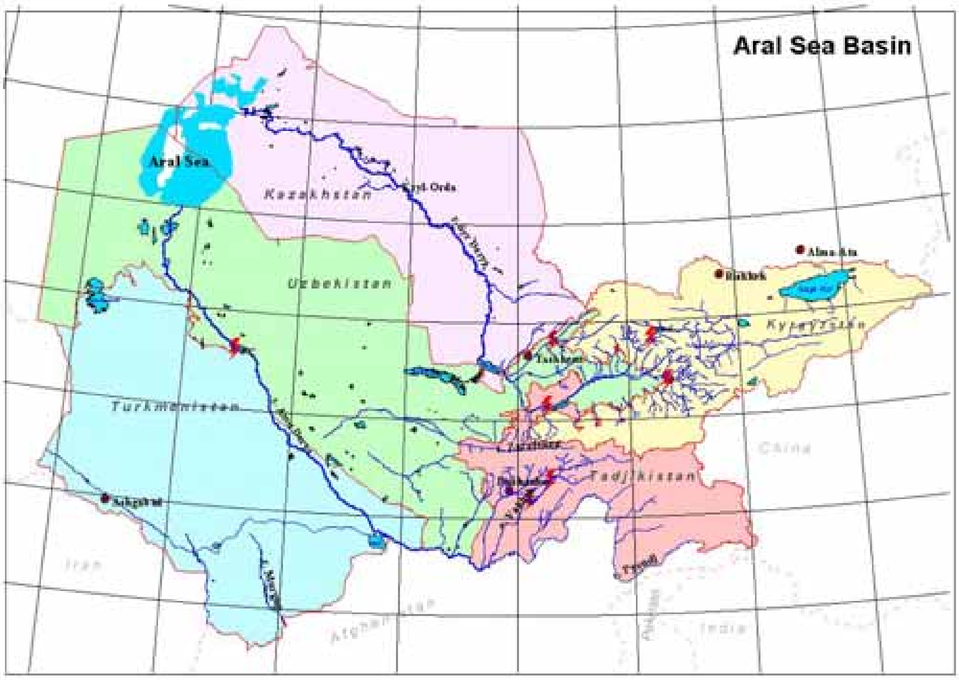
Uzbekistan Kazakhstan Kyrgyzstan Tajikistan Turkmenistan

Executive Committee
International Fund for saving the Aral Sea

BASIN ECONOMIC ALLOCATION MODEL (BEAM)
DRAFT PROGRAMMER'S MANUAL

PROJECT

Comprehensive analysis of the economic value of the integrated use and conservation of water resources in the Aral Sea Basin



Global Water Partnership
Central Asia and Caucasus

COWI

DHI

Comprehensive analysis of the economic value of the integrated use and conservation of water resources in the Aral Sea Basin

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APPENDICES

1 INTRODUCTION AND PURPOSE

This report constitutes the Programmer's Manual" within the project "Comprehensive analysis of the economic value of the integrated use", which has been launched by EC IFAS with financial support from the USAID. The project is undertaken by DHI (Lead Company) in association with COWI and Global Water Partnership CACENA.

The Manual describes the functioning of the Basin Efficient Allocation Model (BEAM) from a model programmer's view, i.e. technical details necessary for completely understanding and modifying the model. In another document, the "User's Manual", the daily use of the model for running scenarios is described.

Programmers intending to alter the data or equations of BEAM should have at least some understanding of GAMS and Excel programming, economics and hydrology. This document aims at providing understanding for the economic and hydrological parts of the model, while readers interested improving their GAMS capabilities are referred to more elaborate sources.

The report consists of eight chapters in addition to the current chapter. Chapter 2 provides the framework for the model, i.e. scope and purpose of the model. Chapter 3 provides some technical introduction to the model. Chapter 4-5 provides an overview of the economic and hydrological logic of the model by exposing the constraints and identities of the model. Chapter 6 provides an overview of the collected data, while chapter 7 provides limitations and possibilities for extension of the model in its present state. Two appendices are attached to the report: A walkthrough of collected data and reference list.

2 MODEL FRAMEWORK

This chapter provides a few initial considerations regarding the model design.

