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"Mathematical models for water resources management in the Aral Sea Basin: review and prospects"

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Remedies

Many regions of the world face reduction of stocks of natural water resources due to quickly increasing population and, therefore, growing demand for water.

Central Asia (CA) is the 7th biggest area in the world including 5 states (Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan and Uzbekistan) and there are considerable areas of irrigated lands (7,95 million ha) which play an important role in economy. CA has a big water and energy potential.

80 water reservoirs with capacity of 60 km^3 and 45 hydro-electric power plants with general capacity of 34.5 GW have been constructed within the Aral Sea basin. Capacity of every power station varies from 50 to 2700 mW.

The Nurek HPP with capacity of 2700 mW (at the Vakhsh River in Tajikistan) and Toktogul HPP with capacity of 1200 mW (at the Naryn River in Kyrgyz Republic) are the largest hydroelectric power plants. Hydro-energy makes 27.3 % from average consumption of energy. The most hydro-energy is developed in Tajikistan (about 98%) and Kyrgyz Republic (about 75 %), the least hydro-energy is developed in Turkmenistan (1 %).

Annual volume of surface runoff of such largest rivers as Syr-Darya (36.625 km3) and Amu-Darya (79.396 km^3) essentially changes according to a season and year.

Ground water resources in the region are estimated as 31.17 km^3 including 14.7 km^3 in the Amu-Darya basin and 16.4 km^3 in the Syr-Darya basin.



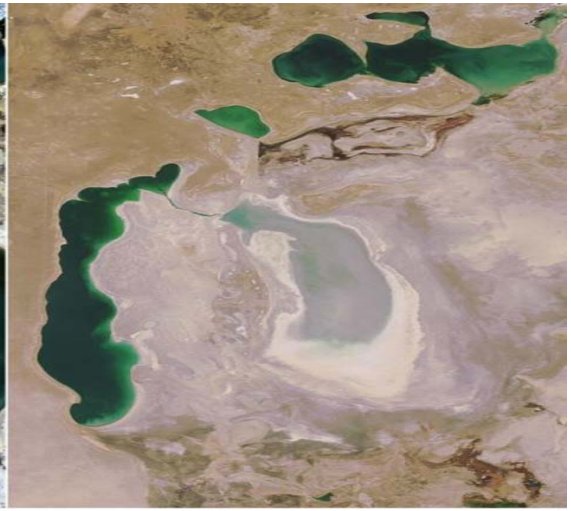

Basic problems

Simultaneous growth of population and areas of irrigated lands led to the world known Aral disaster.

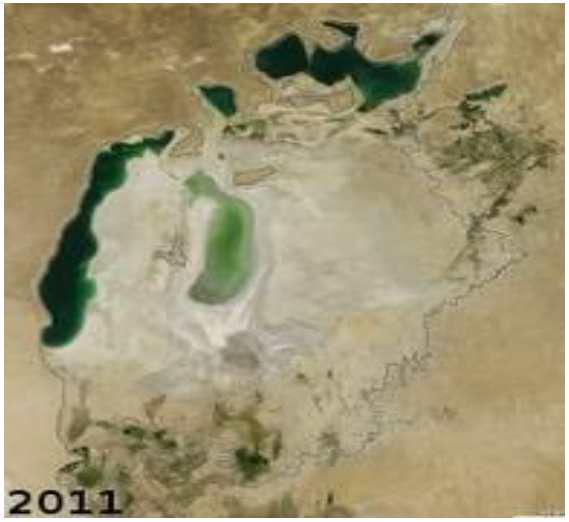
There are the following specific indicators of a disaster: deterioration of the population health, increase of infant mortality rate, the Aral Sea drying, reduction of biological diversity, transfer of salts and dust from the drained bottom of the sea, loss of pastures, fish stocks and areas of humidified territories.

Until 1960, the Aral Sea square was about 67 000 km^3. According to this indicator it was the 4^{th} internal water object in the world. Now the Aral Sea doesn't exist as a single water body. Its area has decreased in 7 times and water volume has grown down in 13 times.

