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RIVERTWIN

A regional model for integrated water management in twinned river basins

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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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Contents

1. Introduction

The report builds on results of the research carried out by SIC ICWC according to the work plan stipulated under the Project.

Analysis and assessment of water availability in the basin are based on data collected in the Project DB and were made using the developed water distribution model, which is a component of the integrated model.

The database covers river, distribution and outlet networks of the whole Chirchik-Akhangaran-Keles basin that includes Tashkent province in Uzbekistan, Keles massif in Kazakhstan and Chatkal district in Kyrgyzstan.

The following data were used in drawing up the report:

- from BWO "Syrdarya": data on the structure and characteristics of objects controlled by the Upper-Chirchik Hydroschemes Administration of the BWO (headworks of Big Karakum Main Canal (BKMC), Parkent Canal, Levoberzhni Karasu, Zakh, Khanym), average ten-day and average monthly discharges over the head water intakes controlled by the BWO.

- from the Chirchik-Akhangaran Basin Authority of Irrigation Systems: data on the structure and characteristics of objects controlled by this organization (irrigation systems, hydroschemes, reservoirs in Uzbekistan), on collector-drainage flows in terms of both districts and collectors; for Irrigation Systems: data on water withdrawal per district in Tashkent province, Uzbekistan, per canal, per consumer (irrigated farming, urban and industrial water supply);
- From Aralconsult: data on the structure and characteristics of objects in Keles massif (Kazakhstan), discharges over Zakh, Khanym, Big Karakum Main Canals, data on water withdrawal in Sariagach and Kyzygurt districts in Kazakhstan (Keles massif).

The work was done according to the provisions of the developed Modeling Concept and requirements to the RIVERTWIN Project Database.

2. Summary

Main components of database (fig 2.1)

- surface water block,
- groundwater block,
- agricultural production block,
- climatic block,
- ecological block,
- socio-economic block.

Software: Access XP, ARC GIS, Visual Basic Net.

An information base for modeling a water distribution system in Chirchik-Akhangaran-Keles basin was developed that includes:

- A set of information objects in the database that correspond to water consumption objects in the models
- Structure of the database: tables and links between them
- Populating the DB with information

In the database, a united network of waterways (rivers, canals, escapes, collectors, conduits of water supply system) with regulating and distributing facilities (hydroschemes, reservoirs), objects of water resources use (power plants), consumption (planning zones, point objects of water supply), and control (gauging stations), located on it, were represented. This system is linked to surface water sources (presented as river flows over gauging stations enclosing catchment areas) and groundwater sources (groups of groundwater intakes). A connection was established with GIS layers through a unique object code.

The Database «Water Demand» (Block Agricultural production) is a component of data support for the hydrological model and for modeling of agricultural productivity and regional water demand. Portion of tables in DB includes calculation data.

We developed a program module that simulates both retrospective and prospective water uses per rayon in Tashkent province. For calibration purposes, water use was computed for previous years for which a full set of input data was collected. For forecast simulations, we considered two climate change models (ECHAM and HADCM2) and a set of cropping pattern scenarios for rayons. Then, the program was developed for coupling with the general interface

