ACTION PLAN # 9

Appendix 6

Brief Introduction to the ASBOM and RIBASIM models

1 INTRODUCTION

1. The original Project Terms of Reference note that the lack of management tools and efficient information systems and reliable databases has been to date a major constraint to progress in establishing a framework for Basin water management. They state also that models are essential for the planning process as well as for later use in the development and implementation of the policies, strategies, and action programs. Hence, the Project had a major Basin Modelling component.

2. The models are seen as being needed during the planning process to simulate current and future water and salt balances at the planning zone level and at the level of the Amu Darya and the Syr Darya river basins. They are also to be capable of being used later for various purposes including: (i) monitoring water resource conditions, (ii) assessing regional and national projects and actions, and (iii) predicting the outcomes and consequences of various actions.

3. The models are required to have the capability to analyse water use, salinity, the inter-connected groundwater systems, and their economic and ecological impacts in all the planning zones including the specific interactions between rivers and command areas, and between surface water, groundwater and salinity in each zone.

4. The Terms of Reference required a careful evaluation of existing models that might be utilised for the above purposes, to ensure that they:

- are based on proven and appropriate scientific principles,
- can be readily understood and can be readily transferred to local agencies,
- are sufficiently versatile for the various purposes,
- are formulated at an appropriate level of detail,
- provide full simulation of the hydrological and salinity characteristics of transboundary waters.

5. In the early stages of the project it was agreed that the tools to be used in the project would be augmented by appropriate optimisation models for the whole Aral Sea Basin and/or separately for the two river basins. The concurrent expansion of the project scope of work to include energy issues, as far as relevant, resulted in a requirement for the development of an optimisation model integrating the water and energy systems of the Basin.

6. After evaluation of existing models, it was concluded that in view of the requirements a new set of modelling tools had to be developed for use in the project and for later use by the project beneficiaries. Essentially two types of models were needed:

- an optimisation model
- a simulation model

7. The purpose of this document is to provide a brief introduction to these models.

2 ARAL SEA BASIN OPTIMISATION MODEL (ASBOM)

8. Earlier models consider the Aral Sea Basin as a single region, and their aims are to maximise the benefits on this basis. This approach has been adopted for some years now, but has not resulted in better co-operation between the countries with respect to more rational use of water and energy in the basin.

9. There are a number of reasons why this approach fails, of which the most important are:

- the two river basins – the Amu Darya and the Syr Darya – have different physical characteristics, problems, and interested riparian parties; their linkage by a power grid is a not sufficient basis for adopting a single region approach,
- the individual countries have different economic approaches to market economy, which makes comparison of the results inconclusive and subject to different national interpretations,
- the countries have become independent only relatively recently, and acting as a regional unit may be many years off.

10. After discussions with the countries, and in line with the recommendations of the Independent Panel of Experts, the project opted to consider and model the region in five different national modules. In conceptualising the situation the countries can be divided into upstream countries (Kyrgyzstan and Tadjikistan) and downstream countries (Uzbekistan, Kazakhstan and Turkmenistan) distributed within two separate river basins.

11. The upstream countries have large hydropower generation facilities and relatively small thermal power facilities, and the irrigable areas are relatively small. In contrast, the downstream countries have large irrigable areas, large fossil fuel resources available for thermal power generation, and little in the way of hydropower generation capacity. The optimal water use will therefore differ between the upstream countries and the downstream countries.

12. The Aral Sea Basin Optimisation Model (ASBOM) has been developed in accordance with this concept, combining technical, economic, environmental and agronomic aspects into a coherent framework. The model consists of five different national modules, although both the Tadjikistan and the Uzbekistan module contains two segments – one for the Syr Darya basin and one for the Amu Darya basin. Each module consists of Water Network and an Energy Network. The Water Network comprises the river(s) major supply systems and collector drains and the planning zones. The Energy Network contains energy supply nodes that are fed by hydropower and thermal power stations, and energy demand nodes. The interconnection between the two networks comes about from the fact that water released from reservoirs for irrigation purposes generates hydropower, or conversely water released to generate hydropower is used for irrigation or will contribute to the ecology of the wetlands and the Aral Sea itself.

13. The goal in the case of each national module is to optimise the water use benefits for the particular country. If energy benefits are larger than land use benefits, the optimisation model for upstream countries maximises hydropower generation, which

gives the water release as output. If the land use benefits are higher than the energy benefits, the maximisation of land use (cropping patterns per planning zone) has priority over hydropower generation. The output of the model is always the preferred water release and water use.

14. Because of the different objectives of the upstream and downstream countries, there is likely to be a considerable difference between countries in the two groupings in terms of the optimum pattern of water releases, and some form of compromise will be required. The ASBOM will be a useful tool for evaluating the benefits of various compromise situations, which may include transfers of energy and/or water between countries, or compensation payments to or from individual countries for benefits foregone or gained in particular situations. It should provide a useful vehicle for direct energy/water negotiations between the upstream and downstream countries, and help in formulating a general framework in which negotiations can be undertaken. Whilst useful for comparative studies of different options or scenarios, however, model results in absolute terms should be treated with caution in view of the sometimes poor technical data and uncertain economic parameters that have to be used.

15. The ASBOM has been constructed as a non-linear holistic model, composed of five relatively small independent modules. Each module (one for each country) combines all sub-models into a consistent whole, which is solved in its entirety. A schematic overview of the model is presented in Figure 1.

16. The optimisation of water use is carried out for a single year with 12 monthly time steps. The input flow data are monthly averages (over the 1960-2000 historical flow sequence).

Optimisation model

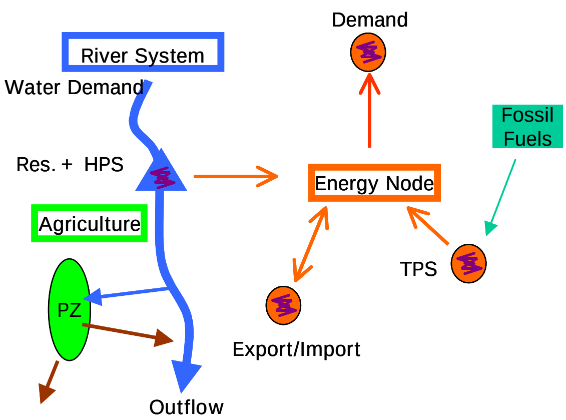


Figure 1 Concept of the Optimisation Model

Optimisation Scenarios

17. The optimisation scenarios are the same for the upstream and downstream countries, but the outcomes will differ. In the case of the upstream countries the monthly reservoir outflow is a free variable, with total outflow limited only by the total inflow. In contrast, the downstream countries have a free water demand variable, restricted by the total inflow

18. In all modules three alternative optimisation processes are available:

- Optimisation of the total benefits, with the restriction of exactly fulfilling the *energy* demand in the country concerned (if there is sufficient capacity in the country). In this case the total hydropower and thermal power generation (plus imports where necessary) equals the total power demand.
- Optimisation of the total benefits *without further restrictions*. The total benefits will be maximised by land use or by power generation or by a combination of the two. If land use benefits are higher than energy benefits or energy cost reduction, the model will optimise the land use first even for the upstream countries.
- Optimisation of energy generation and land use using *agreed* (e.g. as a result of negotiations) monthly reservoir outflows. This alternative would enable evaluation of various compromise positions between upstream and downstream countries.