By way of introduction it is worth emphasizing that it is proposed to develop one model covering both water flows and economics. It shall concern the 5 countries of Kazakhstan, Uzbekistan, Tajikistan, Kyrgyzstan and Turkmenistan and also Afghanistan. In the model each Central Asian country is modelled as a number of sub-regions, covering the two rivers Amudarya and Syrdarya. The Aral Sea is to be highlighted. In the model 5 water using sectors are to be specified: nature, drinking water, industry, agriculture and hydro electric power stations.

2.1 Framework and questions to answer

This project centers around three important concepts when dealing with allocation of water:

- **Effectiveness:** How to allocate water to different human, economic and ecological purpuses in order to maximise the general welfare from using the water

- **Efficiency:** How to improve the delivery of water services in order to use less water

- **Equity:** How efficiency and effctiveness improvements affect the welfare of different groups of people in the societies

These concepts are very dependent on each other, so that changes in effectiveness affect the efficiency choices of allocation, which again affects equity considerations. In order to analyse the three concepts rigorously, the used methodology should incorporate all three concepts.

2.1.1 Effectiveness questions

Questions concerning effectiveness centers around optimising the allocations of water so that the general welfare of the countries affected is improved. The economic concept of Pareto Optimallity is important here. An allocation of water is Pareto Optimal, if it can not be changed in a way that makes someone better off, without making others worse off.

In this respect economic compensations for changes in water uses may facilitate that one group's gain partially can be used to offset another group's loss. If the gain is larger than the loss, then economic compensations can ensure that the new allocation is Pareto Optimal. Therefore the change in allocation can be in the interest of both groups.

The core questions around effectiveness focus on today's situation and the changes that can be made, which will improve overall economic effectiveness of water use:

- o What is the economic value of the use of the basin water today, based on the water's part of value creation in the 5 sectors?

- What is the economic value of **changing the use** of basin water between the 5 sectors? How are the changes in value distributed across the 5 countries?

- How can the operation of parts of the water system (e.g. reservoirs, canals) be improved in order to increase effectiveness of the different economic sectors

- How will environmental requirements (e.g. improved runoff to the Aral Sea) change allocations, at what cost, and with which measures (e.g. changed crop patterns)?

- Is it possible to calculate "fair prices" for water, and to what extent can these be used as guidance for production decisions in agriculture, hydro power and industry?

To sum up, the effectiveness discussion addresses which uses of water that are most advantagous in terms of improving general welfare including environmental concerns.

2.1.2 Efficiency questions

Efficiency questions address a more technical level of water management, where improvements in equipment or practices lead to less water use for obtaining the same output. Among efficiency questions are:

- What is the economic value of **increasing efficiency** of water use (e.g. reservoirs, management) in the different sectors, and how does this value scale against the needed economic investments?

- Where does improvements in efficiency materialise in more productive allocation and use of water?

Efficiency questions are tightly related to effectiveness, as improvements in efficiency can have important consequences for which allocations of water that are most beneficial to society.

2.1.3 Equity questions

Equity questions evolves around which groups of people that benefit or bear losses from changes in water allocations and and water system efficiencies.

- How do altered allocations of water impact the different countries in monetary terms? Are there obvious compensation opportunities that will lead to Pareto improvements?

- How are the different sectors and regions affected in terms of employment, output and exports?

- Are there some group of water consumers

Equity question thus evolves around the **socio-economic impacts** of altered prioritisations of water flows, that is how the changes will affect the people living in the region.

2.2 Time horizon and seasons

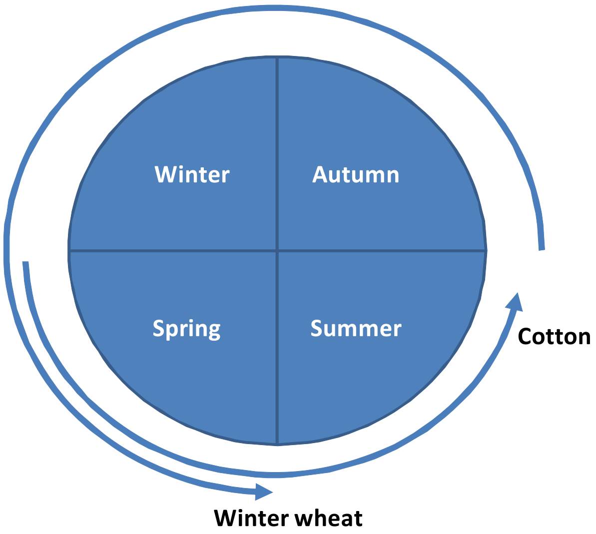
The choice of time horizon and seasons depend on the questions that the model should analyse. At the same time practical reasons, such as computational time and complexity, set limits on how many years and seasons that can be modelled. For hydro-economical models can analyse questions in two general and opposite categories:

- **Long term questions:** These concern inter-annual consideration such as reservoir management in relation to dry and wet years, in order to smooth out water supply. Also climate change questions belong to this category, insofar the climate changes affect the inter-annual decisions

- **Short term questions:** These concern allocation of water during each year, and is thus relevant for crop choice and scheduling of HEPS dispatch in relation to favorable electricity prices along the months of the year.

In specific, the short term questions centers around the seasonality of the crops in question. While cotton has a growing season running from March to September, winter wheat has a growing season from october to june. Consequenctly, the water demand from these two crops is very different, and this difference can be important when it comes to allocation of water and the timing of HEPS scheduling. The growing seasons are roughly presented in Figure 1.

Figure 1 Growing seasosn of cotton and wheat



Further, electricity prices are varying over months too (as well as weeks, days and in some cases hours), thus heavily influencing the optimal timing of HEPS dispatch. In order to analyse the influence of changes in the electricity price versus changing water needs from different crops, a monthly model seasonality seems appropriate. The short term scope of this problem implies that multi-year modelling does not add significant analytical benefits of modelling more than one year.

On the other hand it is quite likely that the numerical complexity of a long term model spanning over all months from 2010 to 2050 would grow to such a numerical complexity, that it would be very impractical for working purposes.

It can be concluded that a bi-seasonal model spanning over 40 years is appropriate for analysing long-term questions, while a monthly model spanning one year (with single year modelling of e.g. 2010, 2020, 2030, 2040 and 2050) would be appropriate for analysing short therm questions.

Considering the objectives of the project mentioned in section **Ошибка! Источник ссылки не найден.**, the model has been designed in such a way that it can handle both monthly and bi-annual seasonality. However, in order to maximise the outcome of the project's ressources, the collection of data has centered on making available a short term model. Availability of a long term model thus awaits collection of data for this purpose.

2.3 Economic model base concepts

The base questions posed by this project is to characterise the economical value of water today as well as in a future. The criteria for future allocations of water is that overall economic efficiency of water use should be improved.

2.3.1 Optimisation criteria

The standard basic concept for measuring economic improvement is Gross Domestic Product (GDP), i.e. the value of output produced in the Aral Sea region. In other words, *the model should try to maximise the economic output by improving the allocation of scarce ressources such as water.*

While the water supply is a very important economic activity in the Aral Sea region, its primary effects are especially prevalent for some economic resources, while other resources are only affected indirectly. An overview of the possible economic effects allow us to choose which effects to model and which effects that will be ignored. This overview is given by the showing the GDP identity with respect to factor income from the productive factors[1]:

$$P\ GDP = K\ PK + L\ PL + A\ PA + W\ PW + E\ PE$$

We simplify our economic model by using the following assumptions:

- The price of **capital** is determined by the international capital market, while the supply is determined by the long run domestic savings rate and foreign capital inflows.[2] We assume that the effects of water allocation on domestic savings is small, and therefore changes in domestic capital income (i.e. K PK) need not to be modelled.

- On **energy and mineral resources** it is assumed that there is no effect from changes in water uses. However, HEPS is counted as an energy ressource

- Regarding **labour** markets, it is likely that changes in water allocation *will* affect both wages and allocation of labour across the different economic sectors, in particular water intensive agricultural sectors with significant labour inputs. It is

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[1] K for capital, L for Labour, A for land, W for water and E for Energy/minerals. The P's note prices for the relevant factors, such that e.g. total factor income for labour is described by L PL. P describes the overall inflation.

[2] We ignore income to foreign investments as this does not count into Gross National Income (GNI).

outside the scope of the project to model labour markets. Therefore, economic effects major reallocations of water that impacts labour income (e.g. decreasing agricultural water and labour use) will not be adequately modelled. However, if the reallocation happens gradually, already existng migration patterns (rural to urban) may alleviate the smaller need for agricultural labour, thus keeping labour income reasonably stable. Thus, for sufficiently small changes, $\Delta (L\ PL) = 0$.