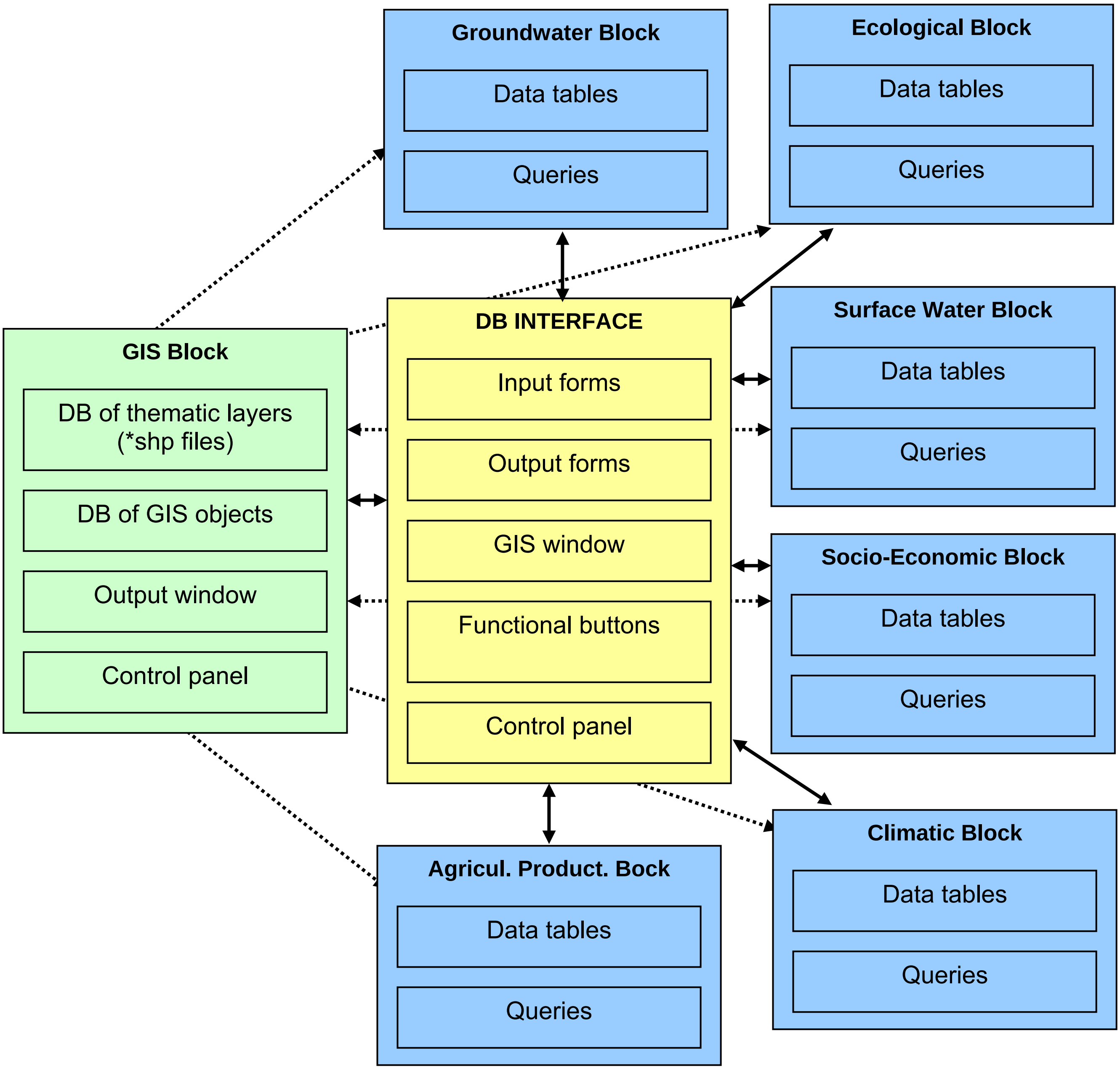


Fig 2.1. Scheme of linkage between the main blocks of DB

Within the framework of the Project, a task was assigned to assess water availability in the Chirchik-Akhangaran-Keles basin based on data from the existing monitoring network (surface and ground water). Work done:

- Information was selected and analyzed from DB (i) on water resources - accounting of flow in existing monitoring network (surface and ground water) in the Chirchik-Akhangaran-Keles basin, (ii) on water consumption and flow utilization (irrigation, water-supply system "Vodokanal", etc.).

- Basin water availability was assessed in context of main sub-basins, rivers (Chirchik, Akhangaran, Keles, Parket sais) in flow formation zones and along the river channels, and aggregated water balance of flow formation and utilization was performed.

Water resources in Chirchik-Akhangaran-Keles area that include natural and return flows are estimated to be 12.4 km^3, of which surface runoff is about 9 % for normal year. Utilizable water resources at the boundaries of districts (water resources minus losses) are estimated as 11.7 km^3, of which about 6.1 km^3 are withdrawn by users (irrigation, system "Vodokanal", industry), while the rest (5.6 km^3) is discharged outside the basin into the Syrdarya river (through the rivers Chirchik, Akhangaran, Keles, canal Bozsu, and collectors) and transferred through Tashcanal to Bekabad district.

3. Database on water resources
3.1. Description

The database on water resources has been designed to store initial information necessary for hydrological model calculations. It is planned to store calculated information in the DB in the future, having prepared appropriate structures for that (for example, design hydrographs derived by HBV according to adopted scenarios). The database contains the following information objects:

- Point objects - gauging stations, river and canal outlets, outlets for industrial and municipal wastewater, head water intakes at canals, hydroschemes, hydro power plants, hermal power plants, reservoirs
- Linear objects – rivers, canals, collectors
- Areal objects - planning zones (districts), flow formation zones (sub-basins).

3.1.1 Surface water

The description of river network rests upon two tables: list of rivers (List_River) and list of river and canal escapes (List_Escape). Rivers as linear objects are described in the list of rivers: code of river, code of escape (to river or canal), code of sub-basin, name.

Reference to river or recipient canal is given in the list of escapes (to river or canal): code of escape, code of recipient, code of object in GIS layer, location (1 – river, 2 – canal, 3 – reservoir, 4- collector), type of discharge source (1- river, 2 – canal), distance point (km).

The list of gauging stations (List_Hydro) contains reference to river or canal, at which gauging stations are located: code of gauging station, code of object in GIS layer, code of canal or river according to location of gauging station, code of gauging station location, code of irrigation zone, distant point (km), catchment area (km2).

In flow use zone, canal and collector networks are connected to the river network. The irrigation network is presented in the DB in three tables: list of water intakes (List_Intake), list of canals (List_Channel) and list of escapes (List_Escape). The latter has already been used in description of the river network. The description of canals as linear objects is given in the list of canals: code of canal, code of water intake, code of escape, code of object in GIS layer, name of canal in Russian, length (km), forced flow capacity of water intake (m3/sec), design flow capacity of water intake (m3/sec), efficiency of main canals (%), efficiency of irrigation system (%), net canal command area (th. ha).

Canal links in irrigation network are described by references to river/canal – source - in the list of water intakes, and to river/canal/collector/reservoir – recipient – in the list of escapes. The description of head water intakes at canals as point objects is given in the list of water intakes: code of water intake, code of water body, code of object in GIS layer, location (1- river, 2 – canal, 3- collector, 4-reservoir, 5 – aquifers), distance point (km).

The description of the list of escapes is given above. Further, the description of point objects is given linking them to river/irrigation/escape networks. The list of hydroschemes (List_HydroEngin): code of hydroscheme, code of river or canal, code of object in GIS layer, location (1- river, 2-canal), name of hydroscheme in Russian, distant point (km).

The list of reservoirs (List_Reservoir): code of reservoir, code of river or canal, location (1- river, 2-canal), code of object in GIS layer, code of weather station, name of reservoir in Russian, maximum capacity (million m3), dead capacity (million m3).

Please complete the units!!

Tables with transient data:

- Monthly discharges per gauging station (Hydro_Volum_Month) - code of gauging station, year, discharge values from January to December. (m3/s)
- Ten-day discharges per gauging station (Hydro_Discharge_Dec) - code of gauging station, year, discharge values from ten-day period 1 to ten-day period 36. (m3/s)
- Average daily discharges per gauging station (Hydro_Discharge_Day) - code of gauging station, year, month, discharge values from day 1 to day 31 of month. (m3/s)
- Monthly volumes of water withdrawal at canal heads (Intake_Volum_Month) - code of water intake, year, values of water withdrawal volumes from January to December. (million m3)
- Ten-day discharges per water intake at canal head (Intake_Discharge_Dec) - code of water intake, year, discharge values from ten-day period 1 to ten-day period 36. (m3/s)
- Monthly volumes of releases from canals and rivers to rivers (Escape_Volum_Month) - code of escape, year, release values from January to December. (million m3)
- Ten-day discharges from canals and rivers to rivers over escapes (Escape_Discharge_Dec) - code of escape, year, discharge values from ten-day period 1 to ten-day period 36. (m3/s)
- Average ten-day inflow to reservoirs (Reservoir_Inflow_Dec) - code of reservoir, year, inflow values from ten-day period 1 to ten-day period 36. (m3/s)
- Average ten-day outflow from reservoirs (Reservoir_Outflow_Dec) - code of reservoir, year, outflow values from ten-day period 1 to ten-day period 36. (million m3)
- Average ten-day reservoir volume values (Reservoir_Volum_Dec) - code of reservoir, year, discharge values from ten-day period 1 to ten-day period 36 (m3/sec).
- Monthly reservoir volume values (Reservoir_Volum_Month) - code of reservoir, year, volume values from January to December (million m3).
- River water resources in the basin (RiverResource_Month) - code of river, year, monthly flow values from January to December (million m3).
- Volumes of water transfer between rivers in the basin (RiverTransfer_Month) - code of transfer, year, monthly flow values from January to December (million m3).