Note that, in order to implement the old Soviet water allocation system (or any other), the modules have the capability to restrict the total flow that can be used consumptively.

19. If water is released from reservoirs during the non-vegetation period it will generate hydropower, but the water will often be lost for irrigation (it can sometimes be used for leaching) and may be spilled (e.g. to Arnasay) or flow through to the Aral Sea to meet environmental demands. When the water is released during the vegetation period it will generate hydropower and will be used for the irrigation. However, the energy demand in winter is higher than the energy demand in summer. The water releases

depend on the countries' use and need of the resource. The monthly reservoir outflow is the free variable in the reservoir equations.

20. For sustainability the reservoir levels at the beginning and end of the hydrologic year have to be the same in the two first optimisation scenarios. This is not necessarily the case in the third (agreed outflow) option because the cases studied may allow depleting the storage to some extent.

Generated Hydropower

21. The generation of hydropower is directly connected to the reservoir water releases and vice versa. Hydropower generation is governed by the power station characteristics like installed and available capacity, efficiency, etc, as well as by energy demand and available thermally generated energy.

Power Grid

22. Nodes and arcs represent the power grid, with each country being represented as a node. Hydropower is generated by the reservoir releases, whereas thermal power generation depends on the demand, generated hydropower and the availability of fossil fuels. Each node has demand and both thermal and hydropower stations. Generating capacity and costs of each plant are specified. Power can be imported and exported between nodes, with transmission line capacity limiting the extent of imports and exports. The gross generated power minus the transmission losses gives the net power. The least cost dispatch for the energy system is calculated subject to constraints on transmission (line) capacity and generating capacity.

Planning Zones

23. The optimal cropping pattern of the planning zones (i.e. the areas under each type of crop in the planning zone) depends on the soil type, climate, yields, net agricultural benefits and energy use. There are four categories of soil type. The possible cropping pattern and crop water use may change depending on soil type. The minimum cropping pattern depends on the needs within the planning zone for food, water and work. The irrigable area mostly defines the maximum cropping pattern. The cropping pattern is the free variable in the PZs, which defines the water use in the PZ, subject to minimum and maximum limits to crop area.

24. The energy demands of pumped irrigation schemes (e.g. Karshi, Bukhara, etc.) are calculated and included in the energy balance.

Wetlands and Deltas

25. The model has the built-in capability to allocate a certain percentage of the total monthly inflow to a country towards meeting the environmental requirements of the Aral Sea and river deltas, thus limiting the total water resource available for other purposes.

Flowchart of the Water and Energy Resources Allocation Model

26. The water and energy allocation in ASBOM has partly been drawn in a flowchart. The flowchart is a representative segment for the model. The segment contains one reservoir with a hydropower station and one planning zone downstream of the reservoir. From the flowchart, the interaction between the different decision variables is made clear. For upstream countries there are three free variables and for downstream countries only two.

27. In the cases of the first two alternative optimisation processes described previously, the first decision variable for upstream countries (‘Reservoir Outflow’) determines the amount of hydropower generated. Therefore the thermal power generation is a decision variable, which is constrained by the installed generating capacity and the available fossil fuels, but depends on the generated hydropower and the energy demand. The third decision variable is the cropping pattern, which depends on the irrigable area and the power demand and generation. In the case of downstream countries, the cropping pattern is the first free variable that defines the upstream flow and thus the reservoir releases and the hydropower generation. The second free variable is the thermal power generation.

28. In cases in which agreed reservoir outflows are to be evaluated (the third optimisation alternative), the first variable is thermal generation because the hydropower generation is defined by the reservoir outflow. The second variable is the cropping pattern.

29. The flowchart shows that the decision variables - cropping pattern, reservoir releases and thermal power generation - constrain each other. The objective is to generate the maximum benefits so that the energy demand and water demand in relation to social and environmental circumstances are fully met. The flowchart of the allocation model is given in Figure 2.

