

ARAL SEA BASIN MANAGEMENT MODEL (ASBmm)

GUIDING MANUAL FOR PROGRAMMER

The screenshot displays the ASBmm website interface. At the top left is the ASBmm logo. To the right, there are links for 'Go to the interface' and 'Eng'. Below the logo is a horizontal navigation menu with items: HOME, PROJECT DESCRIPTION, HELP, NEWS, HISTORY, FAQ, DEVELOPERS, FORUM, and 'Eng / Eng'. The main content area features a heading 'ASBmm – integrated model for assessment of aral sea basin development scenarios' followed by a brief description of the model's scope. Below this, there are three feature highlights: 'Authorization' (with a key icon), 'Navigation system' (with a ship's wheel icon), and 'Long-term forecasts' (with a binoculars icon). A world map highlights the 'Aral Sea Basin' region. On the right side, there is a 'See also' section with two links dated 28 November 2014 and 1 November 2013. At the bottom of the screenshot, there is a copyright notice: '© ASBmm 2010-2014. Users Inquiries / Feedback'.

UNESCO-IHE
Institute for Water Education



August 2014

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1.Introduction

In this context, if you are a journalist, student or a novice in hydrology, hydraulic engineering or energy and you would like to get more knowledge about characteristics, issues and prospects of developments in the Aral Sea basin, ASBmm will serve you.

In addition, ASBmm is a helpful tool if you are a professional in the area of water and energy resources management and you are interested in assessment of alternative water development scenarios in riparian countries of the Aral Sea basin, taking into account socio-economic, environmental, energy and climatic factors, optimization and trade-off solutions.

1.1 What is ASBmm?

The ASBmm Version, which is available on-line on <http://www.asbmm.uz/>, was developed jointly by IHE-UNESCO and SIC ICWC. The main objective is to develop an Internet-based platform in support for regional dialogues and desk-top studies in Central Asia, ensure free access to integrated analysis of the Aral Sea basin development scenarios.

The set of models is designed for those working in the water sector, agriculture, environmental and governmental institutions and dealing with prospective planning and development strategy building. By using this set of models, the user can: get assessments of the proposed solution and project options depending on availability of water, land and other natural resources; see consequences from these proposed options for social, ecological, and economic conditions of particular zones and countries; and compare the proposed solutions and projects with sustainable development indicators. For transboundary water projects the models make it possible to assess an impact of actions undertaken in one country on water availability and environment in neighboring countries and further may serve as a tool for coordination of mutually acceptable decisions.

The models solve practical tasks and demonstrate advantages of an integrated approach since they consider in their structure the main characteristics of integrated management. The primary objective of integrated management is to coordinate elements, levels, and sectors of water use in a certain order, while assigning common aims and criteria (social, ecological, economical). As a result, a consensus should be reached for meeting both national and regional interests. An important element of such consensus is maintaining balance between water supply and water demand of economic sectors and ecosystems at various hierarchical levels and for different periods of time.

The set of models was designed to answer the “what if” questions. How much water the countries would demand in the future if they develop exclusively on the basis of their own potentials and capacities? And what if the countries are integrated into a single economic space, assuming specialization (in food production, energy generation, etc.) and coordination of water management in order to achieve regional well-being and security?

So that the models “could answer” such questions, they have the feature of economic analysis. Moreover, there is an assumed relationship between territorial and basin management levels. It is not effective to simulate only a river channel without a link to irrigated lands (planning zones). And vice versa, the solutions that are made at territorial level should be surely checked at basin level, with account of regional restrictions and requirements, mainly environmental ones.

The built-in socio-economic block and indicators showing dynamics of certain planning zones offer new features, such as assessment of country economic development options, demographic situation, and investment policies, identification of the needs of economic sectors, and analysis of the future in terms of sustainable development. Every state in the region has its own national interests and issues regarding water resources management. However, there are challenges that are key and common for most of the states. Those include avoidance of critical situations that could be caused by natural factors (drought) and ineffective management. The range of criteria applied in the models allows finding trade-offs that exclude, for example, conflicts between irrigation and hydropower. Potential effects and damages in economic sectors and relevant compensations can be estimated as well.

2. Models inside the complex

Integrated ASBmm model is a software product consisting of several information modules and computer programs:

- ~ Socio-economic model (calculate sector-specific indicators),
- ~ Model for water allocation and flow regulation by reservoirs with hydropower (water and energy balances, etc.),
- ~ Planning zone model (calculates agricultural production, water supply and water balance of irrigated land),
- ~ Database,
- ~ Control routine,
- ~ User WEB-interface.

Scheme of interactions between different elements of ASBmm complex see Fig.1.

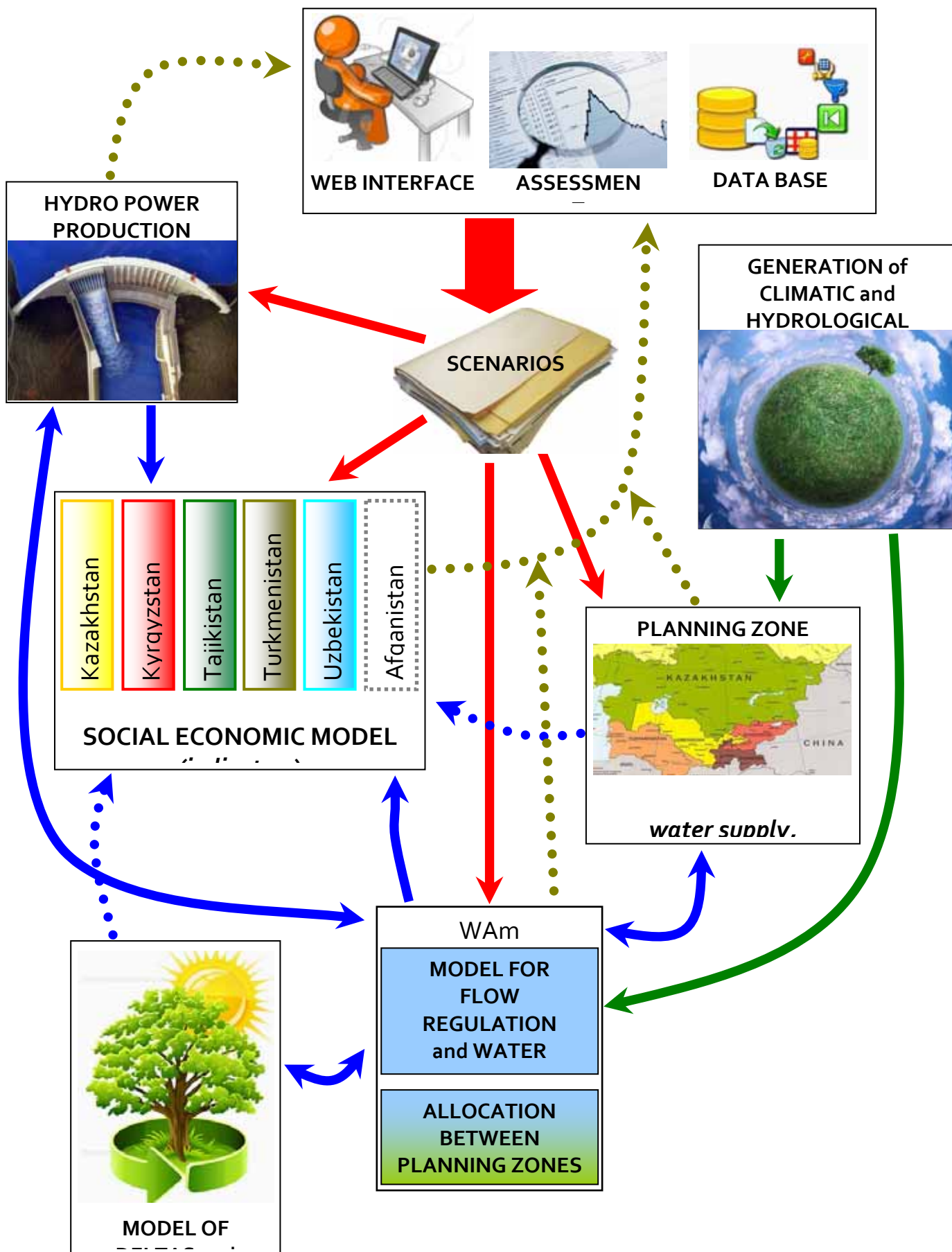
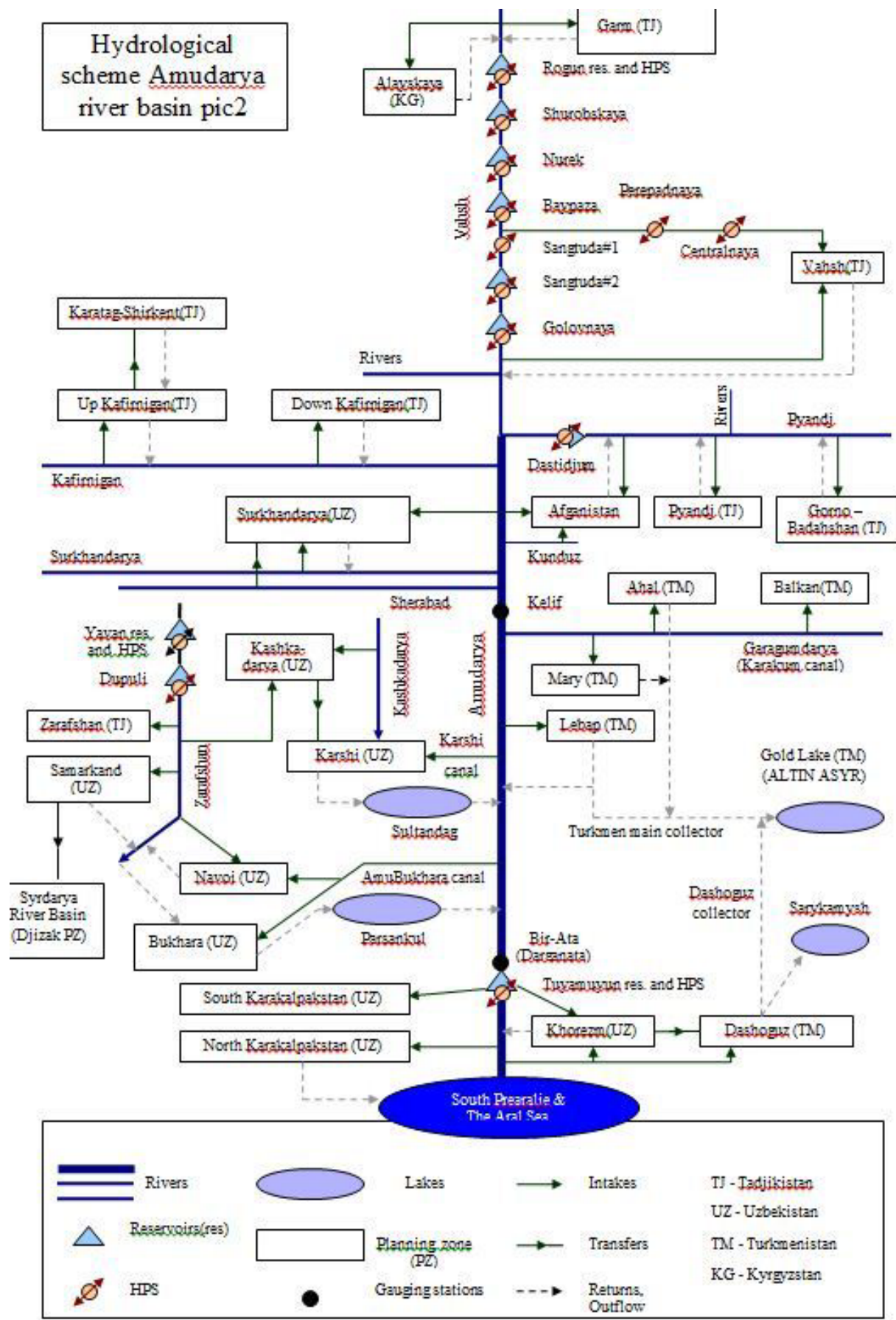