July - September, 1989



October 5, 2008

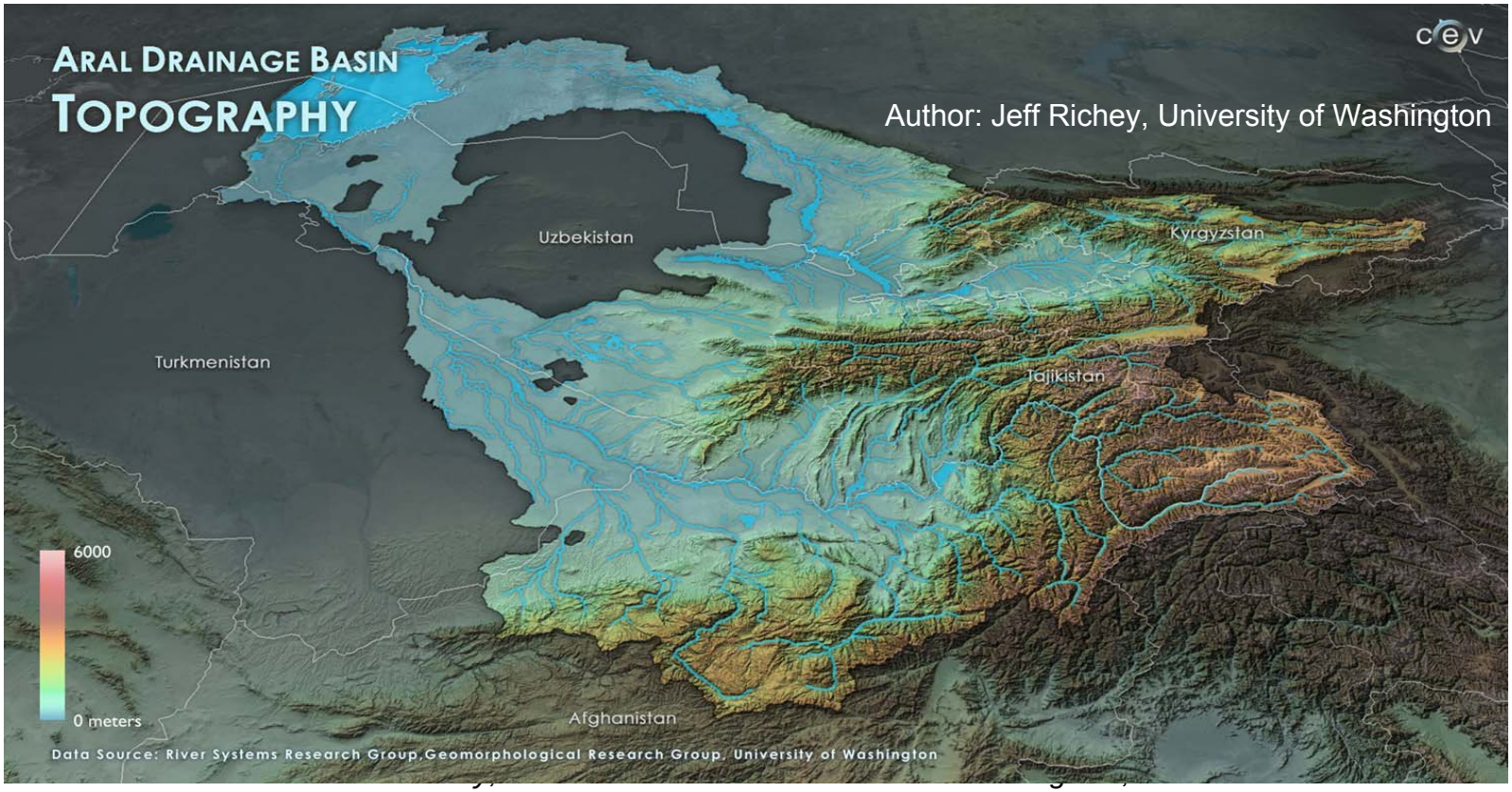


General characteristics of types of models revealed in the countries of Central Asia

Country	Objects of models	Quantity of models
Kazakhstan	Ground waters in the context of connection with surface waters + Surface water and economic aspects	8 + 1
Kyrgyzstan	Hydroelectric potential	1
	Mountain lakes	1
	Surface waters: Issyk- Kul Lake	1
	Surface waters: irrigation	1
	Glaciers and river flow	1
	Mountain glaciers	3
	Snow covering	1
	Ground waters	3
	Relief	1
	Moisture circulation and soil moistening	2
	Forests	1
Tajikistan	Surface waters. River flow.	1
	Surface and ground waters, hydroelectric power plants	complex
Uzbekistan	Surface and ground waters, hydroelectric power plants	1
	Hydroenergetics	2
	Surface waters: the Aral Sea aquatory	2
	Surface waters: canals, irrigation	2
	Surface waters: optimization of water reservoirs work	1
	Surface waters: hydrological forecasts	3
	Water operational balance of the river basin	1
	Surface waters and economic aspects	1
	Surface and ground waters	6
	Ground waters	1

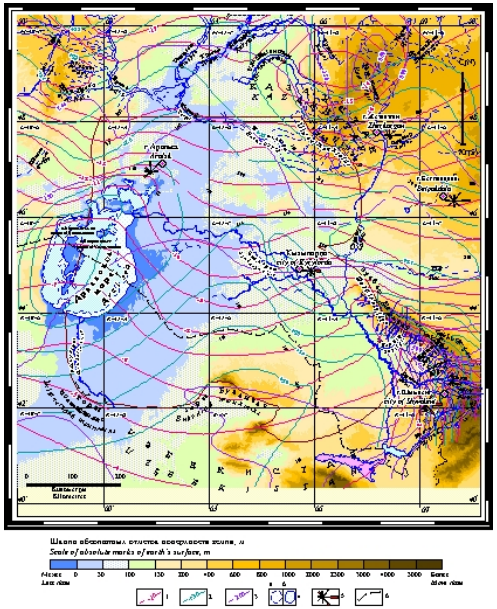
Models reviewed

1. NIBADSS	2. ASB MM	3. EPIC	4. TWEP-NAPSI	5. Syr-Darya Real-Time RBM	6. MMTB	7. ASBOM	8. Aral-DIF	9. Economic Allocation	10. Public Domain
(Kazakhsthan w /UNDP) Nura Ishim River Basin Management Project Integrated Water Resources Planning Decision Support System	(EC-IFAS w/ UNDP-GEF) Aral Sea Basin Management Model	USAID w/University of Texas/IFPRI) USAID Environmental Policies and Institutions for Central Asia Optimization Model	(Kyrgyz Republic w/USAID) Transboundary Water and Energy Project-North America Syncrophasor Initiative	(Kazakhstan w/Denmark) Water Management and Simulation System (WMIS)for Syr Darya	(Tajikistan) Mathematical Modeling on transboundary basins	(SIC-ICWC w/ UNDP/GEF) Aral Sea Basin Optimization Model – (the Haskoning Model)	(World Bank w/University of Washington) Dynamic Information Framework – Variable Infiltration Capacity - Aral Sea Basin Earth Systems Model	(USAID w/ EC-IFAS) Economic Valuation of Water	USA Variety of public domain models prepared by US Army Corps of Engineers US Geologic Survey Private Sector



Examples of models in Kazakhstan.