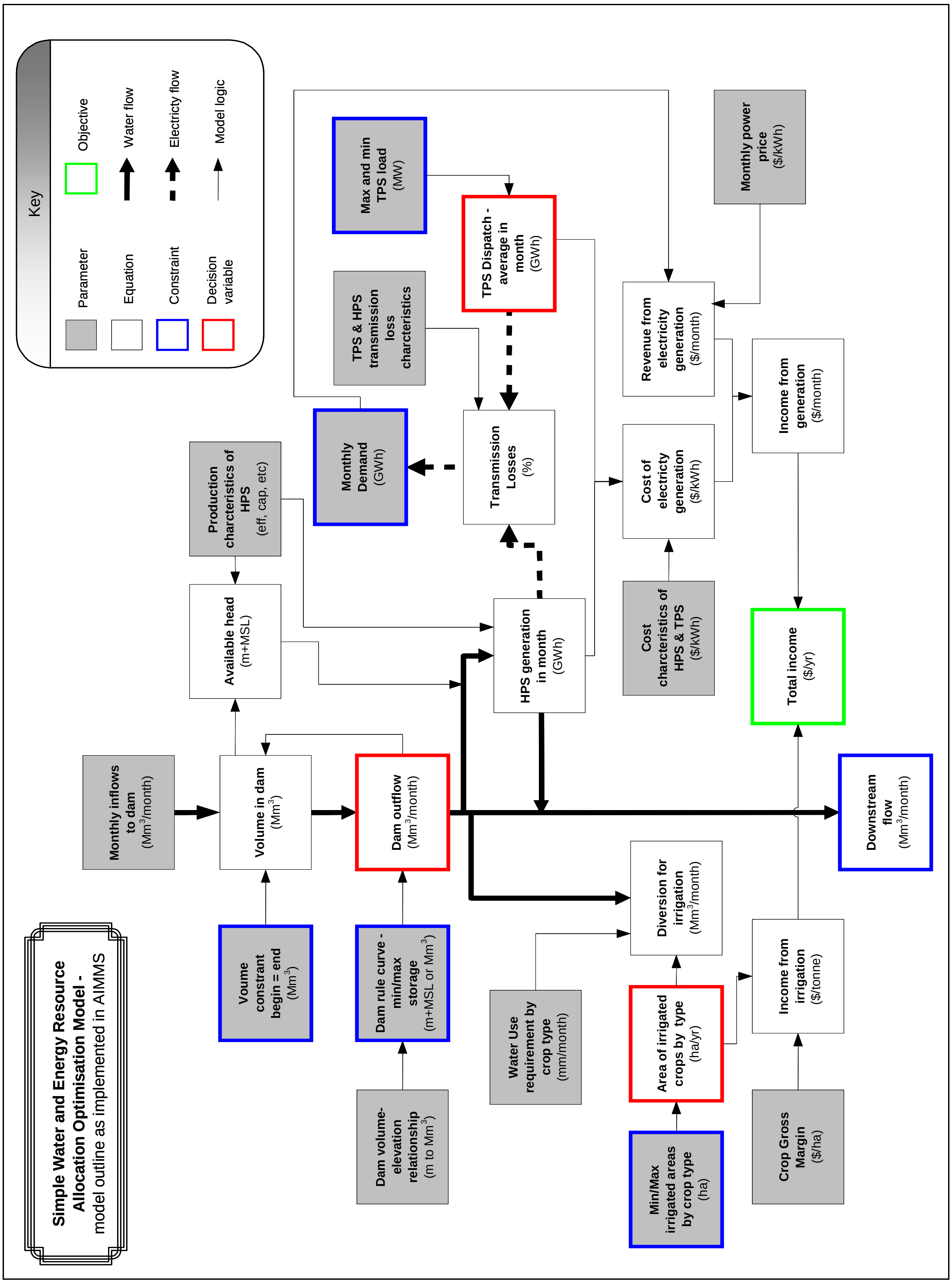


Figure 2 Flowchart of Water and Energy Resources Allocation Model

30. A brief description of the national modules is presented in the following sub-sections. These modules are shown in the following order: Kyrgyzstan, Tadjikistan,

Uzbekistan, Kazakhstan, and Turkmenistan, as this is the most logical way from upstream to downstream. A schematic overview of the total Aral Sea Basin and the main electric grid links is presented in Figure 3.

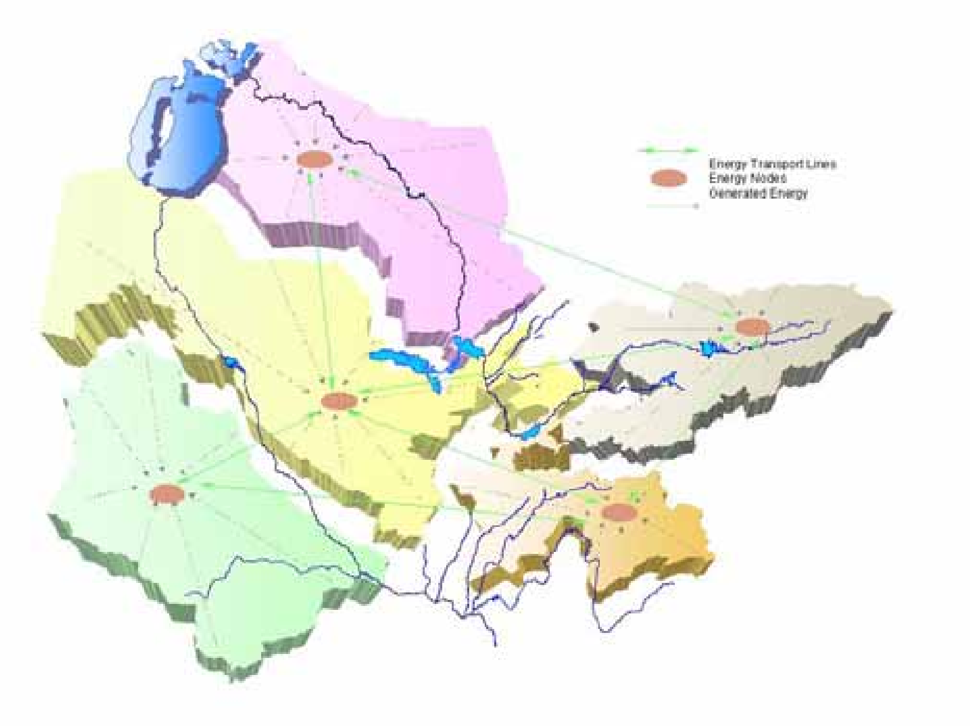


Figure 3 Schematic Overview of ASB

Kyrgyzstan Module

31. As an upstream country in mainly mountainous terrain, Kyrgyzstan has large hydropower resources but only relatively small irrigated areas. It contains two main tributaries, which join to form the Syr Darya in Uzbekistan - the Naryn River and the Karadarya. Tributaries upstream of the junction of these two rivers are modelled as a single entity.

32. Large reservoirs have been constructed on the main tributaries and on the Syr Darya itself, the main one in Kyrgyzstan being Toktogul. Downstream of Toktogul there is a series of four small but relatively deep reservoirs (Kurpsay, Tashkumir, Shamaldysay and Uchkurgan) with high hydropower generation capacity. These depend on releases from Toktogul for through flow. A further project, the Kambarata Hydroelectric Project, which is proposed but has not yet been constructed, would consist of two reservoirs upstream of Toktogul. These reservoirs have been included in the model and can be activated or de-activated as required.

33. The Syr Darya system in Kyrgyzstan consists of five Planning Zones: Naryn Upper Reach; Naryn Middle Reach; Fergana Valley North; Fergana Valley South; and Kampar Ravat. One PZ (Alai) in the Syr Darya basin is supplied only from local water resources and has been omitted from the model.

34. Exports or imports of energy are constrained by the Central Asian grid transmission capacities. All hydropower and thermal power produced in Kyrgyzstan node can be used in the country and can be exported to Uzbekistan or South Kazakhstan. The most important thermal power stations in the nodes are Osh and Bishkek, while the most important hydro-power stations are: Toktogul, Kurpsay, Tashkumir, Shamaldysay and Uchkurgan.