Figure 1. Principal scheme of the ASBmm complex

Hydrological scheme Amudarya river basin pic2



Hydrological scheme of Syrdarya river basin (ASBmm)pic3

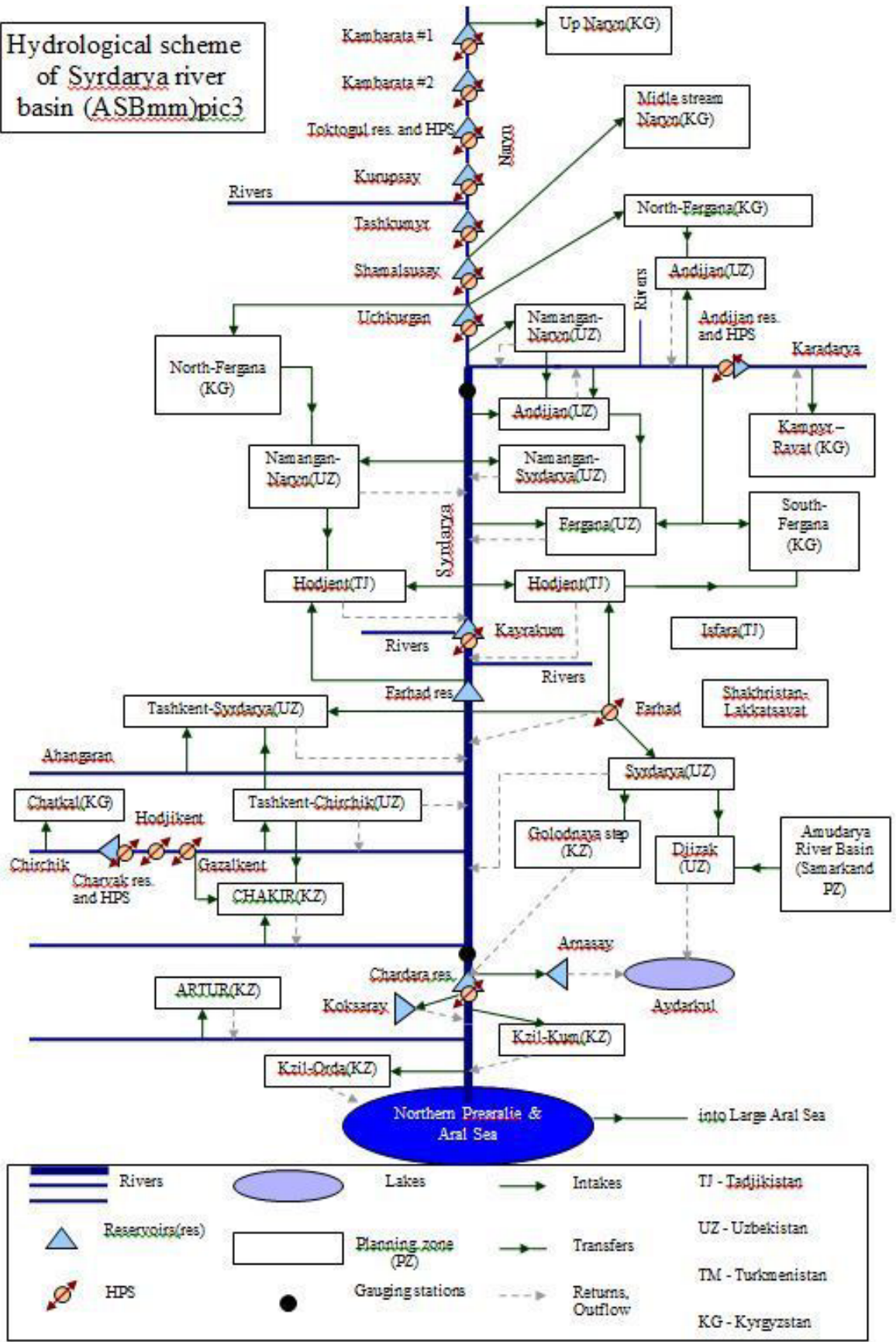


Fig. 2 and 3. Morphological schemes of both river basins

2.1 The Water Allocation Model (WAM).

2.1.1 Model description

The model solves the following main tasks:

- Simulation of natural inflow to boundaries of watershed;
- River flow regulation by reservoir hydro systems – two options of searching operation regimes:
 - Optimization on the base of accepted by users criteria,
 - Simulation of the strictly definite regime;
- Simulation and allocation of regulated surface water resources among states, PZs (including Prearalie), and river reaches using criteria (target functions) – given task is solved jointly with the flow regulation task,
- Assessment of HEPS operation regimes (electricity generation) – given task is solved using the results of the flow regulation task,
- Assessment of water use by channel balances – given task is solved using the results of the water allocation task.
- Assessment of degree satisfaction of environment flow.

Variables

The variables included in the water allocation model are classified by blocks:

- reservoirs – in connection with distribution network,
- distribution network – river, irrigation network in connection with PZ through water diversion and return flow (for a conditional balancing site),
- HEPS – in connection with reservoir,
- lakes – in connection with the distribution network.

List of variables allocated in chapter 5.2.

2.1.1.1 Flow regulation model

The WAM should be based on the proper assessment inflow to upper watershed reservoirs where supposed hydrological flow will be untouched by anthropogenic impact. This assessment could be done by specific models that estimated predicted row of rivers' discharges based on the forecast of precipitation, change of snow reserves and dynamic of snow and glaciers' melting as was done in Rivertwin project for Chakir sub-basin. Another method suppose to use proper real data of dynamic hydrograph of discharges with correlation on the predicted by Hydromet climate changes and its impact on the weather (temperature, humidity of air, precipitation and so) vis a vis rivers' flow. Present option of WAM use last approach on the base of preliminary investigation, result of which will be done in chapter presented to building of climatic scenarios.

The simulated system is that of channels of the main rivers divided into balancing sites, including related lakes, reservoirs, HEPSs, planning zones that are interlinked through diversions and return water discharges. The river system is represented using the method of graphs. The river system is divided into simulated reaches and sites, reservoirs, and lakes, as well as diversions into canals, drainage collectors that are simulated through a grid of arcs and nodes.

Graph $G(J,I)$ is specified as two sets: $J=\{1, \dots, j\}$ - a set of nodes, and $I=\{1, \dots, i\}$ - a set of arcs. Each arc i is characterized by a pair of nodes (j,k) : the starting node j and the end node k , where $j \in J, k \in J, i \in I$.

The model uses the equation of conservation of water mass. The equation is solved for each node for a fixed time step $t \in \{0:T\}$ over the period of T (step – month, period – 300 months or 25 years, the start of simulation – October 2010, the end of simulation – September 2035).

$$\frac{dW_j}{dt} = \sum_{(k,j) \in I_j^+} Q_{k,j} - \sum_{(j,k) \in I_j^-} Q_{j,k} \quad (1)$$

This equation reflected all sources to water income in the first part (natural and regulated flow, return flow from canals, collector-drainage system, precipitation and underground flow) and all water delivery and losses in second part of equation (infiltration, evaporation, any release) .

The problem is to search such a control $W_u(t)^*$, $t \in \{0:T\}$, which meets a criterion of system management quality and the boundary conditions. Different conditions can be chosen as the criterion, for example, the maximum annual cumulative net profit from water use in all PZs or in all PZs belonging to one state with account changes of benefits for other states touched by proposed actions:

$$z \quad T \\ \sum_1 [P z * \int_0^T Q_{j,z} dt] \rightarrow \max \quad (2)$$

The main boundary conditions are

$$\max \quad \min \\ Q_{j,k} \geq Q_{j,k} \geq Q_{j,k} \quad (3)$$

$$\max \quad \min \\ W_u \geq W(t)_u \geq W_u \quad (4)$$

where:

W_j is water volume in j -node (m^3), $Q_{j,k}$ is discharge between j and k (m^3/s); $Q_{k,j}$ is discharge between k and j (m^3/s); $Q_{j,z}$ is discharge between j and z (m^3/s); Q_z is needed inflow to z -node (m^3/s); $z \in J$ is node of water use (PZ), $z \in Z$; Z is quantity of PZs; W_u is water volume in u -node (m^3), $u \in J$ is node of management (reservoir), $u \in U$; U is quantity of management nodes, I_j^+, I_j^- is set of arcs entering node j and exiting node j , respectively; P_z is irrigation water productivity ($\$/m^3$), t is current time; 0 and T are a start and end time of the process.