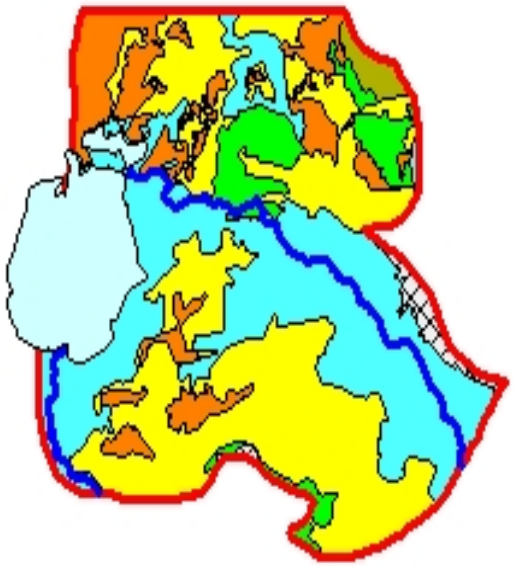
Territory of the East Sub-Aral area

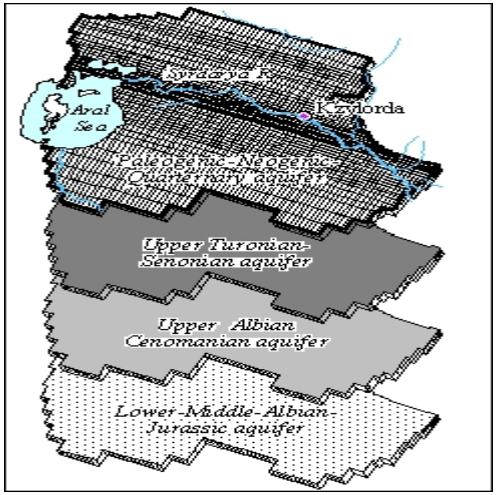


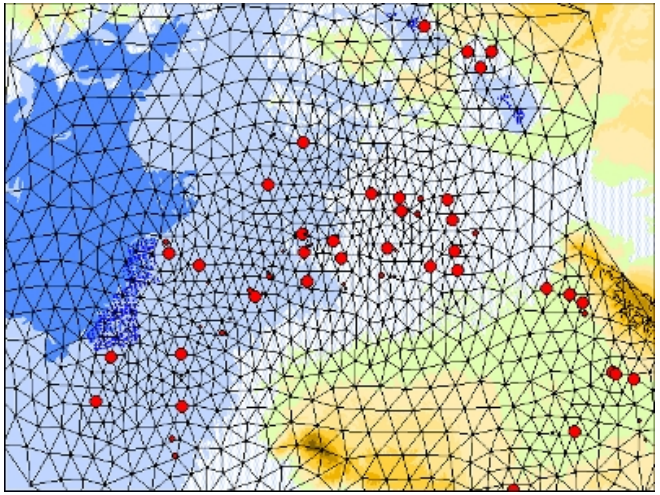
Водный баланс Аральского моря, км^3/год
(по материалам КазНИГМИ, КазНИИМОСК, [212])
Aral sea water balance, km^3/year
(as of the materials of KazNIGMI, KazNIIMOSK, [212])

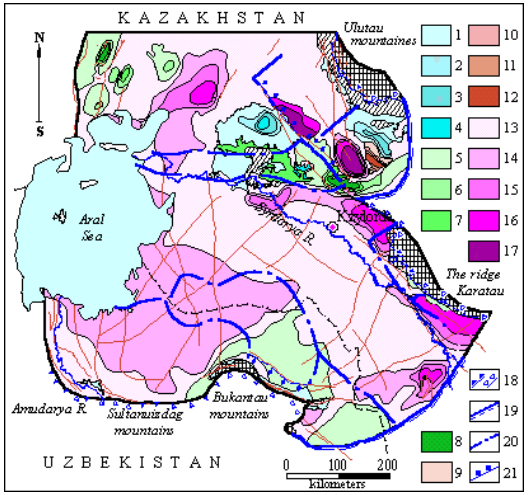
Период, годы *Period, years*	Приход *Advent*		Потери воды на испарение *Water losses for evaporation*	Баланс *Balance*
	Сток *Discharge*	Осадки *Precipitations*		
1911 - 1960	56,0	9,1	66,1	-1,0
1961 -1970	43,3	8,0	65,4	-14,1
1971 - 1980	16,7	6,3	55,2	-32,2
1981 - 1990	3,9	6,2	43,7	-33,6
1991 - 1994	21,0	4,6	33,6	-8,0
1995 - 2002 *	4,81**	3,5	28,6	-20,29

*оценки ИГГ МОН РК, **приток в Малое море.
** estimation of IGG MON RK, **advent into Small sea.*