35. The structure of the module is illustrated in Figure 4.

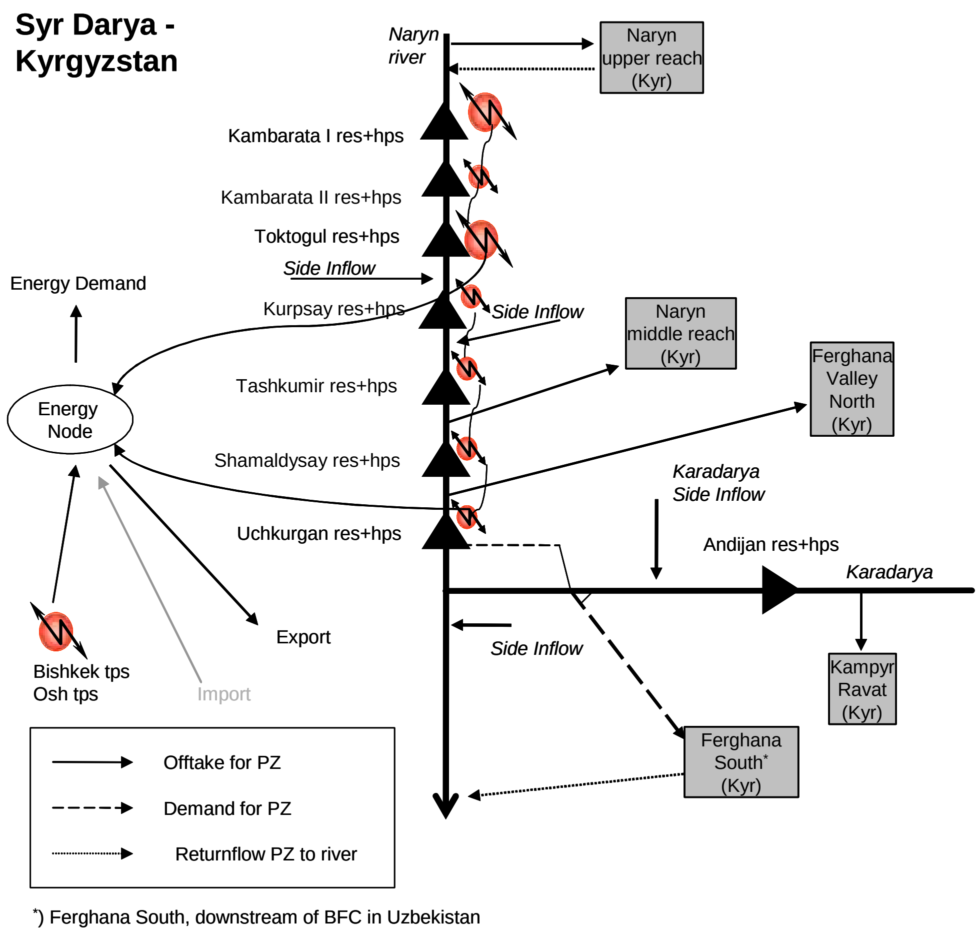


Figure 4 Kyrgyzstan Module

Tadjikistan Module

36. Tadjikistan is an upstream country with water resources from both the Syr Darya and Amu Darya systems. The Syr Darya flows from Kyrgyzstan through Uzbekistan into Tadjikistan and has no significant tributaries in the country. The main tributaries of the Amu Darya include: the Vaksh River; Pyandj River with its tributaries the Kzylsu and Yaksy Rivers, Kunduz River; and Kafirnigan River. Large regulating reservoirs have been constructed in Tadjikistan on both the Syr Darya (Kairakkum) and the Vaksh River

(Nurek). Downstream of Nurek is the Vaksh Cascade, which consists of two small reservoirs (Baypazin and Golovnaya) which are purely for hydropower generation.

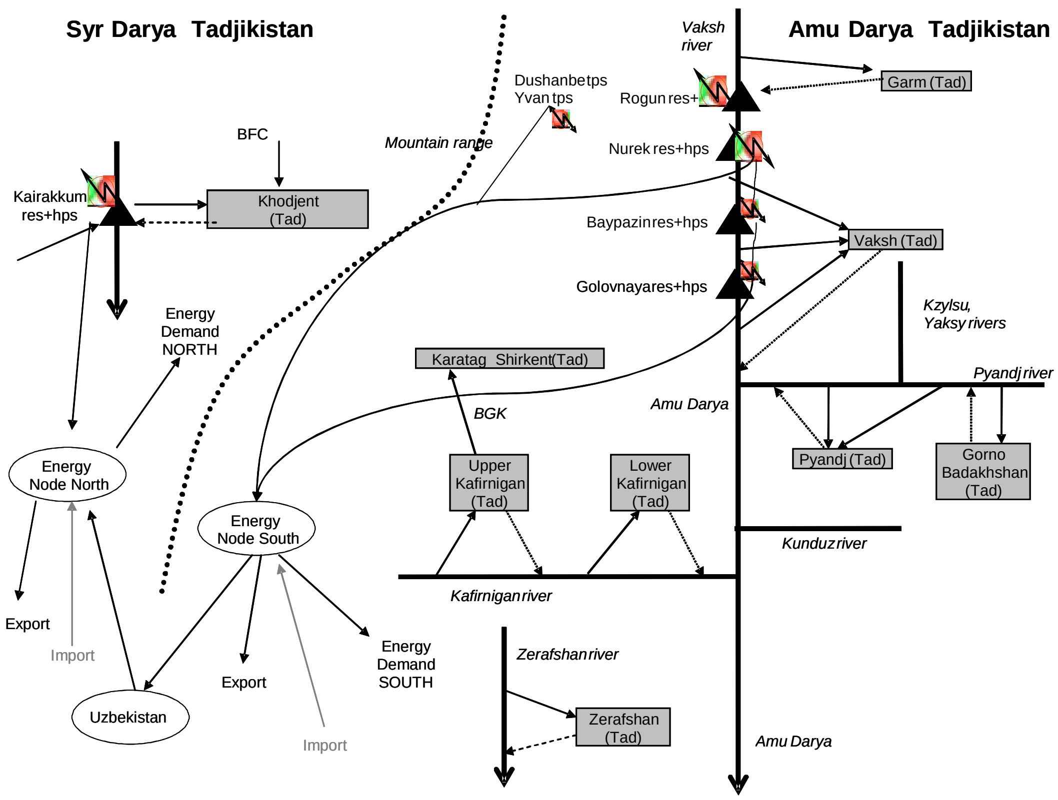
37. Tadjikistan planned and started the construction of other reservoirs, the most important of which was Rogun. Construction of these has stopped, however, and also a plan has been studied to construct a tunnel to connect the Pyandj with the Vaksh River in order to generate more hydropower in winter. Rogun reservoir and the Pyandj diversion have been included in the module, and can be activated or de-activated as required.