- The reallocation of water has no inflationary effects (on *P*), as it is assumed that changing allocations of water will lead to that some goods become more expensive, while others become cheaper, and that this will roughly balance.[3]

With these simplifying assumptions we can strip factor income from capital, labour and energy resources from the model, and focus on the changes in GDP from land and water factor income. Since the total supply of land and water is fixed, these changes can be described by

$$\Delta GDP = A\ \Delta PA + W\ \Delta PW + E\ \Delta PE$$

This means that *any chagnge in GDP is caused by change in allocation the production factors of energy, land and water touses that generate a higher factor income*. Thus, the optimisation problem evolves around allocating water and land to the economic activities (HEPS, agriculture etc.) which offers the larger factor income, and away from activities that offer smaller factor income.

The formation of income may also be viewed from the production side, i.e. through the sale of output and cost of input.

$$GDP = O\ PO - I\ PI$$

where O is the output quantity, PO its price, I the inputs and PI the input prices. Since the price of inputs (besides water and land) and outputs into agricultural production is a model assumption, the value added from land and water can be calculated as a residual of the agricultural GDP identity above, i.e.

$$VA^{water} + VA^{land} = O\ PO - \ K\ PK - L\ PL - G\ PG$$

where *G* and *PG* are quantity and price other goods used in agricultural production. In this equation, all prices are known, the calculation of value added in agriculture is a problem of allocating land, water, capital, labour and other goods in an efficient way-

It is important to note, that hydro power does not "use" the water, it merely withhold the water in the reservoirs (not considering evaporation). The amount of water that runs through a given HEPS cannot be managed on the longer term, but the timing of electricity production can. So in isolation, the HEPS should try to maximise production when electricity prices (*PE*) are high.

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[3] To model precisely the balance of such effects, a full size Computable General Equilibrium (CGE) model is needed.

The timing of the HEPS production should on the other hand be held up against the seasonal water needs from agricultural production. Therefore, the model also incorporate constraints such that the timing of HEPS production and water use must be coordinated.

With the considerations above a criteria function for the optimisation problem can be specified as the sum of factor income over time *t* and regions *r*:

$$\max GDP(W,A) = \sum VA_{rt}^{water} + VA_{rt}^{land} + E_{r,t}PE_{r,t}$$

subject to a number of constraints:

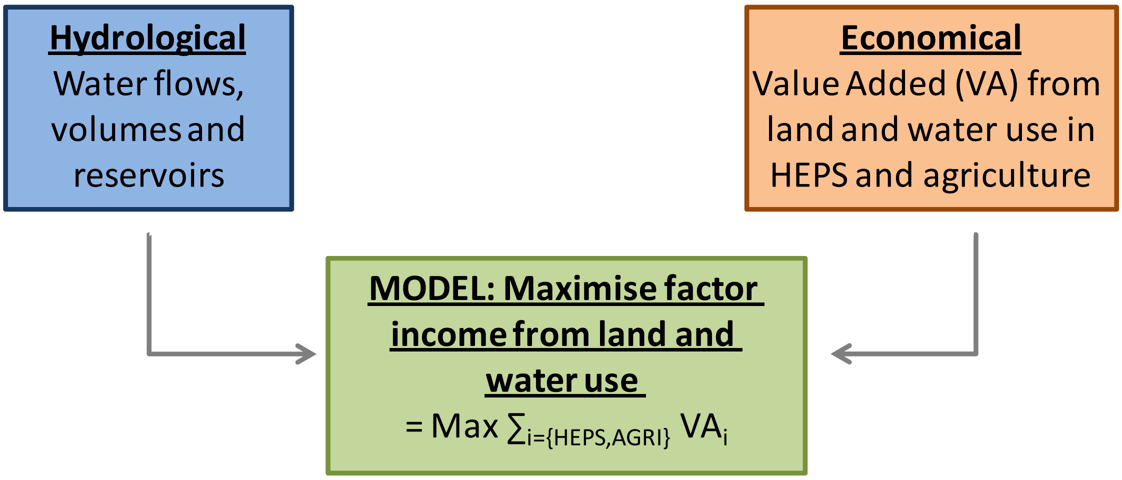
- hydrological constraints, losses and demand for water
- constraints describing relations between agricultural inputs and outputs
- energy production from HEPS taking into account that a close to full reservoir produces more electricity per cubic metre of water than a half empty, due to the larger head (differnce between reservoir water surface and outlet elevation).