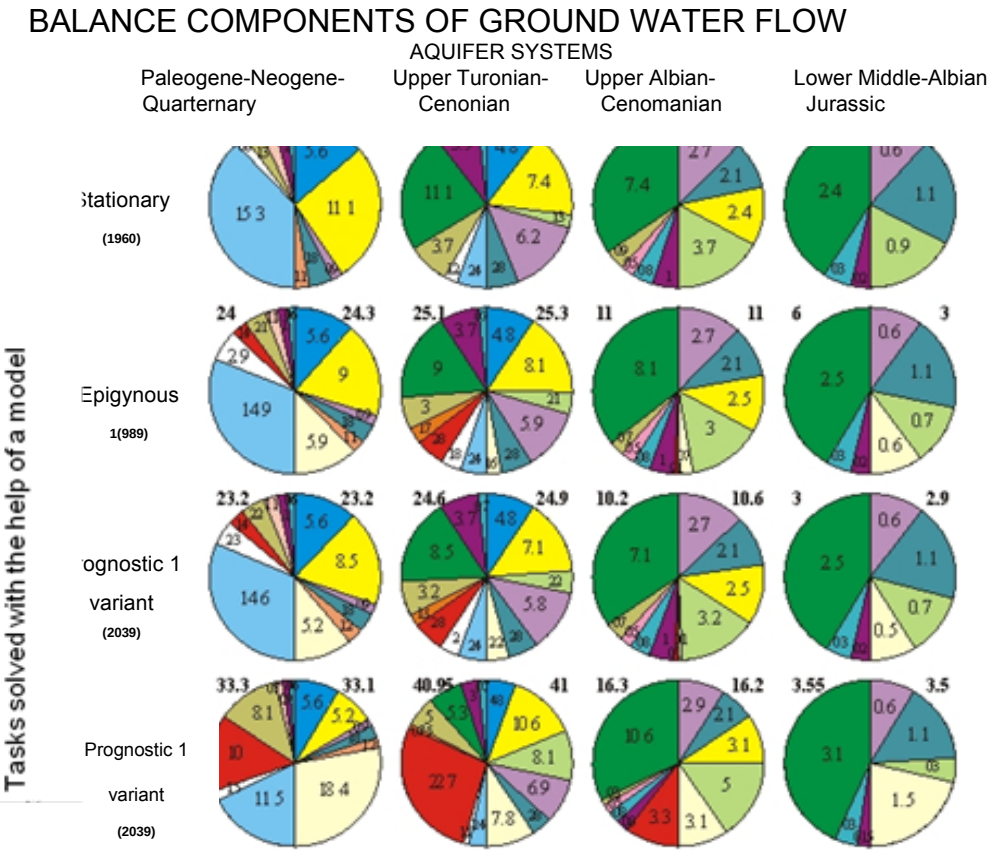


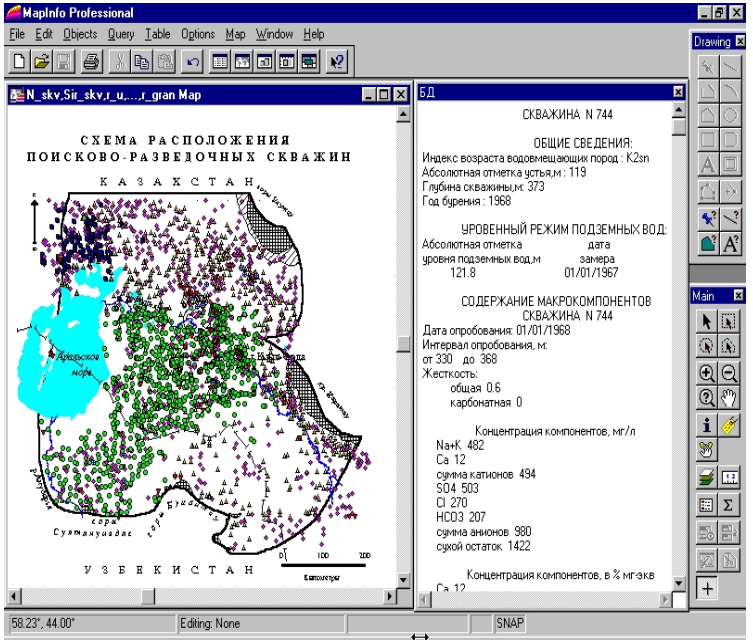




Results of modeling of ground water resources of the East Sub-Aral area

(over an area more than 450,000 km²)





Left part of the diagrams – expense items, right part – receipt items, m³/sec
Numbers in the diagrams – amounts of expense and receipt items, m³/sec.

Expense items

- evaporation
- discharging into the Aral Sea water intake
- outflow into the lower aquifer system
- outflow into the upper aquifer system
- outflow within the external boundaries of the 1st type
- outflow within the external boundaries of the 2nd type
- discharge of artesian flow wells
- outflow within the internal
- boundaries of the 1st type
- outflow within the internal boundaries of the 2nd type

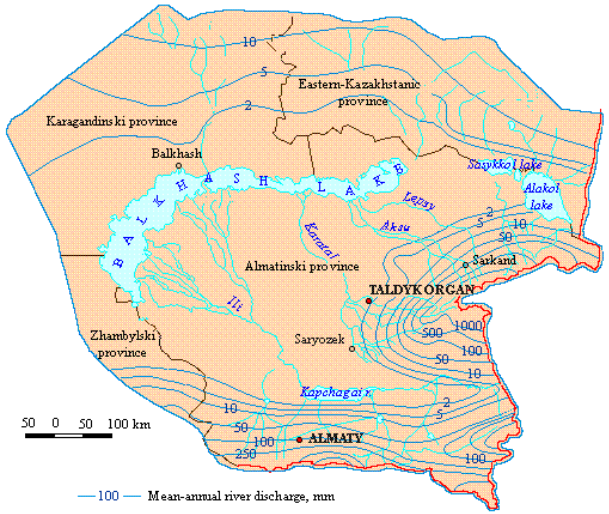
Receipt items

- Areal delivery
- inflow from the lower aquifer system
- inflow from the upper aquifer system
- inflow within the external boundaries of the 1st type
- inflow within the external boundaries of the 2nd type
- inflow within the internal boundaries of the 1st type
- evacuation of natural resources

Model of the large internal-drainage South Sub-Balkhash Depression

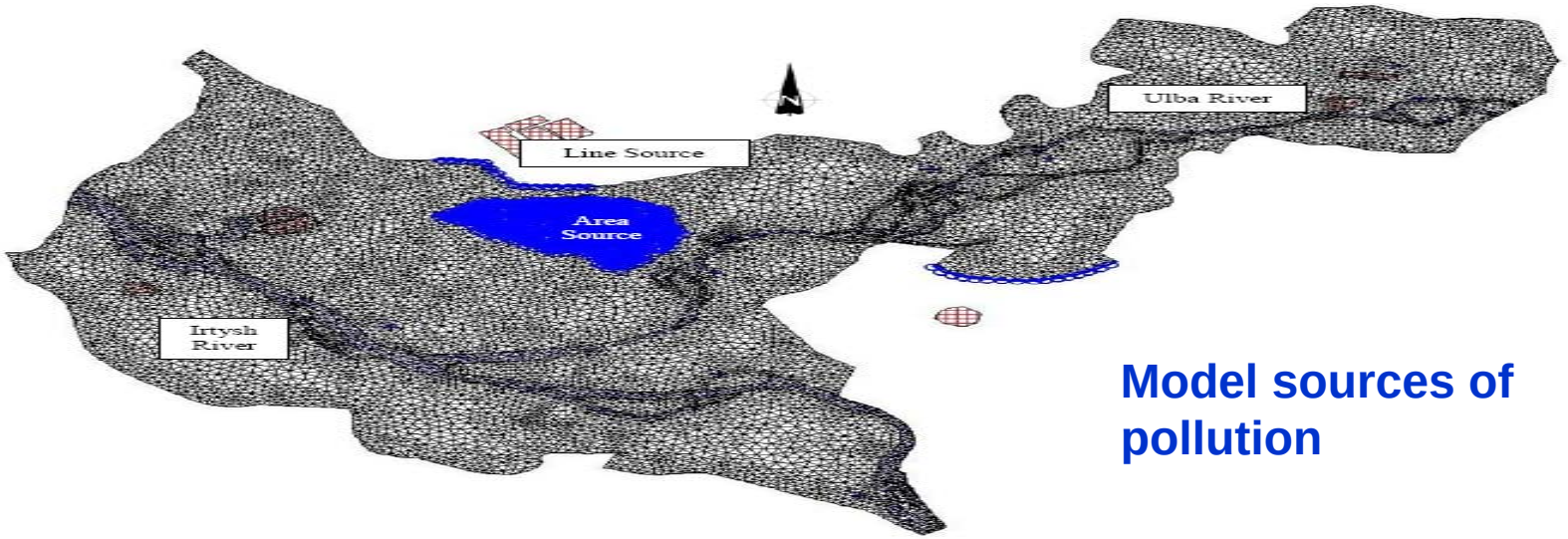
Hydrographic network of the South Sub-Balkhash area is presented with the rivers Ili, Karatal, Aksu and Lepsy with their numerous tributaries.

The Ili River gives about 80% of the whole water discharge of Balkhash Lake, including 70% of water discharge forming in the territory of China where intensive development of agriculture invites danger of further reduction of water discharge to Balkhash Lake.