38. The Syr Darya system in Tadjikistan consists of one PZ, while the Tadjik Amu Darya system consists of eight PZs. Two other PZs that are fed by local water resources have not been included in the model.

39. The existing electrical network in Tadjikistan is divided into northern and southern networks. Because of the high mountains in between, the energy transmissions from the south to the north, or vice versa, have to go via Uzbekistan, as do all exports and imports of thermal and hydropower. The most important thermal power stations in the Tadjikistan module are Dushanbe and Yuan, while the most important hydropower stations included are Nurek, Baypazin, Golovnaya and Rogun.

40. A flow chart of the Tadjik model is presented in Figure 5.

Figure 5 Tadjikistan Module



Uzbekistan Module

41. The Syr Darya flows from Kyrgyzstan into Uzbekistan, then through Tadjikistan and back into Uzbekistan. The main tributaries in Uzbekistan downstream of Tadjikistan are the Ahangara River and the Chirchik River.

42. Flows in the Amu Darya from Tadjikistan are divided equally between Uzbekistan and Turkmenistan. Two major tributaries of the Amu Darya within Uzbekistan are the Surkhandarya and the Sherabad (Karasu) River. The Kashkadarya and the Zerafshan River are not directly connected with the Amu Darya, but their waters are used in the planning zones from which return flows enter the Amu Darya.

43. The main regulating reservoirs in Uzbekistan are Andijan (Karadarya, Syr Darya basin), Charvak (Chirchik, Syr Darya basin) and Tuyamuyun (Amu Darya).

44. Each of the Syr Darya and Amu Darya systems in Uzbekistan consists of nine Planning Zones.

45. Adjacent to Chardara Reservoir in Kazakhstan is the Arnasay depression in Uzbekistan. This depression receives drainage water from the Hunger Steppe, and also may receive spills from Chardara Reservoir in Kazakhstan. These occur during high floods and also when releases for hydropower generation are made from Toktogul Reservoir in the non-vegetation season when the flow cannot be utilised for irrigation and the capacity of the Syr Darya further downstream is limited by ice formations.

46. A number of desert sinks have been created in the Amu Darya system. Two are important enough to include in the model - Lakes Sultandag and Solenaye. Lake Sultandag receives drainage water from the Karshi PZ and Lake Solenoye from the Bukhara PZ. Both sinks are used also as holding basins, and overflows are returned to the Amu Darya.

47. The deltas of the two rivers, together with the Aral Sea, are considered in the module as an independent water user.

48. Uzbekistan’s power is mostly thermal power. The energy-producing and energy-using node is Uzbekistan. All hydropower and thermal power produced in Uzbekistan node can be exported to Kyrgyzstan, Tadjikistan, Turkmenistan or South Kazakhstan. The most important thermal power stations in the nodes are Syrdarya, Tashkent, Novo-Angren and Navoi, while the most important hydropower stations are Andijan, Farkhad, Charvak and Tuyamuyun;

49. The flowchart of the Uzbekistan Module is shown in Figure 6.

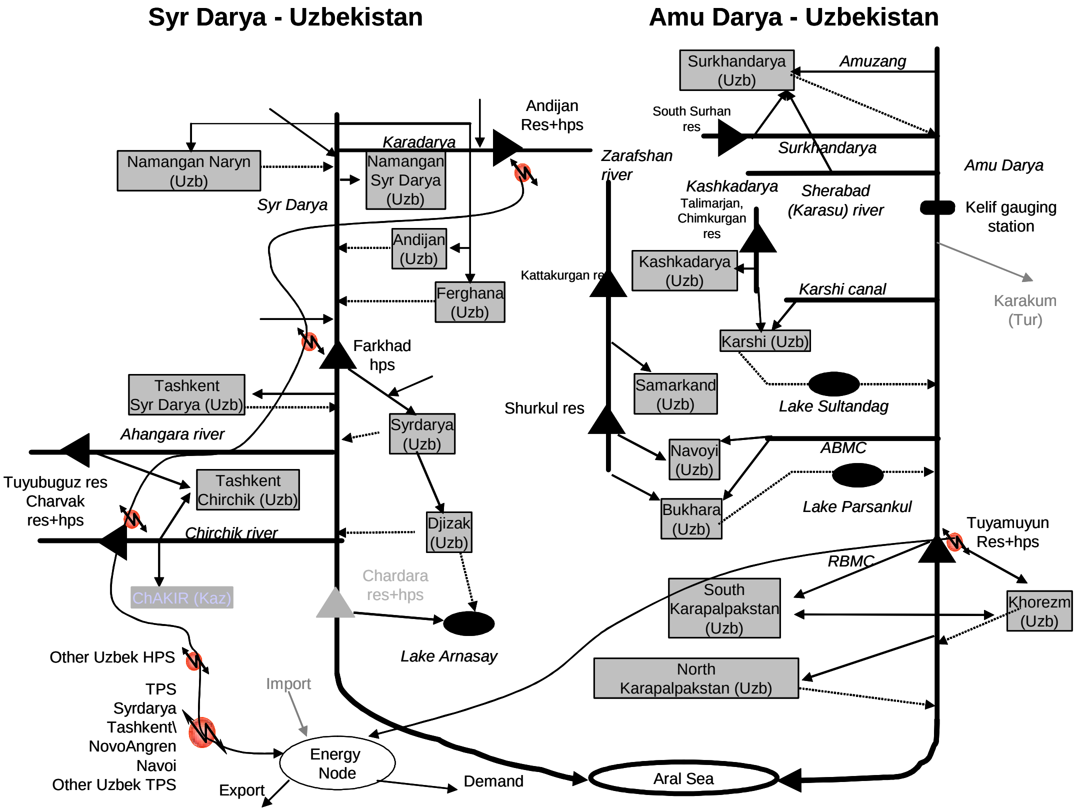


Figure 6 Uzbekistan Module

Kazakhstan Module

50. The most important regulating reservoir in Kazakhstan is Chardara on the Syr Darya. It was constructed to regulate the irrigation water supplies but also generates hydropower. The capacity of the reservoir outlets of Chardara reservoir is limited, while in winter the flow capacity of the river further downstream is limited due to ice formation. The main tributaries are the Keles and Arys Rivers.

51. The Syr Darya system in Kazakhstan consists of five planning zones: Hunger Steppe, Chakir, Artur, Kzylkum, and Kyzyl-Orda.