2.1.1.2 Water balance model

Reservoir's water balance for the time interval $\Delta t = t - (t-1)$, which equals 1 month has the following form:

$$W_R(\Delta t) + W_{CR}(\Delta t) - W_{IR}(\Delta t) - W_{RR}(\Delta t) - W_{ER}(\Delta t) + W_{GR}(\Delta t) - W_{FR}(\Delta t) = V_R(t) - V_R(t-1) \quad (5)$$

Starting condition

$$V_R(t=0) = V_{R0} \quad (6)$$

Evaporation losses are calculated as

$$W_{ER}(\Delta t) = 0,5 * E * [F_R(t-1) + F_R(t)] \quad (7)$$

The area is determined by the following function

$$F_R(t) = f(V_R(t)) \quad (8)$$

Lake's water balance

$$W_L(\Delta t) + W_{CL}(\Delta t) - W_{EL}(\Delta t) - W_{LL}(\Delta t) + W_{GL}(\Delta t) - W_{FL}(\Delta t) = V_L(t) - V_L(t-1) \quad (9)$$

Starting condition

$$V_L(t=0) = V_{L0} \quad (10)$$

Evaporation losses are calculated as

$$W_{EL}(\Delta t) = 0,5 * E * [F_L(t-1) + F_L(t)] \quad (11)$$

The area is determined by the following function

$$F_L(t) = f(V_L(t)) \quad (12)$$

River reach's water balance

$$W(\Delta t) + W_{CD}(\Delta t) + W_C(\Delta t) - W_i(\Delta t) - W_{out}(\Delta t) - W_{LOS}(\Delta t) = V(t) - V(t-1) \quad (13)$$

$$W(\Delta t) = Kw(\Delta t) * Ws(\Delta t) \quad (14)$$

$$Ws(\Delta t) = W_{in}(\Delta t) + W_{ins}(\Delta t) \quad (15)$$

$$W_{LOS}(\Delta t) = W_E(\Delta t) + W_G(\Delta t) - W_F(\Delta t) \quad (16)$$

Starting condition

$$V(t=0) = V_0 \quad (17)$$

$$V(t) = f(0,5 * W(\Delta t) + 0,5 * W_{out}(\Delta t)) \quad (18)$$

For reservoir (symbols as adopted in the Annex - variables)

$$V_{Rmax} \geq V_R(t) \geq V_{Rmin} \quad (19)$$

$$W_{RR}(\Delta t) \leq W_{Rmax} \quad (20)$$

For the task 2 (simulation of operation regime of reservoir) the following options are possible

$$V_R(t) = V_{RD}(t) \quad (21)$$

$$W_{RR}(\Delta t) = W_{RRD}(\Delta t) \quad (22)$$

For lakes

$$V_{Lmax} \geq V_L(t) \geq V_{Lmin} \quad (23)$$

$$W_{LL}(\Delta t) \leq W_{Lrmax} \quad (24)$$

2.1.1.3 Hydropower model

The operation of HEPS is described by the below relationships:

Capacity

$$N_{hs}(\Delta t) = K_{hs} * H_{hs}(\Delta t) * Q_{hs}(\Delta t) / 102 \quad (25)$$

Electricity generation

$$G(\Delta t) = N_{hs}(\Delta t) * T_{hs} / 1000 \quad (26)$$

HEPS flow rate

$$Q_{hs}(\Delta t) = K_{qw}(\Delta t) * W_{hs}(\Delta t) \quad (27)$$

HEPS head

$$H_{hs}(\Delta t) = 0.5 (H_R(t) + H_R(t-1)) - H_Z \quad (28)$$

Water level

$$H_R(t) = f(V_R(t)) \quad (29)$$

Boundary conditions on water discharge from HEPS

$$W_{hs}(\Delta t) \leq W_{RR}(\Delta t) \quad (30)$$

$$Q_{hs}(\Delta t) \leq Q_{hsmax} \quad (31)$$

Boundary conditions on capacity

$$N_{\max} \geq N_{hs}(\Delta t) \geq N_{\min} \quad (32)$$

2.1.1.4 Target functions

Hydropower target function (for conditional HEPS):

Minimization of idle discharge

$$|W_{hs}(\Delta t) - W_{RRD}(\Delta t)| \rightarrow \min \quad (33)$$

Minimal deviation of simulated generation from the required one

$$|G(\Delta t) - G_d(\Delta t)| \rightarrow \min \quad (34)$$

Maximization of energy generation

$$G(\Delta t) * P_g(\Delta t) \rightarrow \max \quad (35)$$

Water-management target function (for conditional reach):

Minimal deviation of simulated water diversion from the required one

$$|W_i(\Delta t) - W_{id}(\Delta t)| \rightarrow \min \quad (36)$$

Maximization of profit

$$W_i(\Delta t) * P_i(\Delta t) \rightarrow \max \quad (37)$$

2.2 The planning zone model (PZM).

2.2.1 Model's principal positions.

PZM is the principal bridge from watershed area to river and back (through water release and return flow) from one side, but from second side it is area where is creating production of water use, such as irrigated agriculture, livestock, processing, sector of service, industrial goods and machines. Here water supplies and sanitation of urban and rural areas are introducing proper well being conditions same as input in return flow to rivers and off them. It's clear that volume production same as degree of well being satisfaction depends from delivery water from different sources in PZ. PZM also is laying in framework of National Socio Economic Model (SEM) that base on the summarizing of all indicators of PZ that includes in states' content.

Tasks PZM ASBmm as a professional software to compute water requirements in given water-management district (planning zone - PZ) - domestic sector, agriculture, industry, by using different climatic, socio-economic and water-management scenarios by 2035. The model computes water availability of given planning zones and agricultural production losses as a result of water scarcity, produces water-management balances of planning zones in connection with a river network (WAM model), including water balances of irrigated areas, estimation of return water; considers local resources, including groundwater, and flow regulation by local reservoirs.

PZM can decide the following objections:

- calculation of agricultural water requirements,
- calculation of irrigated area's water balance,
- calculation of potential irrigated agriculture production,
- calculation of drainage (return) flow and its allocation between river, second use in canals and fields and release to sinks.
- calculation of planning zone's water-management balance (water use per economic sector, local and transboundary sources, etc.),
- calculation of agricultural output losses (in case of water shortage).

Total content of blocks and tasks PZM had represented on the figure 4.

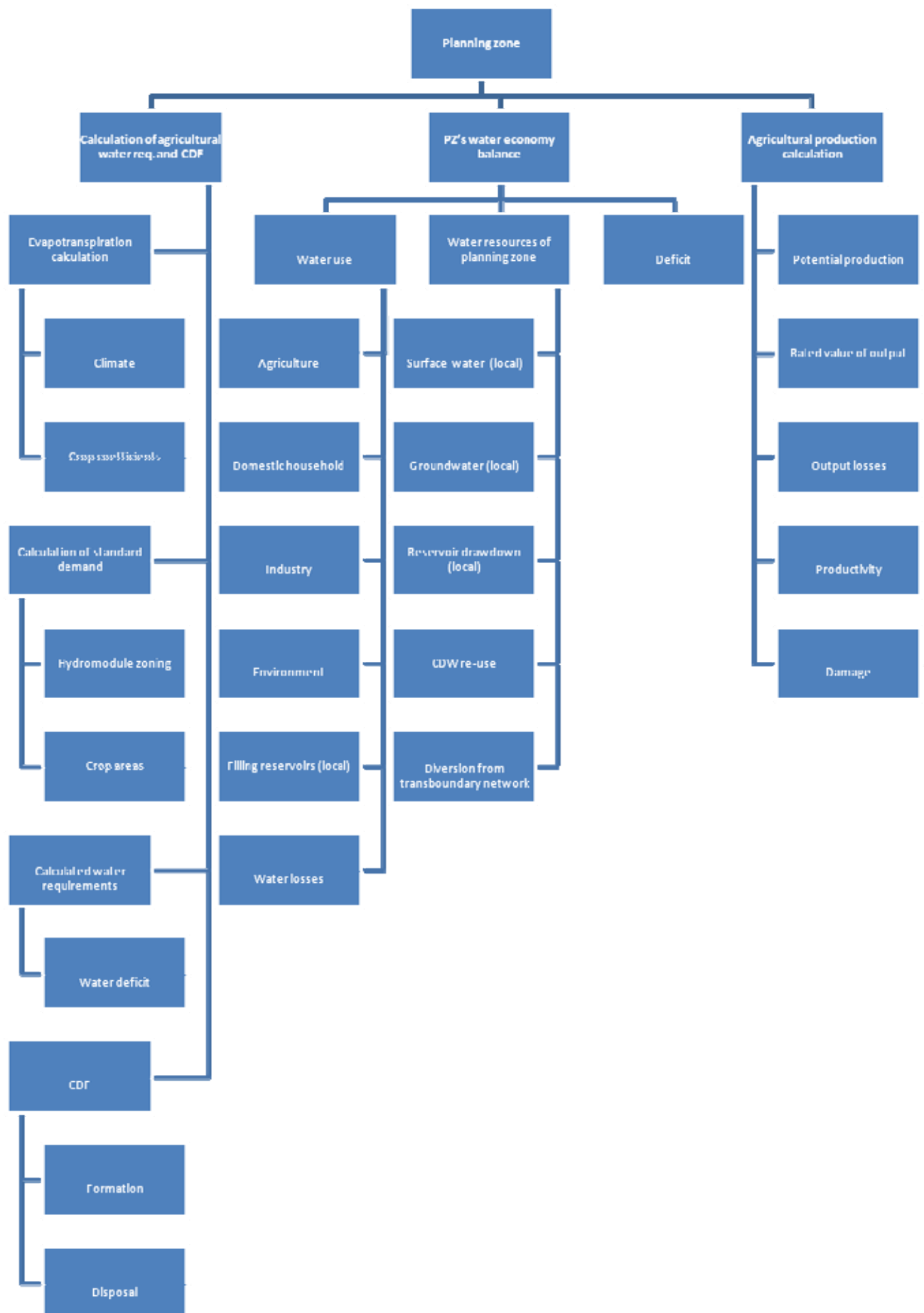


Fig.4 Scheme of blocks and tasks of PZM.