Modelling of ground water filtration and mass transfer of contaminants near the city of Ust Kamenogorsk

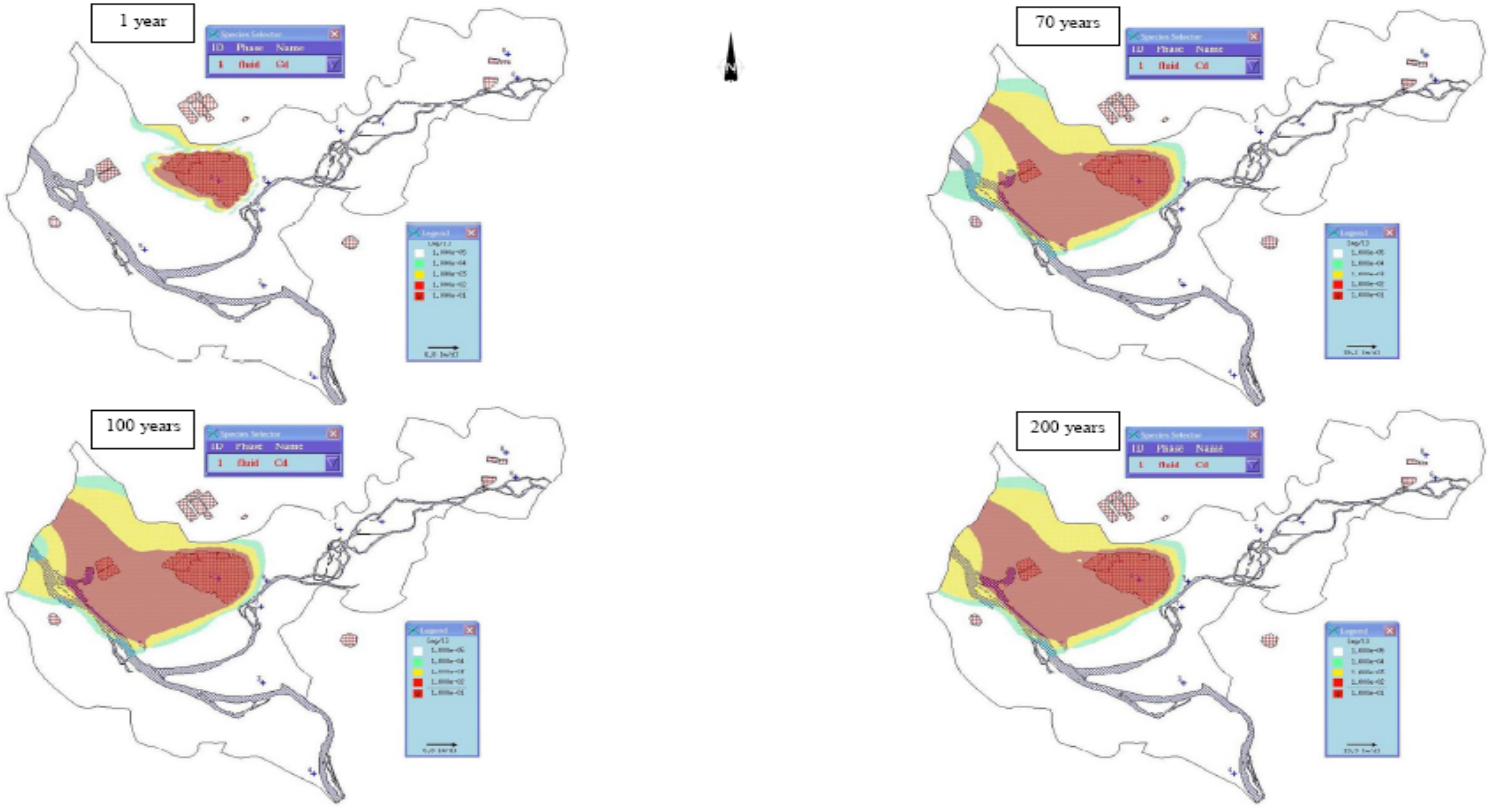
Estimation of alternative variants of quality management of the polluted underground waters on the basis of updating of numerical model of ground waters filtration and mass transfer executed by the Wismut (2005) on the basis of results of field and laboratory researches carried out by the SNC-Lavalin International Inc in 2009.



Model sources of pollution

Modelling of ground water filtration and mass transfer of contaminants near the city of Ust Kamenogorsk

Model plumes of cadmium and selenium are moving towards the Oktyabrsky water intake and the Irtysh River and these plumes will reach them less than in 70 years

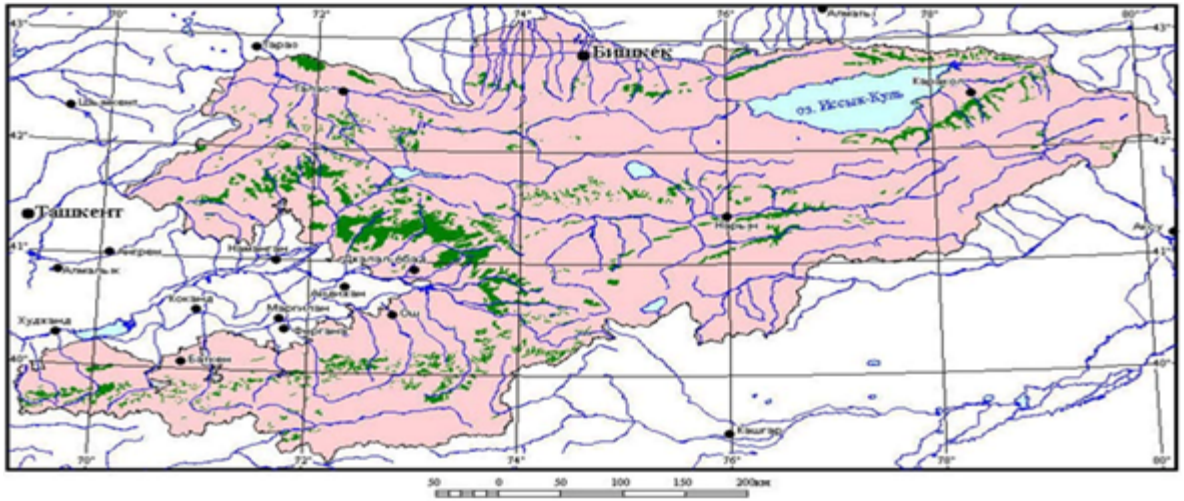


New regional model in Kazakhstan (IFAS)