52. The delta of the Syr Darya is a wetland area, while the northern part of the Aral Sea is still an important area for fisheries. This delta and the Aral Sea together are therefore considered as an independent water user, like the Uzbek northern wetlands on the Amu Darya.

53. The energy-producing and energy-using node is South-Kazakhstan. The most important thermal power stations in the nodes are: Jambul; Shymkent; Kyzyl-Orda; Kentay; and Almaty. The only hydropower station in the node is Chardara.

54. A flow chart of the module is presented in Figure 7.

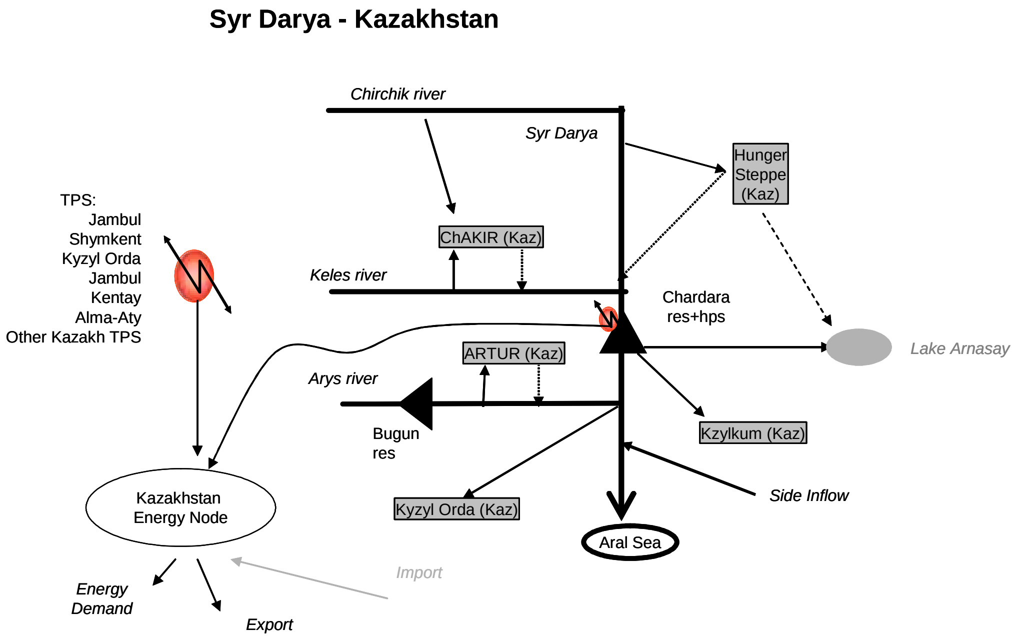


Figure 7 Kazakhstan module

Turkmenistan Module

55. The Amu Darya flows as a border river along Tadjikistan, Afghanistan, Uzbekistan and Turkmenistan, then crosses into Turkmenistan after which it flows to the Aral Sea in Uzbekistan. Near is the offtake to the Karakum River, which runs via Mary to Ashgabat and further west. The total flow at Kelif gauging station is divided equally between Uzbekistan (Amu Darya) and Turkmenistan in accordance with a bilateral agreement. Within Turkmenistan there are no important tributaries of the Amu Darya, but the flows of the Murgab and Tedjen rivers have been included.

56. The most important regulating reservoir for the Karakum River is Zeid, which is an off-stream storage supplied from the Amu Darya. In times when the offtake from the Amu Darya is more than the Turkmen water demand, the water is stored in Zeid. When demands exceed the water availability, water is released from the reservoir.

57. Turkmenistan has five PZs in the Amu Darya basin - Mary, Akhalsk, Lebab, Dashkovus, and Balkan.

58. Turkmenistan only generates thermal power, and the energy-producing and energy-using node is Turkmenistan. The amount of energy generated at the node depends on the energy demand, the transmission losses and the generation costs. All CAR energy import and/or export to the Turkmenistan node has to be transmitted via Uzbekistan. The most important thermal power stations in the nodes are: Mary, Turkmenbashi, Bjuzmen, Seidi and Nebitdag.

59. A flow chart of the Turkmenistan module is presented in Figure 8.

Amu Darya - Turkmenistan

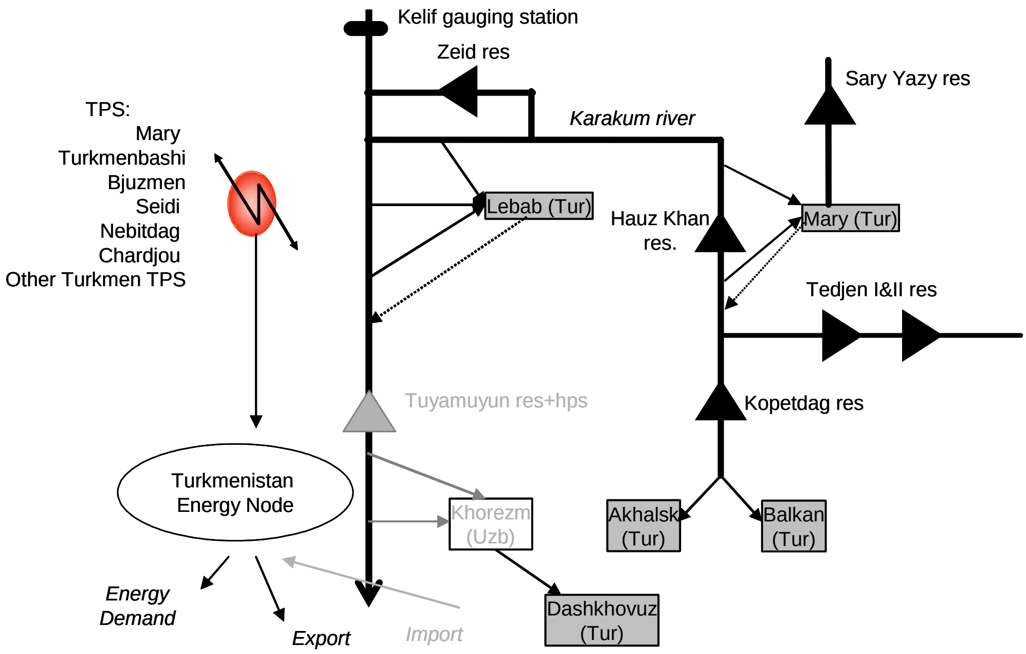


Figure 8 Turkmenistan module

3 RIVER BASIN SIMULATION MODEL (RIBASIM)

60. The main purpose of the simulation model is to evaluate the performance of a defined situation of water use (e.g. current or in future), when such a situation would encounter variations of natural flow over time. It allows to determine if a given water use pattern can be supported by the river flows within acceptable limits of failure or, on the contrary, if such criteria are surpassed to determine where and to what extent water use would have to be adjusted.

