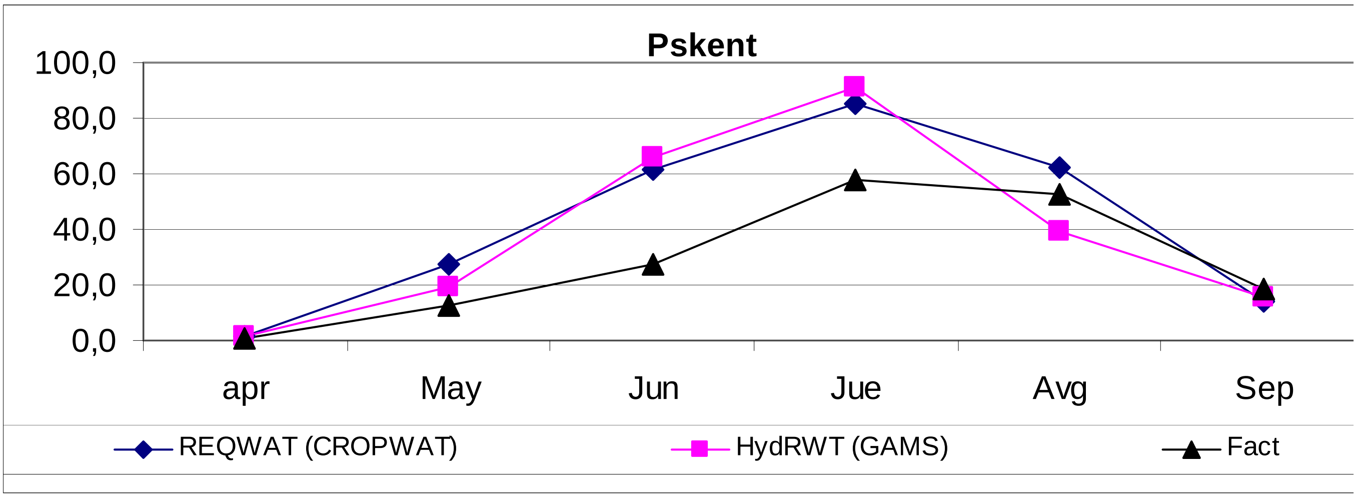
Rayon	ω	Year	Month	WEAP (CROPWAT)	HydRWT (GAMS)	Actual
Kibray	19,3	2003	apr	0,2	0,0	1,8
	19,3	2003	May	9,7	9,4	12,0
	19,3	2003	Jun	33,7	32,8	32,8
	19,3	2003	Jue	56,4	47,0	46,8
	19,3	2003	Avg	43,4	41,0	43,5
	19,3	2003	Sep	21,9	21,3	23,8
				165,3	**151,5**	**160,8**