3.1.2 Groundwater

Reference tables:

- The description of groundwater supply objects is given in the list of aquifers (List_Aquifer) - code of basin, code of aquifer, GIS code, name of aquifer in Russian, name of aquifer in English
- The description of objects of water intake from aquifers is given in the list of water intakes from aquifers (List_Intake_Aquifer) - code of aquifer, type of aquifer (1- upper; 2 – lower), code of district (irrigation zones), code of water intake, GIS code, name of water intake in Russian, name of water intake in English. The total explotable storage capacity is 28.45 m^3/s in Chirchik-Akhangaran aquifer. Information on recharge rate is not available since monitoring is not performed.

Tables with transient data:

- Groundwater use (WaterUse) - code of water intake, year, targeted use (1- domestic and drinking; 2 – production and technical; 3 –land irrigation), consumer, average daily discharge, l/sec, salinity, g/l, water composition
- Operational groundwater supplies for intakes from aquifers (WaterV) - code of water intake, operational supplies based on mean daily discharge, l/sec, category, authority confirming groundwater supplies

3.1.3 <u>Return water</u>

The description of collector-drainage network is given in the list of collectors that contains reference to river/canal/collector – recipient: code of collector, code of object in GIS layer, name of collector in Russian, code of river, canal or collector, location (1- river, 2- canal, 3- collector), distant point (km), design normal capacity of water intake (m3/sec), length (km).

Tables with transient data:

- The description of connection between collector-drainage network and irrigation zones is given in the list of points of collector-drainage water discharge into collectors, per district - code of collector-drainage escape, code of object in GIS layer, code of irrigation zone, code of river, canal or collector, location (1- river, 2- canal, 3- collector), name of sewer in Russian, distant point (km).
- Monthly volumes of collector-drainage flows per district, per collector (OverOut_Month) - code of collector-drainage escape, year, code of district, volume values from January to December.
- Monthly volumes of collector-drainage flows in districts (IrrZoneOut_Month) - code of district, year, volume values from January to December

3.2. Database content

According to the above-mentioned structure, DB “Surface Water” was filled with data on the following objects:

- Gauging Stations (GS)
- Head water intakes at canals
- Collector-drainage water discharges
- Canal outflow
- Industrial and municipal sewage

- Reservoirs – inflow, volume, outflow
- Collector-drainage flows per district, per collector
- Water withdrawal from aquifers

4. Database on water demand and consumption
4.1. Description

The database (DB) on water consumption has been designed to store initial information necessary for calculations of water consumption models. It is planned to store calculated information in the DB in the future, having prepared appropriate structures for that. The database contains the following information objects:

- Point objects - water outlets to irrigation zones
- Linear objects – rivers, canals, collectors
- Areal objects - irrigation zones, flow formation zones (sub-basins)

The structure of the database rests on the description of river, irrigation and collector-drainage networks, which is given in the DB on water resources. The description of water supply system objects is given in table "List_WaterChannel": code of object, code of source, type of source, code of city/town (district), type of consumer (1- city/town, 2 – district).

The description of connection between irrigation network and irrigation zones is given in the list of water outlets: code of water outlet, code of planning zone, code of river, canal or collector, location (1 – river, 2- canal, 3 – collector), name of water outlet in Russian, code of object in GIS layer, code of type (1 - irrigation, 2 – non-agricultural water withdrawal), distant point (km).

Tables with transient data:

- Monthly water withdrawal volumes per district (IrrZone_Month) - code of district, year, volume values from January to December.
- Monthly water withdrawal volume per district, per canal (OverFlow_Month) - code of water outlet, year, volume values from January to December.
- Ten-day flow rate per district, per canal (OverFlow_Discharge_Dec) - code of water outlet, year, flow rate from ten-day period 1 to ten-day period 36.
- Average daily flow rate per district, per canal (OverFlow_Discharge_Day) - code of water outlet, year, month, flow rate from day 1 to day 31 of month.
- Flow rate per object of the Water Supply Organization (“Vodokanal”) (Water_ChanDischarge) - code of object, year, Flow rate (m3/sec)

Tashkent city, Chirchik, Angren, Almalyk town and province districts.

Water consumption per power engineering object (thermal power plants) (ThermWaterUse) : code of thermal power plant, year, % of water withdrawal.

Tashkent hydro power plant, Angren thermal power plant, Novo-Angren thermal power plant.
Water consumption of industrial centers (IndustryWaterUse): code of thermal power plant, year, flow rate (m3/sec).

The information objects of Database «Water Demand» (Block Agricultural production) are as follows:

- Uzbekistan– 14 rayons in Tashkent oblast (province) – Akkurgan, Akhangaran, Bostanlyk, Buka, Kuichirchik, Zangiata, Yukorichirchik, Kibrai, Parkent, Pskent, Urtachirchik, Tashkent, Chinaz, Yangiyul
- Kazakhstan – Keles scheme covering 3 rayons in Southern Kazakhstan province: Saryagach, Keles, Kyzygurt
- Kyrgyzstan – Chatkal rayon

DB is a partial data support to modeling of regional water demand. Output tables are as follows:

- *RT_Rayon_Year_WaterNormDec* – ten-day crop water use;
- *RT_Rayon_Year_SpecificWaterNormDec* – ten-day specific crop water use.