61. The RIBASIM simulation software has been used to set up two separate models, one for the Syr Darya and one for the Amu Darya, in order to simulate the water and salt balances. The original version of RIBASIM software was enhanced by the project to have the capability to keep track of salt movements in the system.

62. In view of obtaining consistency between the models and their interaction, the two models comprise the same features as are represented in the optimisation model ASBOM:

- a network of rivers, main supply canals, collector drains
- reservoirs and diversion weirs
- hydro-power stations
- planning zones
- large lake systems and desert sinks

63. The results from the optimisations carried out in ASBOM serve as input sets for simulation of the performance of scenarios over the long term.

64. Both the optimisation and the simulation models provide the water balance for the basins, countries and planning zones. In addition the simulation model provides the salt concentrations in the surface water system and the salt balance per planning zone.

65. The schematisation of the Syr Darya and Amu Darya used in the RIBASIM models is shown in Figure 7 and Figure 8 respectively.

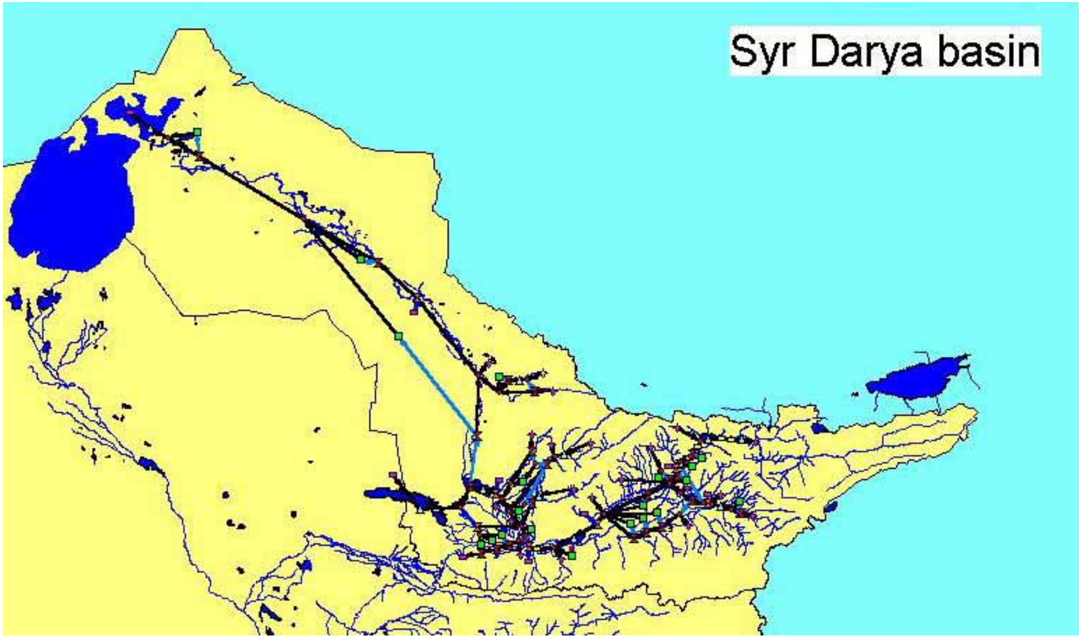


Figure 7 RIBASIM schematisation of Syr Darya basin

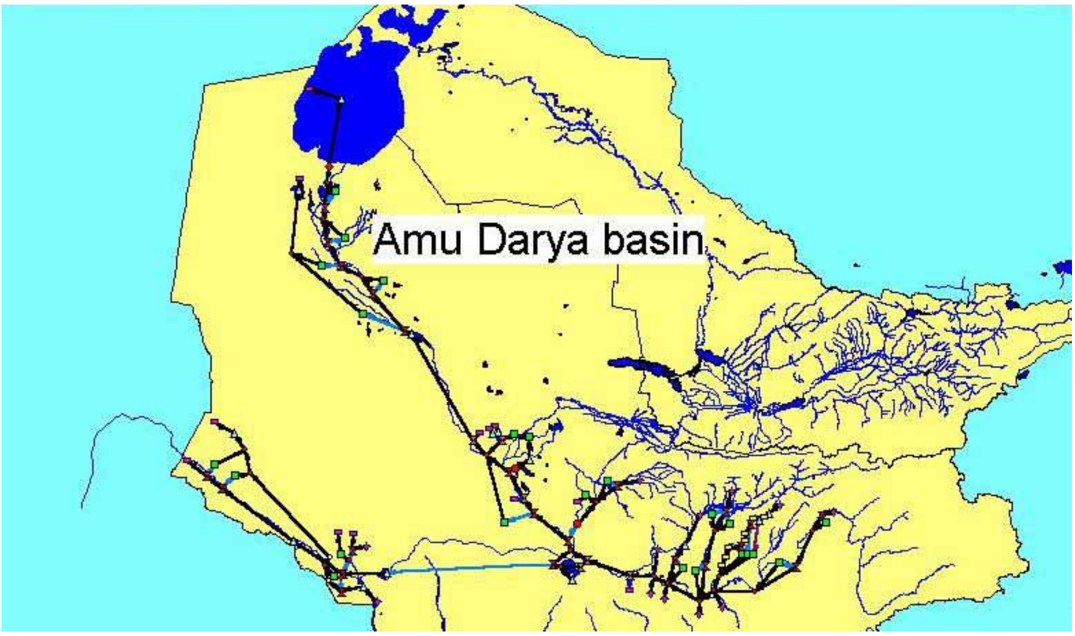


Figure 8 RIBASIM schematisation of Amu Darya basin

4 USE OF THE MODELS

66. The models presented above can be used for two main tasks:

- to calculate water and salt balances in the Aral Sea Basin;
- to provide numerical background for a framework for Basin water and salt management.

67. Once the optimum land use has been established in the various PZs with the ASBOM model, the simulation model is used to calculate water and salt balances for different scenarios. The input water demands are derived from the scenario assumptions regarding extent of irrigation, water quality, cropping patterns etc. The simulation model (RIBASIM) will calculate the water and salt balances in the system, and the energy generated, over the 40-year flow sequence from 1960 to 2000. From this it will be possible to establish how often the system fails, and whether the frequency of failure would be acceptable within the constraints of the scenario. The runs can be used also to manually optimise operating rule curves for the various reservoirs.