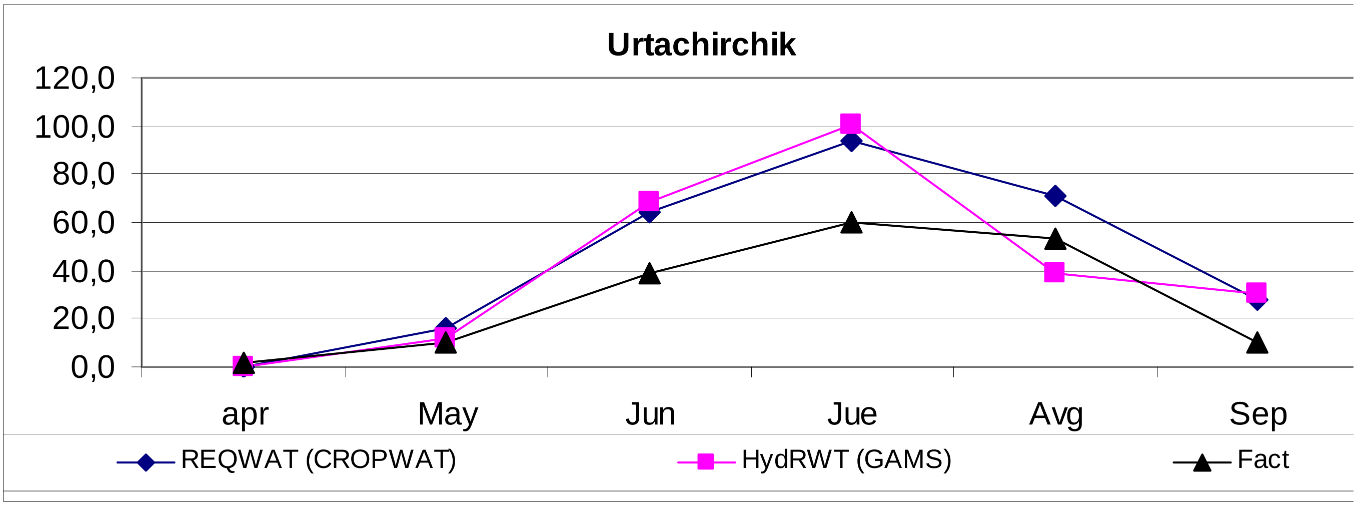
Parkent	14,8	2003	apr	0,5	0,0	0,0
	14,8	2003	May	11,7	8,1	1,6
	14,8	2003	Jun	38,1	33,8	14,0
	14,8	2003	Jue	52,7	47,7	28,1
	14,8	2003	Avg	39,3	36,1	27,3
	14,8	2003	Sep	11,9	10,9	15,9
				154,2	**136,6**	**87,0**



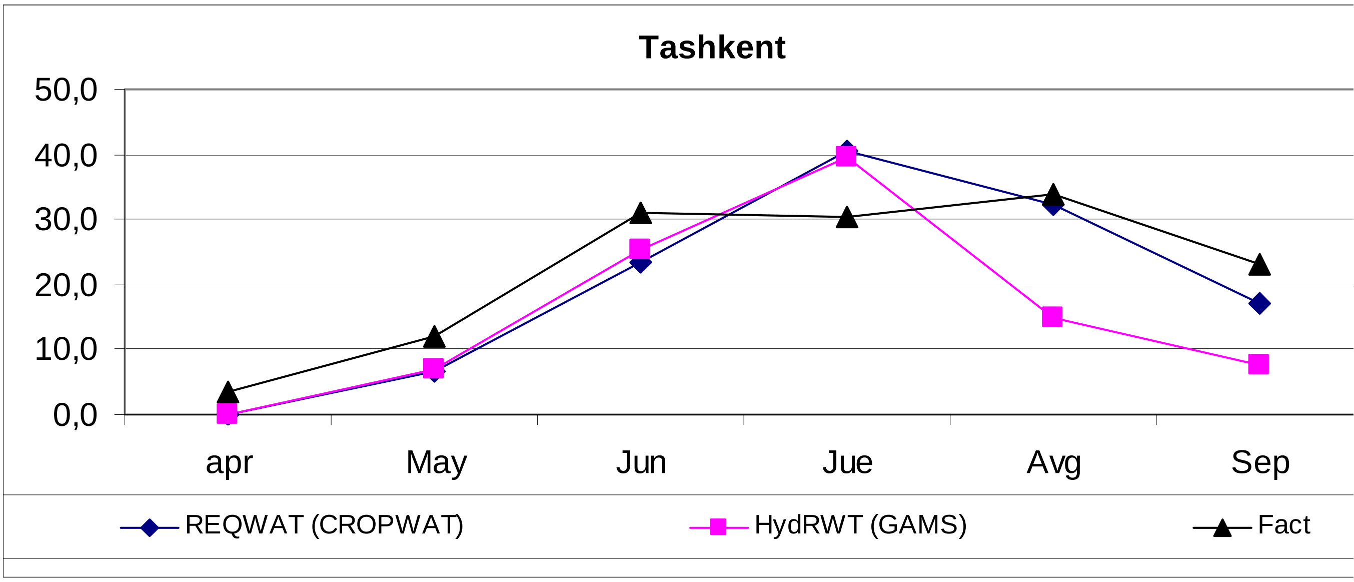
Pskent	24,9	2003	apr	1,3	1,3	0,4
	24,9	2003	May	27,4	18,9	12,4
	24,9	2003	Jun	61,6	65,7	27,1
	24,9	2003	Jue	85,1	91,0	58,0
	24,9	2003	Avg	62,1	39,6	52,8
	24,9	2003	Sep	14,4	15,3	18,7
				251,9	**231,8**	**169,3**