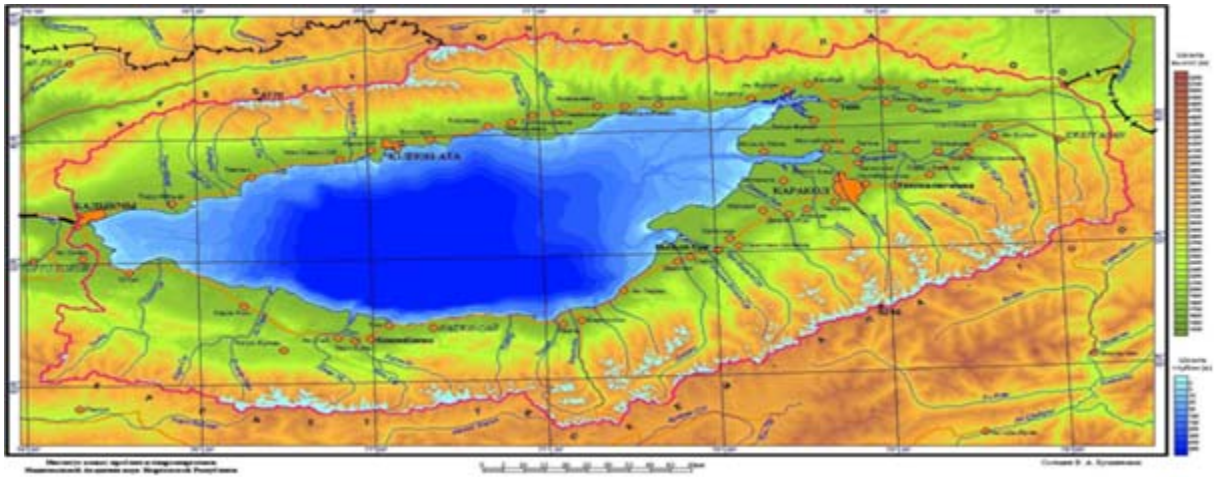
- **BEAM** - Basin Economic Allocation Model

  In 2012 DHI and COWI, in cooperation with the Global Water Partnership CACENA, develop an economic model for water use in the Aral Sea Basin on behalf of the International Fund for Saving the Aral Sea (IFAS). The project is funded by USAID.
- The model is developed on the basis of a comprehensive analysis of the economic value of the integrated use and conservation of water resources in the Aral Sea Basin. It shall serve as a decision support tool to policy makers in the region.
- It will assess the economic value of various allocations of water by countries (especially, Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan and Uzbekistan) and sectors (agriculture, energy, industry, domestic and nature).