Structure of Table *RT_Rayon_Year_WaterNormDec*: rayon code, year, rayon name, weather station name, ten-day period of a year, area, (thousand ha), demand (m3) of the whole rayon, rainfall (m3) for the whole rayon, from groundwater (m3), irrigation (m3) for the whole rayon.

Structure of Table *RT_Rayon_Year_SpecificWaterNormDec*: rayon code, year, rayon name, weather station name, ten-day period of a year, area, (thousand ha), demand (m3) per 1 ha, rainfall (m3) per 1 ha, from groundwater (m3) per 1 ha, irrigation (m3) per 1 ha.

Data presented in these tables were derived from calculations using Penman-Montheit method.

5. Block for calculation of crop water use
5.1 Description
5.1.1 Database
5.1.1.1. Climatic data

In order to calculate evapotranspiration for any day during the growing season, one needs data on weather station location – altitude (height above sea level) (**m**), geographic latitude (^{o} and **sec)** - and also the following meteorological data: mean minimum air temperature (^{o}**C),** mean maximum air temperature (^{o}**C),** mean air temperature (^{o}**C),** rainfall (**mm),** relative air humidity (**%),** wind speed at height of 2 m above the surface (**m/s),** sunshine hours per day **(hour).**

Within the framework of the project, meteorological data were collected from five weather stations in Tashkent province and one weather station in Syrdarya province (Stulina G.V.): Tashkent, Pskem, Dukant, Oigaing, Angren, Syrdarya

Based on historical climatic data and one of the climate change models - ECHAM4 and HadCM2 – climate scenarios are developed for the future. Climatic data in form of the mean long-term monthly values are compiled in the table **BaseClimate** and placed in the main project database. The climatic data were collected for the period from 1980 to 2003.

Command weather station was identified for each rayon in Tashkent province:

Rayon	Weather station
Zangiata	Tashkent
Yukorichirchik	Tashkent
Kibrai	Tashkent
Parkent	Tashkent
Urtachirchik	Tashkent
Tashkent	Tashkent
Yangiyul	Tashkent
Akkurgan	Syrdarya
Buka	Syrdarya
Kuyichirchik	Syrdarya
Pskent	Syrdarya
Chinaz	Syrdarya
Bostanlyk	Dukant
Akhangaran	Angren

5.1.1.2 Crop data

Analysis of data on cropping patterns and crop areas in Tashkent province resulted in identification of the most important, in terms of occupied areas, crops and their collecting in 16 groups: fruits and vine, potato, maize for grain, alfalfa, pastures, winter wheat, spring wheat, beet, cucurbits, kenaf, vegetables, grass, cotton, maize for forage, rice, forest plantations.

Seeding (planting) dates were taken as recommended from reference books (Nerozin S.A.). Data on crop areas were collected partially for the period of 1980 – 2003, partially from 1981 to 2003 (Nerozin S.A., Prikhodko V.) and after processing were compiled in the table **BaseCrop** in DB.

5.1.1.3 Data on irrigated soil

Soil texture in rayons of Tashkent province was identified from soil maps and profiles (Stulina G.V.) by GIS methods (Zherelieva S.). Since soil texture for estimation of groundwater contribution (Kharchenko, Horst M.G.) should correspond to FAO classification, soils were re-classified from Kachinsky form to FAO classification (Stulina G.V.). Percentage composition of irrigated area in terms of soil texture per rayon in Tashkent province is put in the table **BaseSoil** of DB.

5.1.1.4 Data on groundwater level

Data on groundwater level are represented in form of division of rayon's irrigated area into sections by groundwater depth level: 0 – 1; 1 – 1.5; 1.5 – 2; 2 - 2.5; 2.5 – 3; 3 – 5; > 5 m, for the following months 3,4,6,7,9,10 of every year. Information collected in DB (Rysbekov) on annual distribution of rayon areas between groundwater depth ranges has a number of gaps and inaccuracies. Therefore, a procedure was developed for recovery of missing or incorrect data. The recovery proceeds from two assumptions: 1) change in groundwater depth character is so slow from year to year that replacement of missing or incorrect values by the mean long-term ones will have minor impact on groundwater contribution value; 2) distribution of areas by groundwater levels is subject to a certain distribution law (project "Drainage in the Aral Sea basin", Tuchin A.I.) and miss of areas on any level gradation within one year when information on neighboring gradations is available causes mistake. Method for recovery of missing gradations was also suggested by Tuchin A.I. and realized in the program. Partially recovered data on groundwater level are contained in the table **BaseGWT** in DB. Recovery of blank gradations is done during calculation.

5.1.2 Methodology

In order to compute crop water use per rayon in Tashkent province, we used approach described in FAO Irrigation and Drainage Paper № 56 (Crop Evapotranspiration, Guidelines for computing crop water requirements, R.G.Allen, L.S.Pereira, D.Raes, M.Smith, Rome, 1998) which is based on evapotranspiration. Crop water requirements are estimated by balance method as actual evapotranspiration minus effective rainfall and groundwater contribution.

Crop water use is calculate by balance method as

ETirr = ETc – EffRain - ContrGWT

where
ETirr is irrigation water (mm)
ETc is crop water demand (mm) = **ETo** x **Kc**
ETo is reference evapotranspiration (mm)
Kc is crop coefficient (n/d)
EffRain is effective rainfall (mm)
ContrGWT is groundwater contribution (mm)

Crop evapotranspiration

Crop evapotranspiration is related with reference evapotranspiration through crop coefficient:

$$\mathbf{ET_c = K_c\, ET_o}.$$

where $\mathbf{ET_c}$ is crop evapotranspiration
$\mathbf{K_c}$ is crop coefficient
$\mathbf{ET_o}$ is reference evapotranspiration.