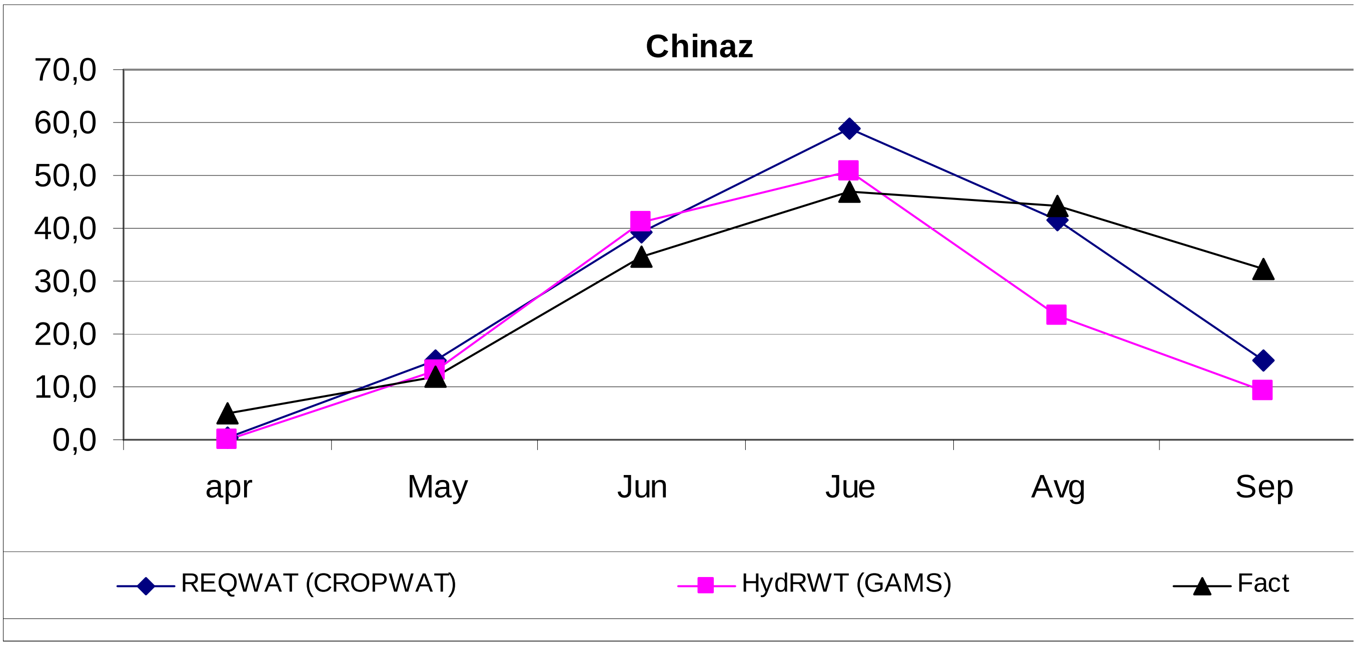
Rayon	ω	Year	Month	WEAP (CROPWAT)	HydRWT (GAMS)	Actual
Urtachirchik	32,7	2003	apr	0,3	0,3	1,3
	32,7	2003	May	16,1	11,5	10,4
	32,7	2003	Jun	64,0	68,8	38,6
	32,7	2003	Jue	94,2	100,8	60,0
	32,7	2003	Avg	70,8	38,8	53,3
	32,7	2003	Sep	28,1	30,1	10,5
				273,4	**250,3**	**174,1**