Examples of models in the Kyrgyz Republic: Model of Forests

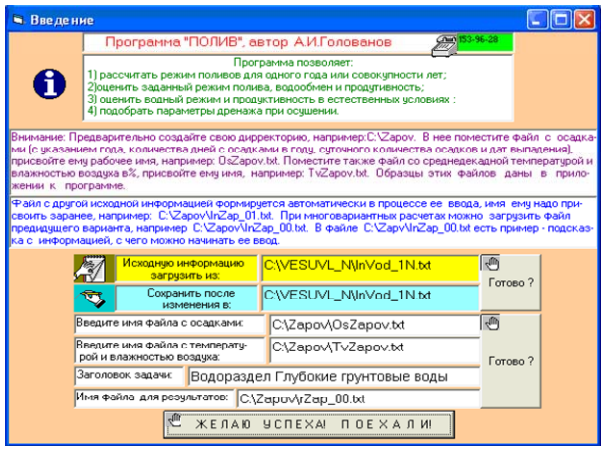


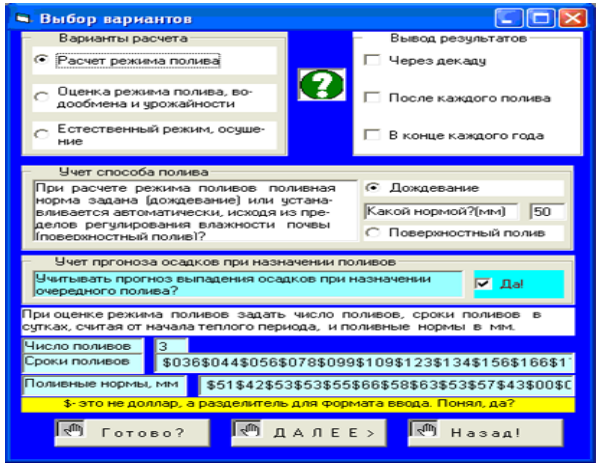
Model of the Issyk Kul Lake basin

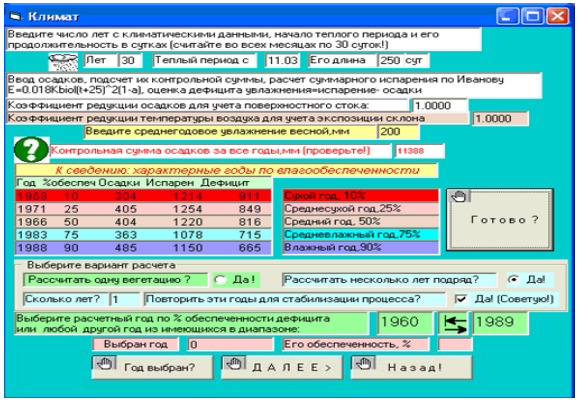


Mathematic “IRRIGATION” simulation system

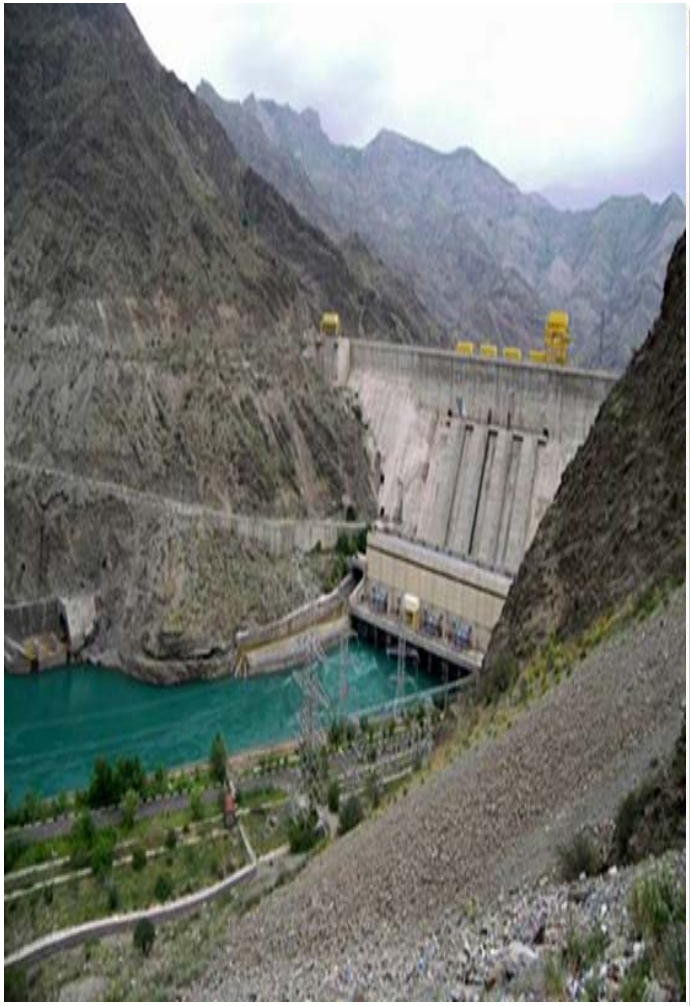
Interface of the “Irrigation” model by A I Golovanov

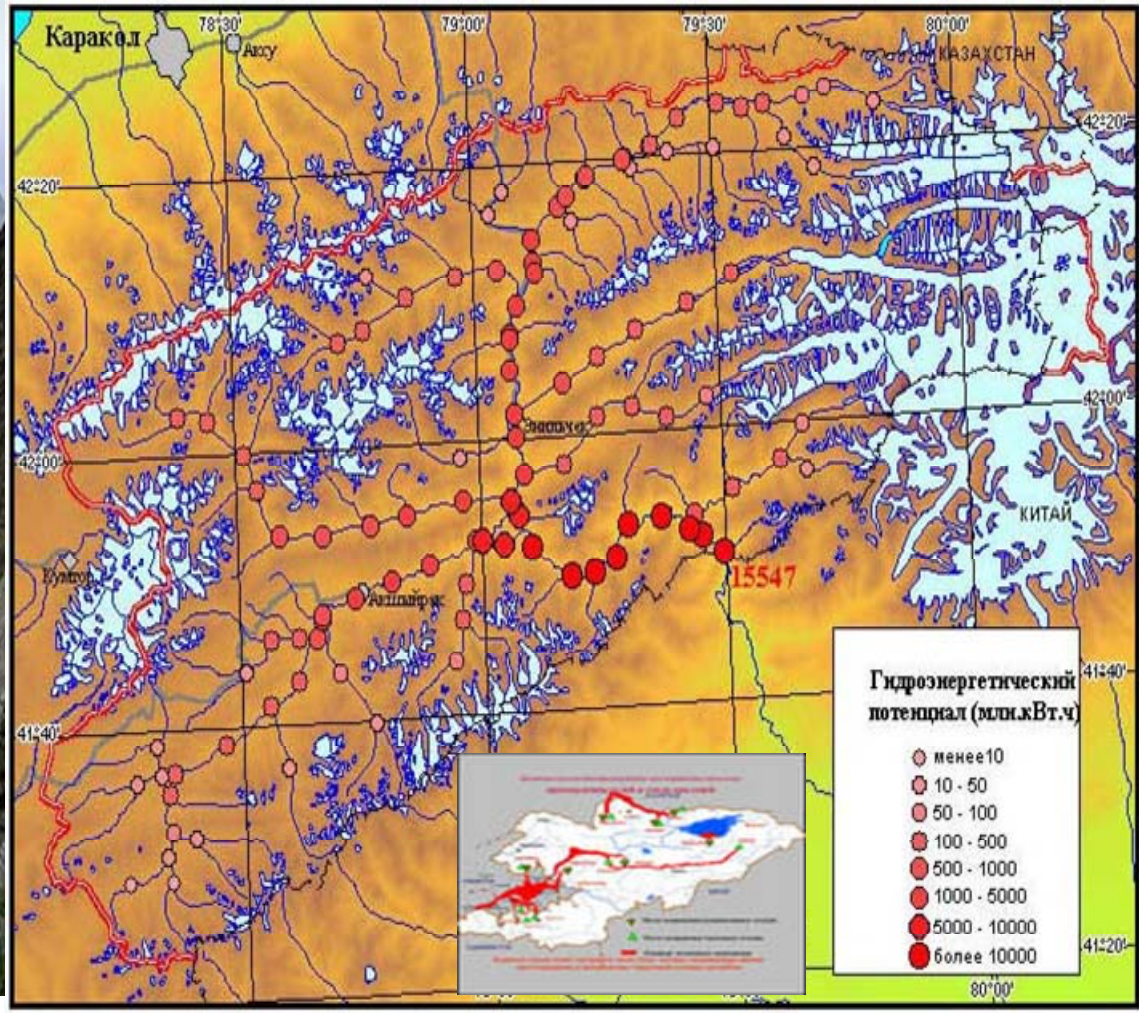






Model of hydroelectric potential assessment

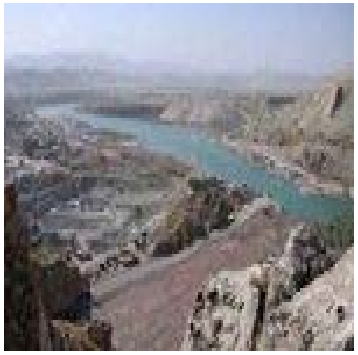




Example of regional model in Uzbekistan (SIC ICWC)

ASBmm software includes the following:

1.Water Resources Distribution Model (WAM)
2. Planning Zone Model (PZM)
3. Social and Economic Model (SEM)
4. Package of the water ecosystems models
5. Database
6. Control program
7. User web-interface