Reference evapotranspiration, per se, is a function of altitude, geographical latitude and climatic parameters and is calculated by Penman-Montheit formula:

$$ET_o = \frac{0{,}408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0{,}34 u_2)}$$

where:
$\mathbf{ET_o}$ is reference evapotranspiration [mm day^{-1}];

$\mathbf{R_n}$ is net radiation on crop surface [MJ m^{-2} day^{-1}];
G is density of soil heat flux [MJ m^{-2} day^{-1}];
T is mean daily air temperature at a height of 2 m [^{0}C];
$\mathbf{u_2}$ is wind speed at a height of 2 m [m s^{-1}];
$\mathbf{e_s}$ is saturated vapor pressure [kPa];
$\mathbf{e_a}$ is actual pressure [kPa];
$\mathbf{(e_s - e_a)}$ is deficit of saturated vapor pressure [kPa];
Δ is inclination of vapor pressure curve [kPa $^0C^{-1}$];
γ is psychometric constant [kPa $^0C^{-1}$].

Input data for calculation of reference evapotranspiration in given point include:

1. Altitude above the sea level
2. Latitude, North

Daily climatic data:

1. Mean daily maximum air temperature (at height of weather box) (^oC)
2. Mean daily minimum air temperature (^oC)
3. Wind speed at vane height of 2 m (m/s)
4. Relative air humidity (%)
5. Sunshine hours in given point (hour)
6. Daily rainfall (mm)

Since within the framework of the project climatic data were collected only on monthly basis, linear interpolation of all climatic parameters was done to get daily data. Sunshine hours and latitude (North) are used for calculation of radiation flux; rainfall is needed only for calculation of its effective share. A function subprogram was developed in VBA for calculation of reference evapotranspiration and placed in one of DB modules such as **RT_ReqWat**. All data needed for ETo are also collected in this DB.

There is no common generally recognized method for calculation of effective rainfall since for different climatic zones, a share of rainfall absorbed by the soil may vary depending on amount of rainfall over a period of time, rainfall intensity, soil filtration characteristics, preliminary saturation of soil with water, etc. Program CROPWAT includes four algorithms for estimation of effective rainfall:

1. Fixed share of rainfall
2. Secure share of rainfall
3. Empirically estimated share of rainfall
   EffRain = K1*TotRain – 5 at TotRain < 50 mm/month
   EffRain = K2*TotRain – 15 at TotRain > 50 mm/month
   Here K1 and K2 are empirically chosen coefficients
   TotRain is total rainfall per month
4. USA Soil Conservation Service Method:
   EffRain = TotRain / 125 * (125 - 0.2 * TotRain) ... (TotRain < 250 mm)
   EffRain = 125 + 0.1 * TotRain ... (TotRain > 250 mm)

By recommendation of European Union TACIS Program's expert Michael Armitaj, who supervised WUFMAS Project, the more acceptable method is the fourth one. It was implemented in given project. Then, in order to shift to daily rainfall, the obtained value of effective rainfall was divided by number of days in a month.

Value of groundwater contribution was calculated by Kharchenko's formula (adjusted by Horst M.G. by choosing coefficients a and b in formula for FAO soil texture classification)

Short	1	112	TASM	RainFilt	a	b
C	Clay	Глина	210	12	0.8	1.16
CL	ClayLoam	Глинистый суглинок	180	192	0.94	1.15
L	Loam	Суглинок	155	240	1.03	1.17
LS	LoamySand	Суглинок песчаный	100	300	1.03	1.17
S	Sand	Песок	80	300	1.42	1.5
SCL	SandyClayLoam	Опесчаненный глинистый суглинок	190	240	1.03	1.17
SL	SandyLoam	Опесчаненный суглинок	145	300	1.19	1.23
Z	Silt	Пыль	160	144	0.9	1.15
ZC	Silty Clay	Пылеватая глина	170	48	0.8	1.06
ZCL	Silty Clay Loam	Пылеватый глинистый суглинок	160	120	0.94	1.15
ZL	Silty Loam	Пылеватый суглинок	160	192	1.03	1.17

$$\mathbf{Dop = a*ETo/exp(b*(abs(H - h)))}$$

where:

Dop is groundwater contribution in mm
a is soil-related coefficient
ETo is reference evapotranspiration
b is soil-related coefficient
H is root system depth, m at (**H – h**) < 0.6, otherwise **H** = 0
h is groundwater level (m)

If value of groundwater contribution is larger than needed by crop, this value is equaled to water demand.

Groundwater contribution values as calculated by G.Hasanhanova under Hasconing project is shown below. These results satisfactorily meet those calculated by Kharchenko's formula.

5.2 Calculations

Since there were only soil maps and groundwater level and crop area maps were not available, the following approach was used for solving the task:

1. Percentage composition of rayon irrigation area regarding soil types was taken as the basis (initial blocks).
2. Distribution of crop area in each soil type is similar to cropping patterns in rayon, i.e. initial blocks are divided into sections proportionally to percentage shares of crops in rayon (**working contours**). Such working contour has one soil type and one crop. Number of working contours per rayon varies within 45 - 75.
3. Reference evapotranspiration is calculated for each rayon for each day in a year, whereupon current crop coefficients are estimated and actual evapotranspiration or water use of working irrigation contours is calculated using the coefficients.
4. Then, effective rainfall on calculation day is subtracted from the water use value.
5. Daily rooting depth is estimated on the basis of the following factors: i) rooting depth extends only in the first two plant growth stages (Initial and Develoment); ii) the rooting depth is constant in the third (Middle) and the fourth (Late) stages; iii) stage

duration and seeding dates are known. Then, daily rooting depth is calculated by linear interpolation.

Duration of growth stages and mean depths of root zone for most crops cultivated in Central Asia were given in materials attached to CROPWAT model, which was granted to SANIIRI Institute under WUFMAS project by M.Armitage.

6. Distribution of irrigation contour area between groundwater depth intervals is estimated for each day in a year.
7. Then, groundwater contribution is calculated for every working contour and subtracted from water use value. The obtained results are summed up by all working irrigation contours and saved in DB.
8. Daily, ten-day or monthly final results (according to settings in interface form) are grouped from daily results and inputted into SIC's DB.
9. The program generates text files in GAMS input format for use of calculation results in other models of RIVERTWIN project under general interface.