68. Apart from the two main tasks, the models could also be used to a certain extent for operational analyses. That is, they could provide answers for very short-term ‘what-if’ analyses.

69. The main outputs from the computer models - subject to various scenarios – are, per planning zone and so per country:

- optimal land use (cropping pattern)
- crop yields;
- irrigation water requirements;
- hydro and thermal power generated.

70. The ASBOM optimisation model calculates the optimal water use in relation to hydropower and land use in each country. Calculation starts with the upstream countries, and then proceeds to the downstream countries. The model calculates in the following order:

- Kyrgyzstan;
- Uzbekistan and Tadjikistan;
- Kazakhstan or Turkmenistan.

The interlinking and interdependencies between countries is illustrated in Figure 9.

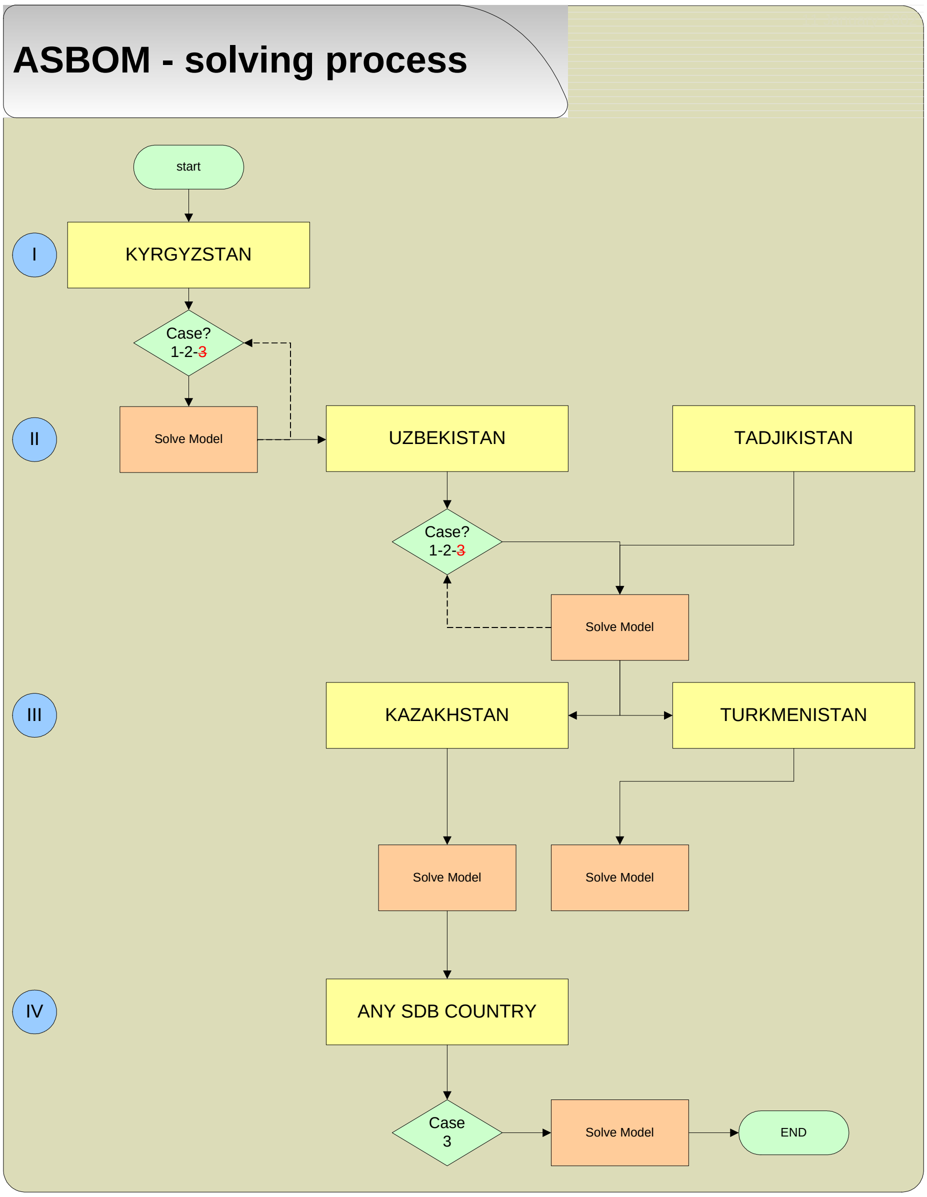


Figure 9 Diagram of ASBOM Solving Process

71. It should be understood that apart from structural data input into the models (data about river capacities, reservoirs, diversion, etc.) there are a number of data that depend on decisions, measures that are going to be taken in the future. For these so-called scenarios have been developed for a time horizon of 25 years. Thus the models will mainly deal with the situation as it is assumed to exist in 25 years time based on various scenarios.

72. The scenarios are, in principle, different for each country and will have an impact on the situation in each planning zone, the smallest spatial and economic unit used in the model studies.

73. The river basins may see further development, i.e. additional reservoirs/HPPs and TPPs. The ASBOM and RIBASIM models have the capability to simply activate the main additional reservoirs and power stations.

74. The models have been developed by the Regional Working Group with assistance from the National Working Groups. It is of importance that the water management organisations in the countries will continue to use the models for their own purposes and in view of the regional work on water cooperation.

75. The Consultant therefore designed a training course for experts from the five countries who will be charged with future model use. The participants in the training were selected by the National Working Group team Leaders on the basis of criteria provided by the International Consultant. In addition, SIC-ICWC, BVO Amu Darya and BVO Syr Darya were invited to participate as well.

76. Before the training, the Consultant developed manuals for the models and software as far as specifically required for the Aral Sea basin models. This material was translated into Russian. Furthermore, tutorials were developed specifically for the training course.

77. The training has taken place from 9 to 13 December 2002 with the participation of 13 experts coming from all the organisations invited. During this intensive one-week course, the participants were able to familiarise themselves with the two software packages, develop small models themselves and to familiarise with the Project models ASMOB and RIBASIM.

78. At the end of the training course all material like software, models, manuals, tutorials have been handed over to representatives of the NWGs, on behalf of the NWG TLs.

79. The set of software licences in use by the Consultant will be handed over to the Client of the Project and should be made available for use by parties who may have an interest in doing so and have been authorised by EC-IFAS to have access to the models.

80. In case modifications would be needed in the models, the EC-IFAS has to ensure that such modifications are consistently carried out in the six sets of the models