As follows from this scheme, model overlap huge quantity of natural and human activities taking place in such big area as province or its' part. Water supply to communal and industry needs estimated as obligatory water needs that will not correspond to proper level of water technology (may be it will be done on the next stage of ASBmm) and only dependent from quantity of population, volume of industrial production based on existed consumption or directive norms. Main variables in PZs connected with agricultural production – irrigated agriculture that is principal producer and consumer of waters. Specific of PZ is that water sources which are use on the common area consists beside delivery water from transboundary main rivers also from local stream and small rivers, part of which are not achieves main rivers, ground water from water supply and drainage wells and CDF. As result common water requirement should be covered by combination of these different sources depend from their allocation and water probability that can change in different years of water availability. But in our version we are going from prediction of proper stability of the correlation between these different sources in different years. We think that identification of this correlation in more precious way can be done in future our work as approach to use PZ model in description of more detail scale of behavior of irrigation system. Accordance fig.7 that describes typical allocation of commands' area from possible sources, we should indentify command area of main canal from transboundary river, command area of mix feeding from local and transboundary source and command area of local (small rivers) source. CDF from three command area need to assess together with clarification their each input depends from points of delivery: transboundary river, main canal or use on fields.

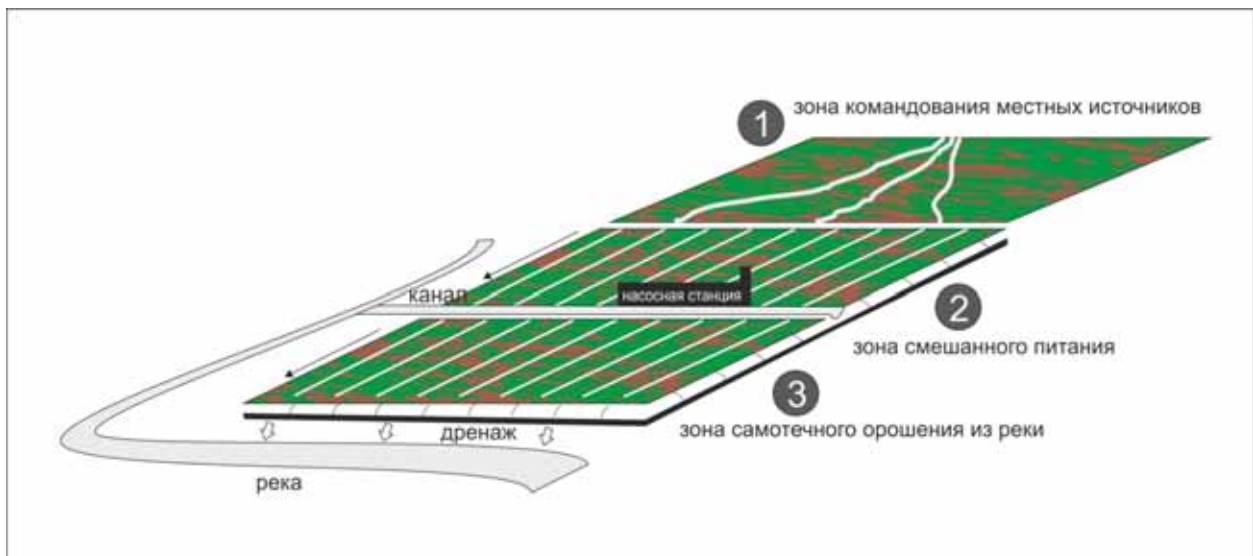


Fig.5 Scheme of interactions between different zones of PZ

Another specific of this PZM is that definition of water availability could be getting only after iteration between WAM and PZM, may be even multiline.

Some approximation should be taking in account in PZM:

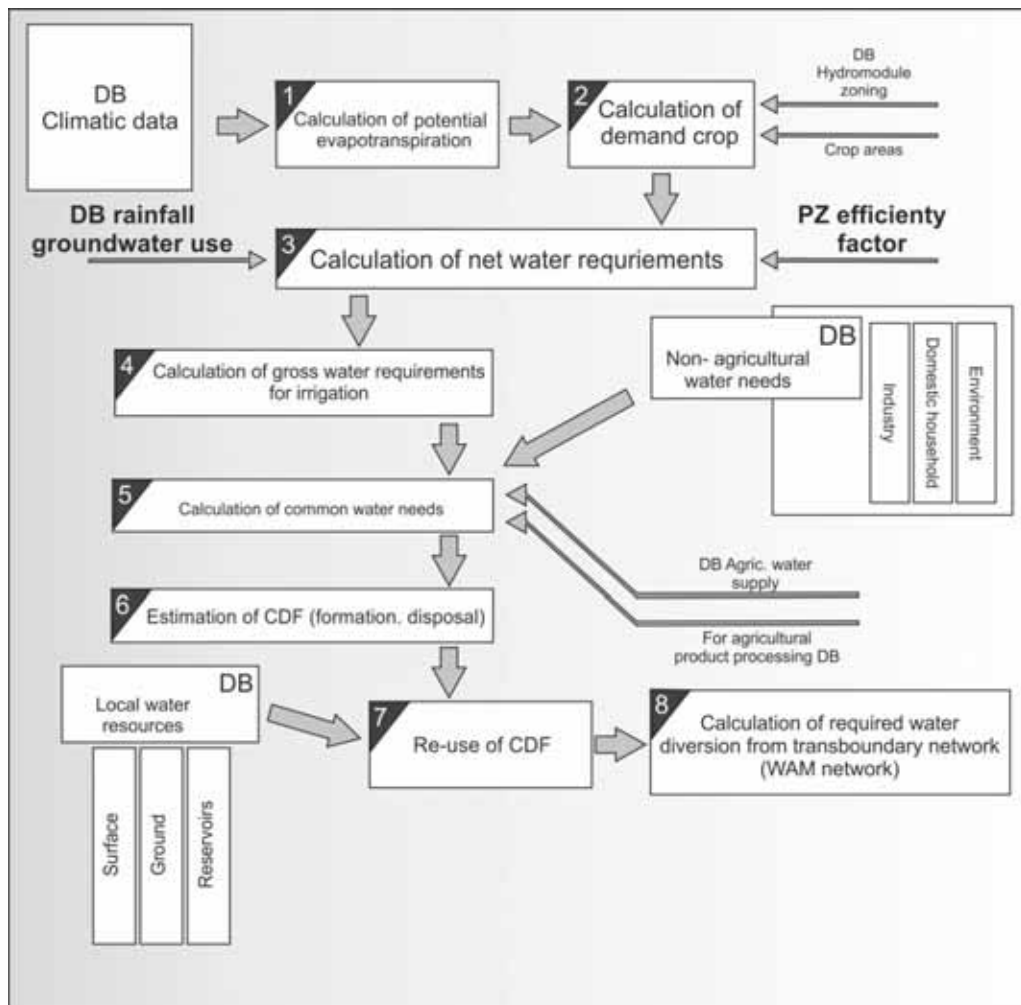
- water availability of local rivers estimated by the same water probability as flow of main rivers;
- water availability from ground water wells estimated as permanent on the present level (or on the base of prediction of their steady growth up to level of potential water pumping);

-
- common water availability of PZ estimated as average independent from different zones of sources same as formation of CDF.

The step 1 (calculation of PZ's water requirements, formation of CDF, requirements for water that has to be delivered from a transboundary network), presented on the Figure 6a. Figure 6b shows the calculation procedure of assessment water deficit oppose to PZ's water requirements that has to be delivered from a transboundary network based on the WAm - water allocation model's output. This information is used by the WAm model under joint operation with the PZ model in proper their iteration (step 2).

Possible Water supply to PZ as estimated more precisely by WAm is used for assessment of more precise definition of collector-drainage flow, CDF (Figure 6b), and then for calculation of agricultural output and productivity losses (Figure 7).