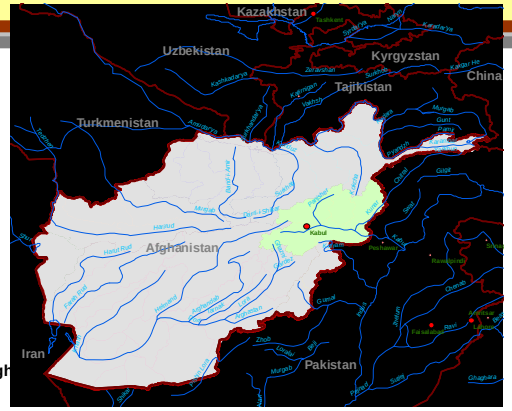
Results of the Comparative Analysis

Model / *escriptor*	1. NIBA-DSS	2. ASB MM	3. EPIC	4. TWEP-NAPSI	5. Syr-Dary Real-Time RBM	6. MMTB	7. ASBOM	8. Aral-DIF	9. Economic Allocation	10. Public Domain
ectors red; essing ate change	No water quality or climate change. But upgradable	Agriculture, irrigation, drainage, hydropower, domestic water supply. Limited flood simulation.	Only flows & salinity. Some irrigation, reservoirs, and hydropower. No ecology or climate change	Hydropower and irrigation reservoir rules. No demands.	Hydropower demand, irrigation demand, conjunctive use, reservoir operations; Real-time climate change. No water quality	Strong hydropower. Rigid subsector demands or climate change.	Agriculture, irrigation, drainage, hydropower, domestic water supply. Limited flood simulation. But upgradable	Limited to flood routing and basin water balance. No irrigation, water quality, hydropower. But upgradable	Balancing irrigation, hydropower, environment flows , domestic and industrial uses. Limited/no hydrologic/ spatial modeling or multiyear reservoir operation.	Ecosystems & hydrology. No hydropower or irrigation.
oral ution ining on)	Monthly	Monthly	From day/hour to year/decade	Short-term. Time travel limited	Real-time management.	Daily; But time travel limited	Daily (hourly doable)	Daily (hourly doable)	Monthly	Likely long term
al coverage; bility	Only Nura Ishim, Balkhash Lake, Alakol Basin and tributaries	Both rivers (Aral Sea Basin)	Both rivers	Syr-Darya reservoirs only. No Basin nor national boundaries	Only Syr Darya Basin; scalable (Amu Darya under development)	Aral Sea Basin with more focus on Syr-Darya (& more basin than national)	Both rivers (Aral Sea Basin); scalable	Both rivers (Aral Sea Basin); scalable	Both rivers; scalable	Needs major work to cover CA both basins
nization or lation; and ain goal.	Optimization. Economic allocation of water amongst municipal, industry, irrigation, environment.	Optimization; Economic inter-sector water allocation. More educational.	Optimization. Minimizes salinity and water deficits.	Simulation. Reservoir operating rules for reliable irrigation and hydropower.	Simulation Short-term only. Long-term needs added module. Flood management and allocation.	Simulation & cross-nation optimization. Hydropower and related reservoir operation.	Optimization (after several simulations). Economic inter-sector water allocation.	Simulation. Flood management and allocation.	Optimization. Maximizes return on investments per country or per sub-basin zone	Usually simulations
of data ss (including alibration)	Data needed for calibration and validation	Relatively yes. Based on CAREWIB database	Unclear database	Relatively yes. Main source is National Hydromet Services.	Remotely-sensed. But Radar altimetry data need agreement with European Space Agency (not cost free).	Data collection needed	Relatively yes. But data needed for calibration and validation	Relatively Yes. Mostly remotely-sensed.	Relatively Yes. (needs mostly Meta data)	Data collection needed
ssibility at nal and nal levels	Based in Kazakhstan (SCWR). Relatively accessible	SIC ICWC	Relatively accessible	USAID owned	Danish Technical University. Not based in CA. But can be procured at	Academy of Sciences of Tajikistan	SIC ICWC; potentially accessible	Accessible	EC-IFAC owned. But soon will make it public domain	Accessible

Authors: *Daryl Fields , Ahmed Shawky, Martha Jarosewich-Holder. Hiromi Yamagochi, The World Bank*

Modeling Basin Planning (e.g. Kabul River Basin in Afghanistan)

Kabul River Basin System Schematic



13 Storage & Hydro Options
6 Conveyance Options
5 Groundwater Options
14 Irrigation Areas

- Proposed DWS
- Existing Irrigation scheme
- Proposed new or expansion of existing irrigation scheme
- Environmental flow requirement (EFR)
- Existing Reservoir
- Proposed new reservoir
- Existing Reservoir to be rehabilitated
- Aquifer Node
- Connection Node
- Start Node

Planning requires a *systems approach* in the basin rather than a project-by-project approach

Author: Nagaraja Rao Harshadeep, The World Bank

http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2010/04/12/000333037_20100412001029/Rendered/PDF/522110ESW0Whit1anistan0Final0Report.pdf

Conclusions

1. Review of models represented in the presentation shouldn't be considered as absolutely full. It can be considered as preliminary but, nevertheless, it gives an idea of the basic types of models and databases in the field of water resources and water-power engineering available in the countries of Central Asia. In total, about 50 models have been presented.

2. Different organizations developed various models in the region of the Aral Sea basin during various time. Objects of modeling included rivers, water reservoirs, lakes, ground waters, irrigation areas and water economic complex of the whole river basin. There were also developed models of objects influencing water resources formation (glaciers, relief and forests) and using water resources (for example, models of hydroelectric potential estimation).

3. In some countries models in the field of water resources and water-power engineering are not available (because they were developed a lot of time ago and then lost – as, for example, in Turkmenistan). In a number of the countries the models of estimation of fresh ground water resources and stocks are not available because of privacy reasons.

4. The executed inventory of databases and models has shown that 2 regional models of the Syr-Darya and Amu-Darya Rivers basins stored in the SIC ICWC (model **ASBmm)** and in IC IFAS (mode**l BEAM**) can be the most useful to create a model of decision-making for the territory of the Aral Sea basin. At the same time practically all other models should be considered as a database.

5. In the process of inventory a lot of experts (developers of models) and users of these models (representatives of the ministries) stated that if the World Bank in the future developed a single model for the whole region each country should have such a model.

6. In the process of development of the Aral Sea basin model, it should include initial data of every particular country which all states can entrust to. There should be confidence to the software product as well. The results of modeling can be considered as an authentic basis for making every possible decision only subject to these conditions.

7 A coherent idea of benefits and losses of each state which can be received as a result of creation of new model of the Aral Sea basin is one of really possible ways of meeting of the minds and development of cooperation between the states concerning joint management of water and energy resources of the basin.

Thank you for attention

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