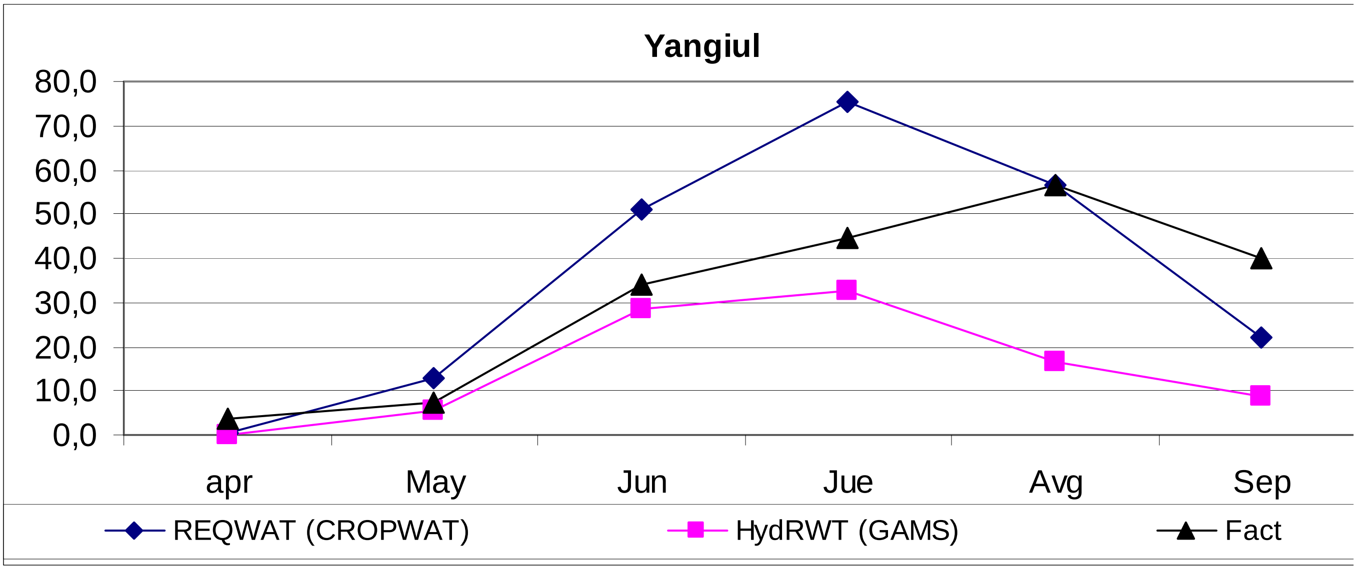
Tashkent	15,3	2003	apr	0,1	0,0	3,4
	15,3	2003	May	6,5	7,0	12,2
	15,3	2003	Jun	23,3	25,2	30,9
	15,3	2003	Jue	40,6	39,7	30,3
	15,3	2003	Avg	32,4	15,0	33,9
	15,3	2003	Sep	17,2	7,7	23,2
				120,1	**94,6**	**133,9**



Rayon	ω	Year	Month	WEAP (CROPWAT)	HydRWT (GAMS)	Actual
Chinaz	21,8	2003	apr	0,4	0,0	4,9
	21,8	2003	May	14,9	13,2	11,9
	21,8	2003	Jun	39,4	41,2	34,7
	21,8	2003	Jue	58,8	50,8	47,0
	21,8	2003	Avg	41,4	23,3	44,2
	21,8	2003	Sep	15,0	9,3	32,4
				169,9	**137,8**	**175,1**



Yangiul	27,8	2003	apr	0,3	0,1	3,6
	27,8	2003	May	13,0	5,6	7,4
	27,8	2003	Jun	51,2	28,6	33,9
	27,8	2003	Jue	75,6	32,7	44,5
	27,8	2003	Avg	56,6	16,7	56,7
	27,8	2003	Sep	22,3	8,7	39,9
				219,0	**92,4**	**186,0**



Rayon	ω	Year	Month	WEAP (CROPWAT)	HydRWT (GAMS)	Actual
Tashkent PZ	**343,8**	**2003**	apr	**6**	**4**	**24**
			May	**213**	**168**	**157**
			Jun	**650**	**653**	**467**
			Jue	**1017**	**894**	**688**
			Avg	**765**	**503**	**690**
			Sep	**282**	**265**	**325**
				2932	**2487**	**2352**