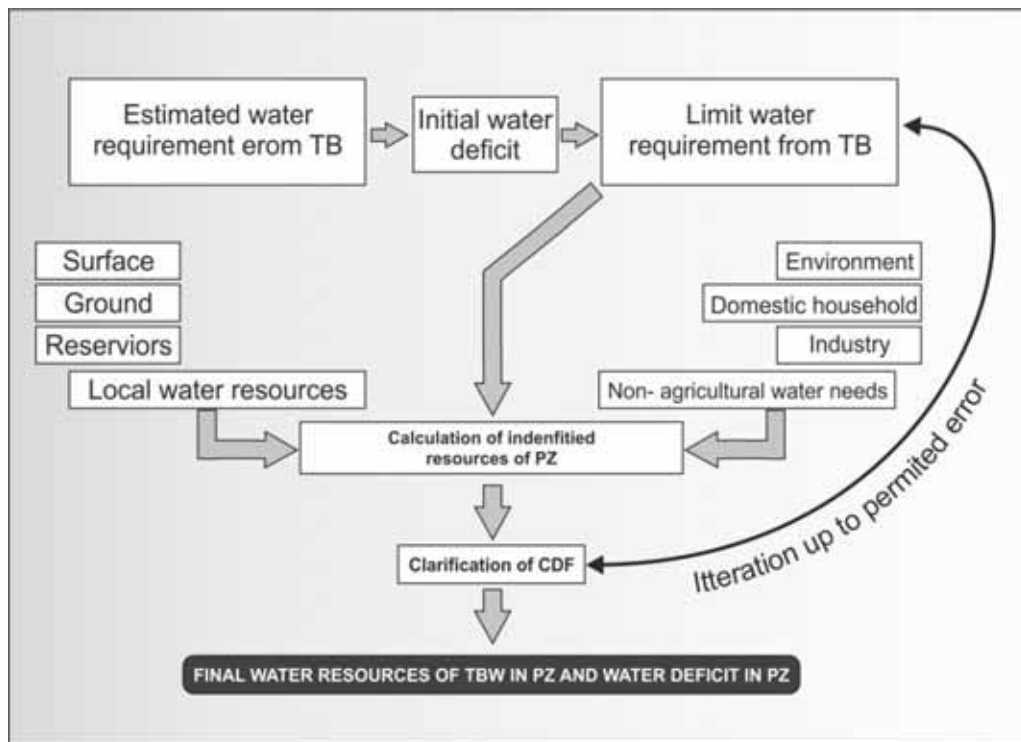
Scheme under fig.6a describes very important specific of PZM - iterative process between PZM and WAM. Taking in account that Collector drainage flow (CDF) that depends from volume of water use in PZ will be changes accordance to limit ICWC on transboundary waters and another constrains that can appears in water resources (scarcity in local small rivers, change in use of wells' water and so). Delivery CDF in river bed will clarify water resources of PZ that request new clarification of water deficit. This iteration should be repeated until change of resources will be in size of permitted error.



Procedure for calculation of PZ's requirement for water from transboundary network (WAM - network)

Note. The operation sequence of blocks is numbered as 1,2...

Fig 6a



Procedure for calculation of water deficit for irrigated agriculture and clarification of CDF in PZ

Fig.6b

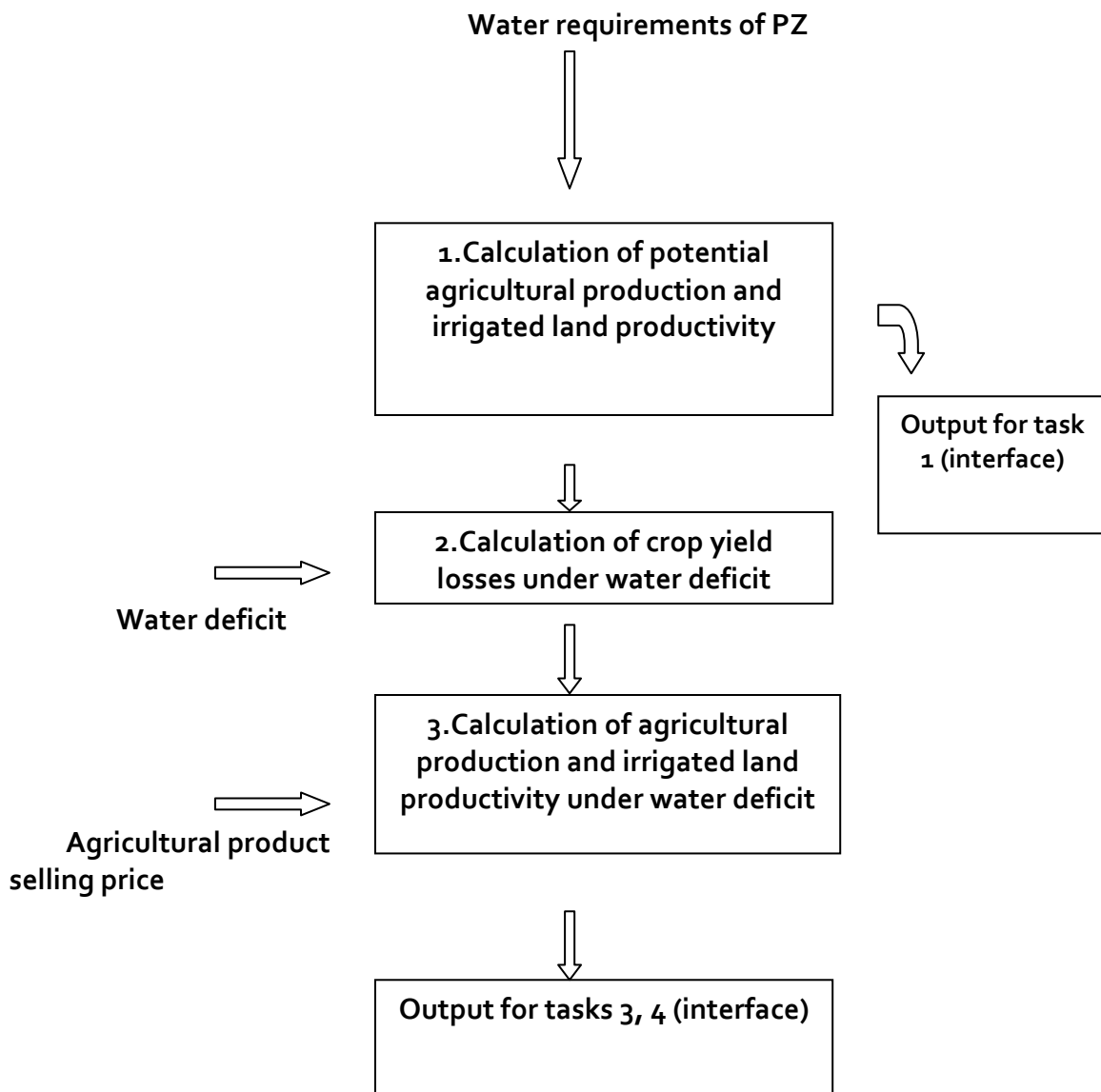


Fig. 7 Procedure for calculation of PZ's irrigated agriculture productivity

2.2.2 Model description

Description of PZM can be begin, may be from formalization of common water balance of it, but taking in account that irrigated agriculture demands is main definator of common water requirement and CDF, we start it from block of irrigated agriculture.

2.2.2.1 Block for calculation of irrigated agriculture requirements

Calculation of crop water requirements in planning zone's irrigated area **based on the well known in the all territory of NIS countries methodic of hydro module zoning by academician A.N.Kostyakov.**

Input data:

- List of crops grown in planning zone's irrigated areas
- Crop areas
- Hydro module zoning areas mapping depends from soils' and hydro geological conditions (ground water level and mineralization) for each type of crops;
- Irrigation norms;
- Mean monthly precipitation, temperature and other climatic indicators.

Variables and units

$z \in Z$ – set of planning zones

$r \in R$ – set of crops in given planning zone

H_z – total irrigated area of given planning zone (thousand ha)

H_{z_r} - fraction of area under crop r in planning zone out of the total planning zone's irrigated area

$c \in G$ – set of climatic zones in given planning zone (desert zone and sierozem zone)

H_{z_c} - fraction of area under climatic zone c out of the total planning zone area (%)

$g \in G$ – set of planning zone's hydro modules

H_{z_g} - area under hydro module g in given planning zone (thousand ha)

$wz_{cgr}(dt)$ – monthly average annual irrigation norm for crop r and hydro module g in climatic zone c (m³/ha)

$wzV_{cgr}(dt)$ – monthly average annual norm of growing season's irrigation for crop r and hydro module g in climatic zone c (m³/ha)

$wzP_{cgr}(dt)$ - monthly average annual norm of pre-tillage irrigation for crop r and hydro module g in climatic zone c (m³/ha)

$wzL_{cgr}(dt)$ - monthly average annual norm of supplemental irrigation for crop r and hydro module g in climatic zone c (m³/ha)

$wzS_{cgr}(dt)$ - monthly average annual norm of leaching irrigation for crop r and hydro module g in climatic zone c (m³/ha)

$wzm_r(dt)$ - monthly average annual norm of irrigation for crop r (m³/ha)

$Wzirn(dt)$ - monthly standard net crop water requirements in PZ (Mm³)

$Wzdirn(dt)$ – standard irrigated agriculture's water demand, including losses in irrigation network

$Wzdir(dt)$ – predicted irrigated agriculture's water demand, including losses in irrigation network

$Wzir(dt)$ - monthly predicted net crop water requirements in PZ (Mm³)

$pzm(dt)$ – average annual monthly precipitation for planning zone

$pzmef(dt)$ - average annual monthly effective precipitation for planning zone

$pz(dt)$ – predicted monthly precipitation for planning zone (m³/ha)

$pzef(dt)$ - predicted monthly effective precipitation for planning zone (m³/ha)

$ET(dt)$ – predicted reference evapotranspiration

$ETm(dt)$ – average annual reference evapotranspiration

$Tm(dt)$ – annual average monthly temperatures (°K)

$Lm(dt)$ – annual average monthly humidity (%)

$L(dt)$ – predicted average monthly humidity (%)

$T(dt)$ – predicted average monthly temperatures (°K)

$\Delta CW(dt)$ – monthly correction for account of climate change relative to the average annual

η_z – coefficient of efficiency of irrigation network in PZ

Equations and relationships

The monthly standard net crop water requirements in PZ are described by the equation

$$W_{zirn}(dt) = H_z * \sum_r w_{zm_r}(dt) * H_{z_r} \quad (38)$$

r

The average annual irrigation norm in planning zone is calculated by formula

$$w_{zm_r}(dt) = \sum_c (\sum_g w_{zcgr}(dt) * H_{z_g}) * H_{z_c} \quad (39)$$

In turn, irrigation norms for each crop include growing season, pre-tillage, additional, and leaching irrigation:

$$w_{zcgr}(dt) = w_{zV_{cgr}}(dt) + w_{zP_{cgr}}(dt) + w_{zL_{cgr}}(dt) + w_{zS_{cgr}}(dt) \quad (40)$$

The use of one or another irrigation norm's component depends on soil-climatic characteristics of planning zone.