According to the project, crop water use should be calculated for every rayon in Tashkent province for series of years (from 1980 to 2003). We succeeded in collecting full set of input data only since 1981. The calculation was made for all plain rayons in Tashkent province (flow distribution zone) on ten-day basis for the years 1980, 1985, 1990, 1995, 2000, 2001, 2002, 2003. Calculation results are placed in the table **WaterDec** in DB. Graphical results of comparison between simulation and actual data and table of correlation coefficients are given in the Annex.

For forecast calculations, one needs to set the following data for the future:

1. Climatic data. Such data are generated by the program as the mean monthly long-term data corrected according to one of two climate change models ECHAM4 and HadCM2.
2. Groundwater level dynamics – distribution of irrigation area between groundwater gradations for 10th month in a year preceding to calculation year, 3, 4,6,7,9,10 months in calculation year and 3rd month in a year following the calculation year. Data of the year 2003 are taken for the future.
3. Crop areas in form of percent share of each crop area. Development and servicing of agricultural scenarios is executed in special form called at stage of preparation.

The program was agreed with the authors of interacting blocks (Sorokin A., Tuchin A.I.) and marked inaccuracies were corrected. Besides, beyond the Terms of Reference, block for development of future agricultural scenarios was created. At present, the program is being connected to the general interface (Sorokin D, Shahov V.)

6. Assessment and prediction of water availability

6.1. Chirchik river basin

The key constituents of the Chirchik river that largely form its natural water availability are the rivers Pskem and Chatkal. These rivers differ on water content and regime.

Table 6.1. Area, mean weighted elevation of catchment, maximum and minimum discharges of rivers Pskem and Chatkal near river mouth

River	Catchment area, km^3	Catchment elevation,	Mean discharge,	Maximum discharge, m^3/s	Minimum discharge, m^3/s

		m	m^3/s		
Pskem	2840	2645	82	118	56
Chatkal	6870	2605	124	180	73
Total	9710		206	298	129

Lower weighted mean elevation of Chatkal catchment as compared to that of Pskem catchment and smaller share of elevations of more than 3500 m (9 % against 14 %) make for smaller contribution from high-mountain snow and glaciers to Chatkal river.

The largest tributary, in terms of water content, of the Chirchik river is the Ugam river, which is low elevated and therefore has earlier flow concentration.

Table 6.2. Area, mean weighted elevation of catchment, and long-term mean discharge of Ugam river

River	Catchment area, km^3	Catchment elevation, m	Mean discharge, m^3/s
Ugam	889	1941	21

Regarding water content and regime, the Chirchik river may be sub-divided into two sections:

- from Charvak reservoir to Gazalkent dam,
- from Gazalkent dam to the mouth.

Water content and flow regime in the first section is formed by natural flow of the key Chirchik river's constituents flowing into Charvak reservoir (rivers Chatkal, Pskem, Koksu, Nouvalisai, Yangikurgan, Chimgansai), by Chirchik tributaries at this section (rivers Ugam and Karankulsai) and depends on its regulation by coordinated Chirchik hydroelectric system– Charvak, Khodjikent, Gazarkent HEPS's.

Water content and flow regime in the second section is formed by small inflow from natural watercourses (rivers Aksagata and Aktash), as well as through inflow of waste water (from canals), return collector-drainage water and sewage water and discharge of groundwater (mainly, on the left-bank). In this section, water is diverted for irrigation, energy and domestic water-supply.

Chirchik river water flows into the Syrdarya river via its channel and Bozsu canal and is transferred to shallow Akhangaran and Keles river basins.

Natural runoff of the Chirchik river and all its tributaries is estimated to be 7.4 km^3 for normal year. Together with return flow and losses, the basin's utilizable surface water resources are 8.5 km^3 at district boundaries (current level of water consumption).

In 2004, for Chirchik aquifer the approved utilizable resource amounted to 0.59 km^3/year that corresponds to mean daily discharge of 18.8 m^3/s. Actual abstraction for 1990…2004 is 2…2.5 times less than approved resource.

6.2. Akhangaran river basin

Natural water availability in Akhangaran basin is assessed on the basis of inflow to Akhangaran reservoir and of lateral inflow downstream of the reservoir – by rivers flowing into the Akhangaran river from its left and right banks.

Table 6.3. Area, mean weighted elevation of catchment, and long-term mean discharge of the Akhangaran river (based on inflow to Akhangaran reservoir)

River	Catchment area, km^3	Catchment elevation, m	Mean discharge, m^3/s
Akhangaran	7710	2284	23

Natural runoff of the Akhangaran river at the outlet from mountains is characterized by coefficients of variation at 0.35 and of skewness at 1.12. The runoff reaches 1.3 km^3 in high-water years (5% flow probability) and decreases to 0.35 km^3 in low-water years (90% flow probability).

Where the river receives water from lateral tributaries, downstream of Shavazsai river (section line at Sharkhi hydrostructure), statistical indicators of flow variability slightly increase: coefficient of variation is 0.45, while coefficient of skewness is 1.4. At the same time, natural river runoff increases to 40 m^3/s.

Together with return flow and losses in the river, the utilizable surface water resources in the Akhangara basin are estimated to be 1.9 km^3 for current level of water consumption and for normal year.

In 2004, for Akhangaran aquifer the approved utilizable resource amounted to 0.4 km^3/year that corresponds to mean daily discharge of 11.7 m^3/s. Actual abstraction for 1990…2004 is 2 times less than approved resource.

6.3. Keles river basin

The Keles river is formed by junction of the rivers Dzhuzumduk and Dzhegirgen and has lower catchment elevation and lower water content as compared to main tributaries of the rivers Chirchik and Akhangaran. The Keles river reaches Syrdarya through flow transfer from the Chirchik basin.

Table 6.4. Area, mean weighted elevation of catchment, and long-term mean discharge of Keles river - Romadan station (Gorniy village)

River	Catchment area, km^3	Catchment elevation, m	Mean discharge, m^3/s
Keles	2471	933	6

6.4. Interfluvial rivers

Chirchik-Akhangaran-Keles basin comprises a number of local surface water sources, such as sai (Parkentsai, Kyzylsai, etc.) with temporary flow.