The standard irrigated agriculture's water demand, including losses in irrigation network, is calculated by formula

$$W_{zdirn}(dt) = W_{zirn}(dt) / \eta_z \quad (41)$$

The predicted standard irrigated agriculture's water demand, including losses in irrigation network is estimated as

$$W_{zir}(dt) = W_{zirn}(dt) * (ET(dt) - p_{zef}(dt)) / (ET_m(dt) - p_{zmef}(dt)) \quad (42)$$

The predicted irrigated agriculture's water demand, including losses in irrigation network, is calculated by formula

$$W_{zdir}(dt) = W_{zir}(dt) / \eta_z \quad (43)$$

The average annual reference evapotranspiration is estimated as

$$ET_m(dt) = 0,00144 * (25 + T_m(dt))^2 * (100 - L_m(dt)) \quad (44)$$

The predicted reference evapotranspiration is

$$ET(dt) = 0,00144 * (25 + T(dt))^2 * (100 - L(dt)) \quad (45)$$

The predicted humidity is taken equal to the average for each decade accordance to multiyear data

$$L(dt) = L_m(dt) \quad (46)$$

2.2.2.2 Calculation of return flow (CDF) in planning zone

The input data for calculation are:

- Average monthly precipitation
- Monthly crop water requirements
- Groundwater outflow/inflow across the planning zone border
- Water diversion for irrigation in planning zone

Variables and units

$p_z(dt)$ – predicted monthly precipitation for planning zone (mm)

$W_{zirn}(dt)$ - monthly net crop water requirements in PZ (Mm³)

$\Delta GW(dt)$ – monthly groundwater inflow/outflow across the planning zone border (Mm³)

$W_{zCDF}(dt)$ – monthly formed collector-drainage flow in planning zone (Mm³)

$W_{CDZ}(\Delta t)$ - monthly collector-drainage flow in planning zone (Mm³) which is discharged into a river

$W_{zcd}(dt)$ – re-used monthly collector-drainage flow

$W_{CDLZ}(\Delta t)$ – monthly collector-drainage flow discharged into lakes

$W_{zdir}(dt)$ – irrigated agriculture's water demand, including losses in irrigation network

$L_{pz}(dt)$ – monthly CDF hydrograph for planning zone, % of annual flow

Total water balance of planning zone's irrigated areas is

$$W_{zdir} + 0,00001 * p_z = W_{zirn} + \Delta GW + W_{zCDF} \quad (47)$$

Equation (5.2.10) interlinks variables in annual dimension.

The first calculation option of the formed collector drainage flow is for planning zones with the known elements of the total water balance. In this case $W_{zCDF}(dt)$ is derived from equation (6.2.11).

The second calculation option is used when there are no reliable data on some elements of water balance. In this case the calculation is based on a reduction relationship between water diversion and CDF:

$$W_{CDF} = Kz * W_{zi} , \text{ where } Kz \text{ is the ratio of reduction} \quad (48)$$

After calculating an annual volume of CDF, the monthly distribution of CDF, according to typical hydrographs (based on flow probability), is estimated for given planning zone.

$$W_{CDF}(dt) = W_{CDF} * L_{pz}(dt) / 100 \quad (49)$$

Discharge of CDF into a river is calculated by the following formula:

$$W_{CDZ}(dt) = W_{CDF}(dt) - W_{zcd}(dt) - W_{CDLZ}(dt) \quad (50)$$

2.2.2.3 Calculation of output losses

Input data:

- Crops grown in irrigated areas of planning zone
- Crop areas
- Distribution of areas under planning zone's hydro modules
- Irrigation norms

Variables and units

$z \in Z$ – set of planning zones

$r \in R$ – set of crops in planning zone

H_z – total irrigated area of planning zone (thousand ha)

$H_{z,r}$ - fraction of area under crop r in planning zone out of the total planning zone's irrigated area

$g \in G$ – set of planning zone's hydro modules

$H_{z,g}$ - area under hydro module g in given planning zone (thousand ha)

$w_{mz,r}$ - average annual irrigation norm (for a season) for crop r (m³/ha)

$w_{nz,r}$ - predicted necessary irrigation norm (for a season) for crop r (m³/ha)

W_{lz} - irrigation water supply limit (for a season) (Mm³)

W_{zdir} – irrigated agriculture water needs, including losses in irrigation network (within the boundaries of PZ) over a season, (calculation in agricultural block of the model PZMASBmm) (Mm³)

$Y_{z,r}$ – maximal crop yields under no water shortage and when all agronomic measures for crop r are observed (t/ha)

Yz_{gr} – actual crop yields under water shortage and when all agronomic measures for crop r are observed (t/ha)

δYz_{gr} – relative crop yield losses in case of water shortage form crop r (%)

ET_r – predicted evapotranspiration for crop r over a season (m³/ha)

$pzmef$ - average annual effective precipitation rate over the growing season for planning zone

$pzef$ - predicted effective precipitation rate over the growing season for planning zone

α – coefficient of irrigation norm reduction under water shortage,

$k_r(t)$ – average monthly crop coefficient for crop r

Equations and relationships

Average crop yield drop in planning zone:

$$\delta Yz_r = s_r * (100 - \alpha) * \eta * wnz_r / ET_r \quad (51)$$

Necessary irrigation norm with account of climate change is calculated by formula

$$wnz_r = wmz_r * (ET - pzef) / (ET_m - pzmef) \quad (52)$$

The coefficient of irrigation norm reduction is calculated as

$$\alpha = 100 * Wlz / Wzdir \quad (53)$$

Predicted seasonal evapotranspiration of crop r is estimated by formula

$$ET_r = \sum_t k_r(t) * ET(t) \quad (54)$$

2.2.3 New features of planning zone model

2.2.3.1 Improved scheme for calculation of PZ water balance components

One of the ASBmm development objectives is to improve PZ water balancing and algorithm for calculating the water balance. The solution to this problem is based on the results of a 2013 study of the water balance of the Fergana PZ.

To solve this problem, we developed a new scheme of PZ water balance items accounting and calculation. Table 1 provides a list of elements (components) of the water balance, on which there is a difference between the old and new ASBmm schemes.

Table 1. Main differences between old and new water balance calculation schemes

Water balance elements	Accounting in old ASBmm scheme	Accounting in new ASBmm scheme
Local water resources	Full use in PZ	Calculation of the distribution of local resources between PZs (countries) and water surplus (idle discharges)

Discharges to transboundary rivers through sais	Set	Calculated by balance of local water resources
Canal discharges to rivers	Not considered	Considered in PZ water balance
Inflow from CDS from neighboring PZ and into neighboring PZ	Not considered	Considered, including: transit, discharge to the river within given PZ, CDS from neighboring PZ, CDS delivery to neighboring PZ
Discharges from CDS into reservoirs, lakes and depressions	Considered cumulatively	Considered separately
Re-use of CDS	Set	Optionally: calculation in % of irrigation water use or set

2.2.3.2 Food calculation block

Development of food calculation block is based on the algorithm of the ASBmm Economic Model. The block is programmed in PZm, and has the following features:

- Access to cropping scenarios (food security, export orientation)
- Procedures for optimization - selection of irrigated agriculture crops in the optimization mode.

Table 2 below shows the structure of food balance of PZm model.

Table 2: Description of the food balance structure of the planning zone

Item	Notation	Equation	Note
Area under agricultural crops			
Cotton	Scot		Input data
Vineyards	Swin		-/-
Orchards	Sgar		-/-
Vegetables	Sweg		-/-
Melons	Smel		-/-
Wheat	Swhe		-/-
Rice	Sric		-/-
Fodder	Sfor		-/-
Corn	Smaif		-/-
Alfalfa	Sluc		-/-
% alfalfa	Pluc		-/-
Maize (grain)	Smaigr		-/-
Total maize	Smai		-/-
Potato	Spot		-/-
Feeding mass conversion factor			
Cotton	Kcot		Reference-information data
Wheat	Kwhe		-/-
Rice	Kric		-/-
Alfalfa	Kluc		-/-
Maize (grain)			-/-

stems	Kstem		-//-
grains	Kgrain		-//-
Silage	Ksilage		-//-
Potato	Kpot		-//-
Feeding mass to feeding unit conversion factor			
Cotton	Kfcot		Reference-information data
Wheat	Kfwhe		-//-
Rice	Kfric		-//-
Alfalfa	Kfluc		-//-
Maize (grain)			-//-
stems	Kfstem		-//-
grains	Kfgrain		-//-
Silage	Kfsilage		-//-
Potato	Kfpot		-//-
Crop yields			
Cotton	Pcot		Input data
Vineyards	Pwin		-//-
Orchards	Pgar		-//-
Vegetables	Pweg		-//-
Melons	Pmel		-//-
Wheat	Pwhe		-//-
Rice	Pric		-//-
Alfalfa	Pluc		-//-
Maize (grain)	Pmai		-//-
Potato	Ppot		-//-
Croppage (gross crop harvest)			
Cotton	GRcot	Scot*Pcot	
Vineyards	GRwin	Swin*PSwin	
Orchards	GRgar	Sgar*Pgar	
Vegetables	GRweg	Sweg*Pweg	
Melons	GRmel	Smel*Pmel	
Wheat	GRwhe	Swhe*Pwhe	
Rice	GRric	Sric *Pric	
Alfalfa	GRluc	Sluc *Pluc	
Maize (grain)	GRmai	Smai*Pmai	
Potato	GRpot	Spot* Ppot	
Feeding mass			
Cotton	Mfcot	GRcot* Kfcot	
Wheat	Mfwhe	GRwhe*Kfwhe	
Rice	Mfric	GRric*Kfric	
Alfalfa	Mfluc	GRluc*Kfluc	
Maize (grain)			
stems	Mfstem	Kfstem*GRmai	
grains	Mfgrain	Kfgrain*GRmai	
Silage	Mfsilage	Kfsilage*GRmai	
Potato	Mfpot	Kfpot*GRpot	
Feed volume in feed units			
Cotton	Fcot	Mfcot*Kfcot	
Wheat	Fwhe	Mfwhe*Kfwhe	
Rice	Fric	Mfric*Kfric	
Alfalfa	Ffluc	Mfluc*Kfluc	
Maize (grain)			
stems	Fstem	Mfstem*Kfstem	

grains	Fgrain	Mfgrain*Kfgrain	
Silage	Fsilage	Mfsilage*Kfsilage	
Potato	Fpot	Mfpot*Kfpot	
Volume of succulent fodder	Fjui	Ffluc+ Fstem+ Fgrain+ Fsilage+ Fpot	
Volume of roughage	Frou	Fcot+ Fwhe+ Fric	
% of roughage for milk production	PFrou		Input data or optimization variables
% of succulent fodder for milk production	PFjui		- //-
Pasture fodder accounting factor	Kpas		- //-
Share of pasture fodder for milk production	Kpasm		- //-
Volume of fodder produced	Fjuirou	Frou+ Fjui	
Volume of fodder, including pastures	Fall	Fjuirou*(1+ Kpas)	
Volume of pasture fodder for mild production	Fpasmil	Fjuirou*Kpasm/(1+Kpasm)	
Volume of fodder for mild production (including pastures)	Fmil	PFrou* Frou/100+ PFjui* Fjui/100+ Fpasmil	
Share of succulent fodder in total volume for milk production	Kjuimil	(PFjui*Fjui+ Fpasmil)/Fmil	
Volume of pasture fodder for milk production	Fpasma	Fjuirou/(1+Kpasm)	
Volume of fodder for meat production	Fmea	(100-PFrou)* Frou/100+ (100-PFjui)* Fjui/100+ Fpasma	
Meat flock structure (per 1000)			
Cattle	Nkpc		Input data
Sheep and goats	Nshe		- //-
Poultry	Nbir		- //-
Pigs	Npor		- //-
Animal nutrition standards in fodder units			
Cattle	PFkpc		Reference-information data
Sheep and goats	PFshe		- //-
Poultry	PFbir		- //-
Pigs	PFpor		- //-
Fodder conversion rates in weight of the animals			
Cattle	Kkpc		Reference-information data
Sheep and goats	Kshe		- //-
Poultry	Kbir		- //-
Pigs	Kpor		- //-
Fodder volume by meat flock			
Cattle	Fkpc	Fmea* PFkpc*Kkpc /(PFkpc*Kkpc+ PFshe* Kshe+ PFbir*Kbir+ PFpor*Kpor)	
Sheep and goats	Fshe	Fmea* PFshe* Kshe /(PFkpc*Kkpc+ PFshe* Kshe+	

		$PF_{bir} * K_{bir} + PF_{por} * K_{por}$	
Poultry	F_{bir}	$F_{mea} * PF_{bir} * K_{bir} / (PF_{kpc} * K_{kpc} + PF_{she} * K_{she} + PF_{bir} * K_{bir} + PF_{por} * K_{por})$	
Pigs	F_{por}	$F_{mea} * PF_{bir} * K_{bir} / (PF_{kpc} * K_{kpc} + PF_{she} * K_{she} + PF_{bir} * K_{bir} + PF_{por} * K_{por})$	
Fodder conversion rate into milk volume	K_{fmil}	$F(K_{juimil}, F_{mil})$	Функция от доли сочных кормов и объема кормов для производства молока
Cottonseed oil production factor	K_{oilc}		
Food			
Meat and meat products	P_{meat}	$F_{kpc} * K_{kpc} + F_{she} * K_{she} + F_{bir} * K_{bir} + F_{por} * K_{por}$	
Milk and milk products	P_{milk}	$F_{mil} * F(K_{juimil}, F_{mil})$	
Fruits	P_{fru}	$GR_{win} + GR_{gar}$	
Sugar	P_{sug}	$P_{erfru} * N_{pea}$	
Vegetable oil	P_{oil}	P_{oilc}	
cottonseed oil	P_{oilc}	$P_{cot} * K_{oilc}$	
Vegetables, melons and potatoes	P_{veg}	$GR_{veg} + GR_{mel} + GR_{pot}$	
Bread and bakery products	P_{bre}	GR_{whe}	
Fish and fish products	P_{fis}	$P_{erfis} * N_{pea}$	
Eggs	P_{egg}	$P_{eregg} * N_{pea}$	
Population	N_{pea}		Input data
Food per 1 person			
Meat and meat products	P_{ermeat}	P_{meat} / N_{pea}	
Milk and milk products	P_{ermilk}	P_{milk} / N_{pea}	
Fruits	P_{erfru}	P_{fru} / N_{pea}	
Sugar	P_{ersug}		Input data
Vegetable oil	P_{eroil}	P_{oil} / N_{pea}	
cottonseed oil	P_{eroilc}	P_{oilc} / N_{pea}	
Vegetables, melons and potatoes	P_{erveg}	P_{veg} / N_{pea}	
Bread and bakery products	P_{erbre}	P_{bre} / N_{pea}	
Fish and fish products	P_{erfis}		Input data
Eggs	P_{eregg}		- //-

2.3 Socio-economic model (SEM).

2.3.1 Principal positions of SEM.

Analyze of social-economic situation in Aral Sea basin and in each country allocated in it, specifically separate by each big river, is impossible in details for such specific goal as we have in ASBmm:

– to assess dynamic of water availability in basin at whole with specification on each planning zone and each river basin (Amudarya and Syrdarya) in their perspective on 25 years;

-to definite, how the changes of this water situation will be reflect on the social–economic parameters of region and their different states and parts.

This analyze should account that relation “social – economic situation vis a vis water availability and management” has both sides impact. Social (at first demographic situation) reflected on the demands to water for drinking, communal needs same on production of crops as framework for food security; development of different branches of industry and different sectors of economic activity will impact on water off-take and quality of water in water sources. From other side water availability and scenarios of water management that depends from regional and national water governance will definite conditions and success of social situation and economic efficiency.

It's clear that ASBmm can't give all parameters socio-economic situation and we should limited by most impacted from water sides: water guarantee, degree of food supply, power supply and change in GDP under water factors.

SEM ASBmm is a part of ASBmm that should in connection with different scenarios to give such ability. SEM ASBmm is a software to build and assess water-management, agricultural and environmental development sequenses for the Aral Sea basin by 2035 in connection with the national socio-economic development scenarios for riparian countries.

SEM ASBmm accumulates and aggregates outputs from the following models:

- WAmASBmm – amount and cost of potential electric energy, which is planned and generated in HEPS following to reservoir hydro system operation scenarios, as well as generation losses (in case of sterile spills),
- PZ ASBmm – water availability of each sectors and amount and cost of potential output planned in Planning zones (by economic sector) of the region's countries, as well as output losses (in case of water shortage) by scenario.

The model assesses per country and Amudarya and Syrdarya basin:

- Water-management balance and water capabilities,
- Energy balance,
- Nutrition balance,
- Socio-economic situation against a range of indicators, including macroeconomic ones.

Water use and availability are assessed in the following main directions:

- Operation and development of household-domestic sector as a first priority;
- Guarantee of water for development of real economic sector (excluding agriculture);
- Water supply and development of agriculture, including irrigation;
- Production and development of power sector.

2.3.2 Description of SEM.

The future correlations between social-economic development, water development and water availability depends from some political lines of governance:

- directions and priorities of national development and allocation of this development between different planning zones;
- countries' water strategy and principles of national water governance, same as food and power strategy;
- stability and strict rules of water allocation of transboundary waters between states;
- priority to allocations water between sectors of economy.

Therefore, the structure of dependence of GDP on water factor will be different in various zones. GDP in country and individual zones is formed by the current main sectors (Fig.8):

- industry;
- agriculture;
- energy;
- processing;
- services.

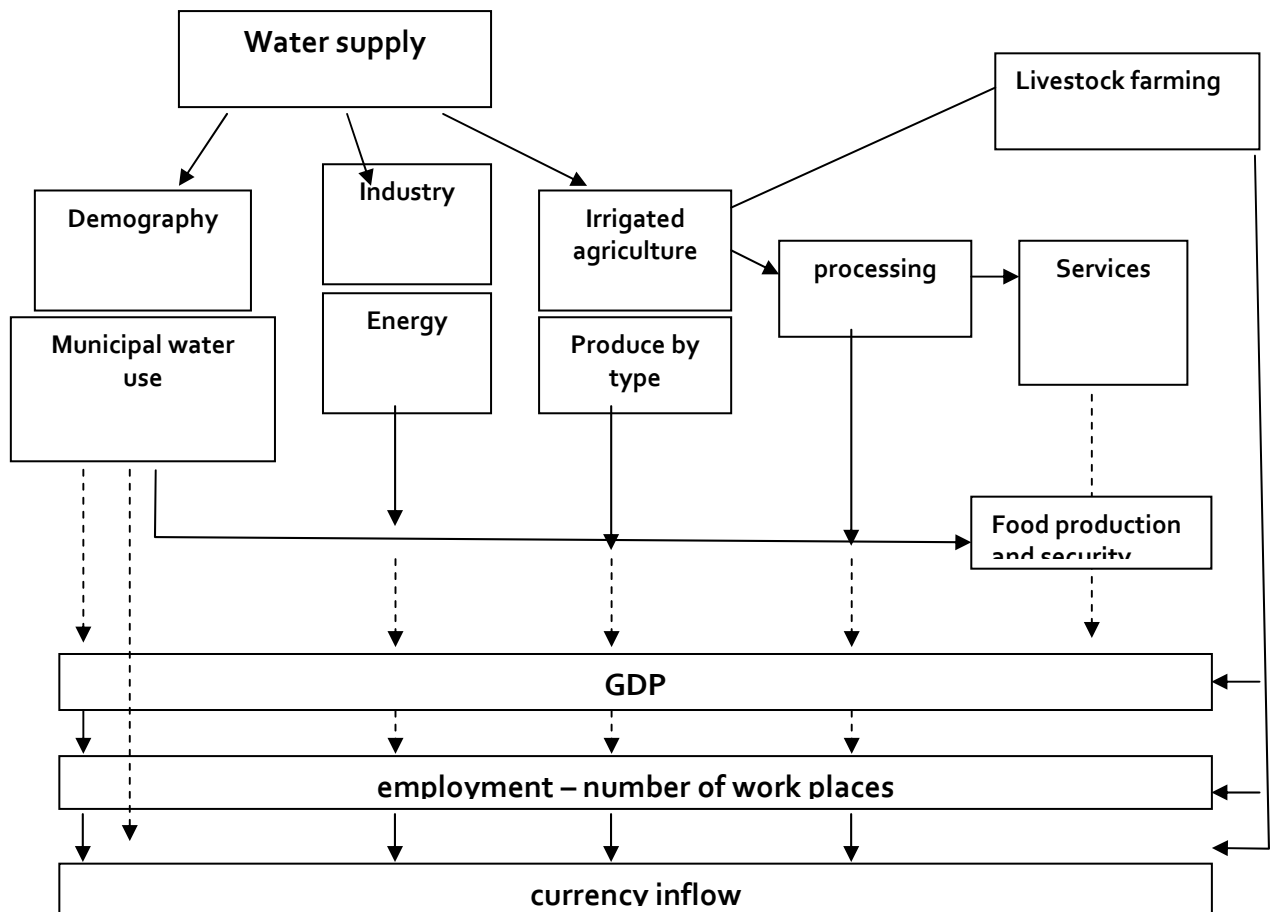


Figure 8. Participation of water sector in GDP formation.