These resources are estimated at 0.1…0.2 km^3, a portion of which is diverted by water users, while the rest is discharged into Left-bank Karasu.

6.5. Water balance

The aggregative annual water balance in Chirchik-Akhangaran-Keles basin for current level of water consumption and for normal year is shown in the Table below. The balance is made up from actual data taken from the DB and checked (simulated) using GAMS-model of basin water distribution.

Table 6.5 Water balance of the basin

№	Balance items	Amount, km^3/year
1	**Surface water resources**	**11.7**
1.1	**Natural river runoff**	**9.2**
1.1.1	Chirchik river basin	7.4
1.1.1.1	Inflow to Charvak reservoir	6.4
1.1.1.2	Ugam river runoff	0.7
1.1.1.3	Other lateral tributaries	0.3
1.1.2	Akhangaran river basin	1.4
1.1.2.1	Inflow to Akhangaran reservoir	0.8
1.1.2.2	Lateral tributaries	0.6
1.1.3	Sais of Chirchik and Akhangaran interstream area	0.2
1.1.4	Keles river	0.2
1.2	**Return flow (excluding discharge from diversion canals)**	**2.5**
1.2.1	Chirchik river	0.9
1.2.2	Akhangaran river	0.8
1.2.3	Keles river (excluding discharge from Zakh canal)	0.0
1.2.4	Chirchik river's right-bank canal system	0.3
1.2.5	Chirchik river's left-bank canal system	0.1
1.2.6	Syrdarya river's collectors	0.4
2	**Utilized groundwater flow**	**0.5**
2.1	Chirchik river basin	0.3
2.2	Akhangaran river basin	0.2
3	**Total: surface and groundwater flow (1+2)**	**12.2**
4	**Flow losses before boundaries of districts (planning zones)**	**0.5**
4.1	Chirchik river	- 0.1
4.2	Akhangaran river	0.2
4.3	Chirchik river's right-bank canal system	0.1
4.4	Chirchik river's left-bank canal system	0.3
5	**Total: utilizable resources (3-5)**	**11.7**
6	**Water withdrawal (excluding delivery for derivation and discharge into Keles river from Zakh canal)**	**6.1**
6.1	Chirchik river basin	3.6
6.1.1	Chirchik river's right-bank canal system (Uzbekistan)	2.0
6.1.2	Chirchik river's right-bank canal system (Kazakhstan)	0.5
6.1.3	Chirchik river's left-bank canal system	1.1
6.2	Akhangaran river basin	1.4
6.3	Keles river (Kazakhstan)	0.5
6.4	Sais of Chirchik and Akhangaran interstream area	0.1
6.5	Groundwater	0.5
7	**Discharge outside the basin**	**5.6**

7.1	Chirchik river - Syrdarya	2.5
7.2	Akhangaran river - Syrdarya	1.1
7.3	Keles river - Syrdarya	0.1
7.4	Bozsu - Syrdarya	1.3
7.5	Gedzhigen – Syrdarya	0.1
7.6	Collector flow – Syrdarya	0.4
7.7	Tashcanal - Bekabad	0.1
8	**Total: flow utilization, excluding losses (6+7)**	**11.7**
9	**Balace: Resource – Utilization (5-8)**	**0**

Given balance includes amount of groundwater abstracted from Chirchik and Akhangaran aquifers and currently used for domestic water supply and industrial purposes. Withdrawal is 4…5.5 km^3 and accounts for about 45…60 % of approved storage.

Water withdrawn from surface and underground sources in an amount of 6.1 km^3 (item 6) is used by "Vodocanal" system – about 0.9 km^3 in Tashkent city and 0.2 km^3 in the province – and is delivered for irrigated agriculture and other users in planning zones - 5.0 km^3, of which not more than 3.5…4.0 km^3 reach farm boundaries due to water losses. Flow transfer from the Chirchik basin through Zakh canal to the Keles river is approximately 0.5 km^3 .

Additional diversion flow delivered from the Chirchik river to Diversion canal for energy needs, besides needs of irrigated agriculture, "Vodocanal" system, and other users, is estimated to be 2.5…3.0 km^3, larger portion of which (about 80%) is discharged into the Chirchik river (diversion discharge), and the rest flows through Bozsu into Syrdarya river while supporting Bozsu cascade of HEPS.

6.6. Water accounting and prediction of water availability

Water accounting (quantity, quality) in the basin is undertaken by several institutions and services, major of which are:

- Central meteorological services (Glavgidromet's) of basin countries – control throughout the river network,
- BWO "Syrdarya" – control in 37 water accounting points of Upper Chirchik waterworks administration (discharge from dams, withdrawals, including delivery of Chirchik basin flow to Kazakhstan),
- Chirchik-Akhangaran basin administration of irrigation systems – control over intakes, waterworks facility and reservoir operation regimes,
- "Vodocanal" – control over withdrawal of surface and ground waters for urban and district water supply and of return flow from domestic sector,
- Hydrological field office at the Committee for Geology – control over groundwater and their utilization,
- Hydrological and land reclamation field office at the Ministry of Agriculture and Water Resources – control over collector flow,
- Analytical monitoring laboratory at the State Committee for Nature Conservation – control over industrial wastes,
- Sanitary epidemiological service at the Ministry of Health – control over drinking water supply.

Water resources monitoring in the basin is undertaken by a range of research institutions and laboratories, including Intersectoral Water Resources Laboratory at the National University of Uzbekistan (IWRL NUU). The monitoring network of IWRL NUU [2] consists of more than 500 water-points (wells, gauging and hydrochemical stations).

Surface runoff forecasts are made by National Glavgidromet's (preliminary and adjusted forecasts for growing and non-growing seasons, as well as one month in advance). They publish hydrological bulletins that contain information on actual water balances of reservoirs and rivers and hydrological surveys on flow of main rivers.

Higher flow forecast reliability is typical for the Akhangaran river (Angren), i.e. river with relatively simple hydrological regime resulting from snow-rain feeding and comparatively low elevation of catchment.

According to SANIGMI's data [3], accuracy of monthly forecast with a lead time of 6 months for the river (Irtash station) is 80 %.

Complex relief and presence of circulation effects in precipitation distribution for the rivers Chatkal and Pskem, as well as substantial contribution from glaciers to Pskem lower accuracy of forecasts for these rivers: Chatkal (Khudaidodsai station) – up to 70 %, Pskem (Mullala station) – up to 57 %.

In Tashkent province as a whole and the city of Tashkent, water supply of non-irrigation users is satisfactory.

The present level of water supply in the city of Tashkent exceeds existing water consumption norms (Table 6.6). Efficiency of the city's water-supply network is low - 0,65-0,75.

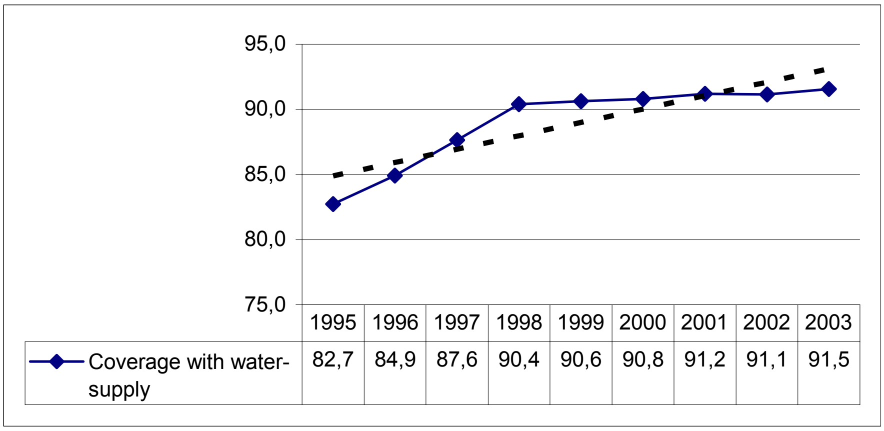
Table 6.6. Actual water consumption in the city of Tashkent

Indicator	Year				
	1965	1975	1980	1998	2004
City population, million	1,174	1,595	1,821	2,130	2,5
Water discharge in city water-pipe (municipal and household needs), million m3/year	101,0	323,0	452,0	687,0	749,0
Actual conpsumtion (l/day per capta)	236				299
Unit water consumption according to standards (SNiP), l/day per capita	250,0	250,0	250,0	330,0	330

Water consumption situation is different in Tashkent province. Average estimates of unit water consumption are 290 l/day/capita for urban areas and 155 l/day/capita for rural areas.

As a whole, coverage with water-supply was 91,5 % in Tashkent province in 2003 (see Figure). Practically, coverage with water-supply ranges from 98,4 to 99,2 % in all cities (except for Angren city – 93,7 %), while this figure is much lower in districts. Average coverage is 88,9 %. Complex situation is in Akhangaran and Buka districts (74,4 % and 76,2 %, respectively).

Fig 6.1. Coverage with water-supply in Tashkent province, %



In the city of Tashkent and in the province, the total industrial water use is estimated at: 407.5 Mm3 – 1985; 302.4 Mm3 – 1995; and, recent years 218.8 Mm3 - 2000; 216.4 Mm3 – 2001; 192.6 Mm3 – 2002; 280.1 Mm3 – 2003; 300.6 Mm3 - 2004.

Water use in energy sector has been stable for many years and is characterized by the following figure (Table 6.7).

Table 6.7. Water use in energy sector

	Year	Water withdrawal, thousand m^3/year	Water disposal, thousand m^3/year
Tashkent city Tashkent heat station	1999	28420,1	6714,2
	2004	35263	7367,2
Tashteplocentral (district heating plant)	1999	128354	13162
	2004	1868000	40307
Total:	1999	156774,1	19876,2
	2015	191206	41687,2
Tashkent province Tashkent state district power plant	1999	1506165	1502143
	2004	1833066	1826689
Angren state district power plant	1999	99501	84834
	2004	142000	124700
Novo-Angren state district power plant	1999	55385	10220
	2004	59840	10220
Total	1999	1661051	1597197
	2004	2034906	1961609

The following picture is seen in irrigation (Table 6.8).

Table 6.8. Comparison of estimated and actual water use – field level (Uzbekistan part)

Year	Estimated withdrawal, m3/ha	Actual withdrawal, m3/ha	Excess (+), shortage (-): %	Irrigated area (net) thousand ha
1995	4908	5914	+ 17	350.9
2000	5114	5539	+ 8	347.2
2001	5176	4788	- 8	345.7
2002	4469	4137	- 8	344.3
2003	4319	4447	+ 3	343.8

Requirements were calculated by CROPWAT model (water use calculation block). Actual withdrawal is taken from monthly data stored in DB.

In Tashkent province, higher irrigation water shortage is experienced in summer months July and August.

7. Conclusions

Work done by us resulted in the following achievements described in the report:

- Developed DB (water resources, demand and consumption)
- Developed "Block for calculation of crop water use", which includes DB (climatic data, crop data, data on irrigated soil, data on groundwater level)
- Performed assessment and prediction of water availability (Chirchik river basin, Akhangaran river basin, Keles river basin, water balance, water accounting and prediction of water availability).

Analysis and assessment of water availability in the basin were made by using the data collected in DB and the developed models included in the integrated model:

- REQWAT – block for calculation of crop water use (Solodky G.),
- HydRWT - water distribution model (Sorokin A., Sorokin D.), which includes elements from WEAP concept and is based on GAMS system.

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The identified, from analysis, minor basin water imbalances are explained, mainly, by impossibility to consider fully all characteristics of flow distribution zone (unaccounted losses and inflows in river network and in canals). While flow is concentrated in major watercourses in flow formation zone (and this is successfully registered by existing gauging stations), as to the distribution zone, flow is diverted from the watercourses and partially returned back after water use and utilization, with losses and flow seepage (here existing monitoring system covers only main courses of water distribution and removal).

This work allowed us to start integrated testing of the whole set of models, with linkage of all streamflows in the basin and to begin model adjustments for future scenario simulations.

References

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