3. Scenarios of future water development

3.1 *Basic provisions on scenario-building*

In all development and future scenarios the driving forces or destabilizing factors, as well as limitations are essential elements. From this position, the driving forces include:

INTERNAL FORCES:

- Demographic pressure;
- Required rate of growth of the economic capacity of each country's industry specifics and GDP increase;
- Needs in food production based on the planned food security of the country;
- Set targets in the welfare of the population, including water supply, employment, health and education;
- Policy focus on the efficient use of resources and protection of the natural environment, as well as the priorities for the use of funds;
- Labor and intellectual capacity of the country.

EXTERNAL FORCES:

- Climate change;
- Stability of the water complex of transboundary sources;
- Geopolitical situation and the state of international economic and financial markets;
- Established regional inter-state relations.

The restrictions include water resources and their distribution in time and space, as well as the land resources possible for use and the amount of available capital investments. By themselves, the natural environmental conditions and infrastructure capacity also act as constraints.

Given the combination of external and internal driving forces, it is clear that external forces mainly form national socio-economic and agricultural scenarios. Climate, hydrology, water management and environmental scenarios are mostly created on the basis of acting external forces, where international cross-border cooperation is among the main ones.

Development scenarios for the Aral Sea Basin should include a number of areas, determining the dynamics of the main driving forces and destabilizing factors that determine both the requirements for water complex as well as the potential opportunities and conditions for the functioning of water systems, the balance (or imbalance) of needs and water and energy resources available for use. These areas group key factors by type of scenarios:

- Climate, including an assessment of the natural and anthropogenically disturbed climate change, defining the temperature and humidity deviations affecting the cyclical fluctuations of surface water runoff formation zone, as well as the required crop water use (deviations from the norm)
- Socio-economic, determining demographic load, distribution of population growth between urban and rural areas; priority areas for industrial development; growth of industrial production and related water requirements; diversification of production between regions; GDP increase rate and, thus welfare and assessment of drinking water requirements as well.

-
- **Agricultural, composition of which will depend on the priority of the state to provide food self-sufficiency and food security, or to increase the export capacity. In this case there are sub-options - sale of cotton and other crops at affordable prices or organization of processing to the final product. The focus (and the ability) to expansion of (development of new) irrigated areas or priority to increase water and land productivity on existing lands, as well as changes in the crop patterns play certain role.**
 - **Water management, which includes construction of new reservoirs, selection and regulation of the flow and releases from reservoirs; intensity of IWRM implementation; increased use of return flows, etc.**
 - **Environmental in a form of requirements to river flow, environmental flow, desertification, etc.**

4. Interface

4.1 System architecture

To enable the multi-user mode, it was decided to use the web as a development environment. Conventionally, the system can be divided into three components:

- Models (GAMS)
- DBMS (MYSQL)
- Interface (PHP, JAVASCRIPT, HTML)

The whole system is built as a web application that uses various server components:

- GAMS - high-level system for mathematical modeling and solving various mathematical problems.
- DBMS MYSQL - database for storing and processing information, including scenarios and user data.
- Web server and PHP interpreter

Several models to calculate various indicators were developed using GAMS system:

- Planning zone model
- River model
- Socio-economic model

Interaction scheme is shown on Figure 9.

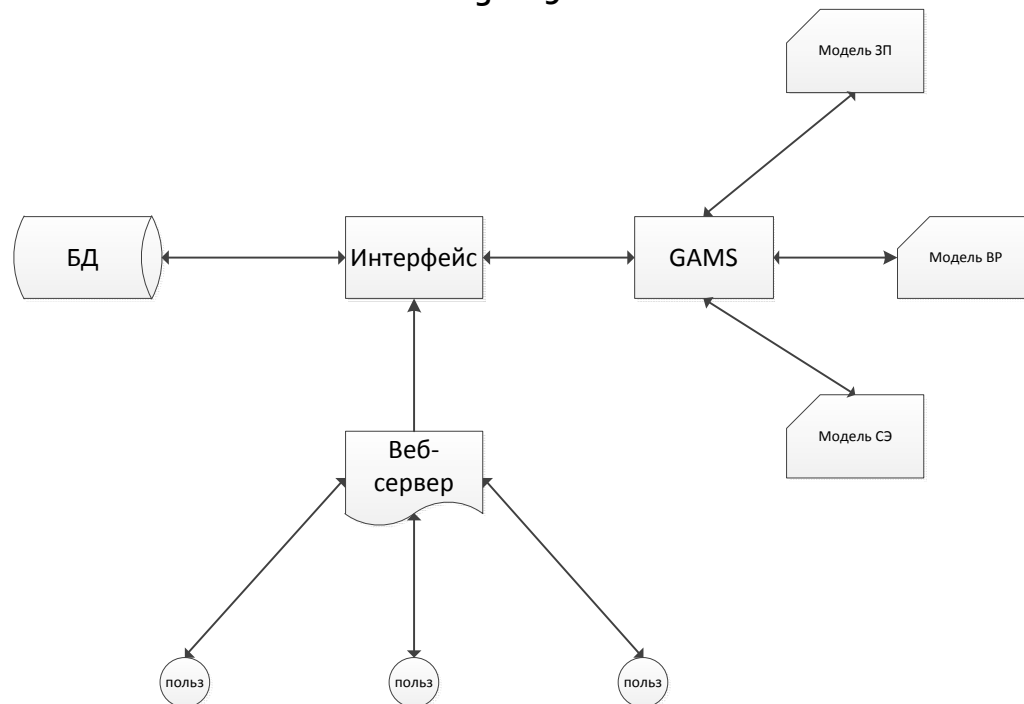


Fig. 9 Scheme of interaction of ASBmm elements with interface.

4.2 Component interaction

Interface acts as front-end part of the system; it interacts with the user and operates his commands. Upon receipt of a command from the user, the interface retrieves data from the database, refers to a specific model, transmits it the data received and after processing model stores the result back into the database. Models do not apply directly to the DB; all operations go through the interface. Thus, the transmitted data monitoring is implemented - error detection, reliability and security.

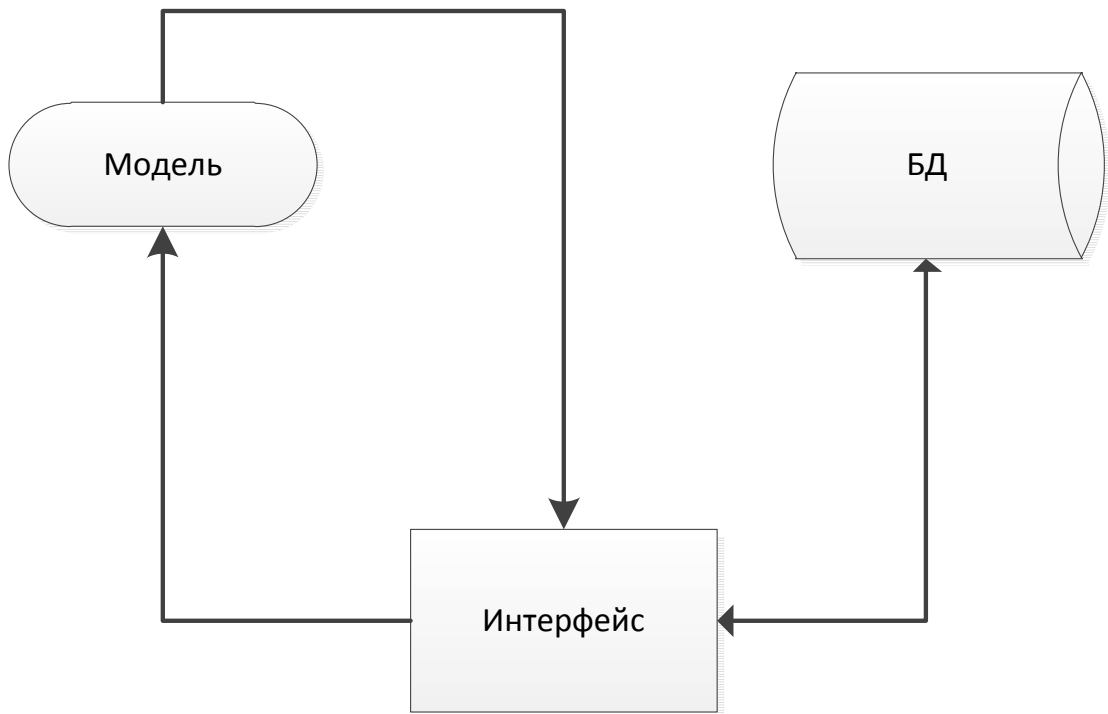


Figure 10 Interface - Heart of ASBmm