The above constraints are presentede here in a very generalised and abstract way. In chapter 3, a much more elaborate description of the hydrological constraints can be found, while chapter 4 describes the economical constraints and identities of the model in detail.

2.4 Modelling the economic water and land value

There are two key elements modelling the economic value of water and land. The one element is to calculate the flows and volumes of water caused by both nature and man made allocations. The other element is to assess the economic value of using the water for the various purposes. From the value and use of water in agriculture, the value of land can be derived.

Figure 2 Overall model concept of flow and volumes combined with water valuation



Hydrological
Water flows, volumes and reservoirs

Economical
Value Added (VA) from land and water use in HEPS and agriculture

MODEL: Maximise factor income from land and water use
$= \text{Max} \sum_{i=\{HEPS,AGRI\}} VA_i$

The value added from water and land that is optimsed in this model comes from two sources: Hydropower and agriculture.

Increasing value added from hydropower depends on two factors: (a) Discharging water with reservoirs as filled as possible in order to maximise electricity production per cubic metre and (b) discharging when electricity prices are high.

Increasing value added from agriculture depends on growing the crops that are most economically valuable and at the same time feasible to grow with respect to land and water use. The crop value added from land and water is thus calculated as sales value minus the input costs for capital, labour and others (fertiliser/diesel), but explicitly not land and water.

3 GAMS PROGRAMMING AND MODEL STRUCTURE

This section gives some useful information on programming in GAMS and how the model files are structured.

3.1 Notational conventions for this document

The equations in this note specify the relations that can be inserted into the model. In general, **endogenous variables** (i.e. model determined) are written with capitals, while data determined **exogenous variables** (called "parameters" in GAMS lingo) are written in lower case letters.

Indices are denoted inside parentheses, *r* being the index for sub-region and *m* being the index for season (could be month, quarter or bi-season or what is deemed most appropriate). The index for year is *y*. Sectors are indexed by *j* and crop by *c*.

A parameter name ending with a zero indicates that this is a **base year data**, e.g. price or quantity. In this note we operate with the variables DEM (for demand) and PRICE (for water price). These variables are indexed over crop, sector, region, season and year.

The variable indices are written in GAMS notation, that is inside parentheses following the variable name, rather than as subscripts to the name. I.e. for the variable *A* indexed by the set *t*, the normal notation would be A_t, while the GAMS notation is *A(t)*.

A multiplication operators denoted by asterisk * is used explicitly. Finally, all indexes are elements in sets, so e.g. summarisations of $B_{i,t}$ into S_i for all elements within set *iX* is written as

$$S(i) = \sum_{t \in T} B(i,t) \quad \forall i \in iX$$

If this was an equation in GAMS (with an identifier called e.g. S_SUM) it would be written as

S_SUM(i)$iX(i).. *S(i) =e= SUM(t, B(i,t))*

where the *S_SUM(i)$iX(i)..* part would take the role of $\forall i \in iX$.

3.2 *Further introduction to GAMS*

This document is not intended as a manual to GAMS. Instead the reader is referred to the online documentation of GAMS which is available at

http://gams.com/docs/document.htm

and

http://support.gams.com/doku.php

The reader is also encouraged to subscribe to the GAMS Mailing list, where general and specific questions on GAMS can be posted. Note that the Intellectual Property rights of the BEAM model does not allow a posting of the model code to this mailing list.

3.3 *Model structure*

The model consists of a number of different files:

`BEAM.xls` - the Excel spreadsheet containing all necessary data for running the model. In this spreadsheet a Excel macro can create the so-called **`.inc`** files (see below),

`BEAM.gms` - the GAMS file containing further data definitions, equations and reporting tables

`sets.inc` - a GAMS file containing all set defintions (see section 4 of this document)

`maps.inc` - a GAMS file containing all map definitions (see section 4 of this document)

`data.inc` - a GAMS file containing all data definitions (see section 5 of this document)

`assumptions.inc` - a GAMS file containing all scenario specific assumptions (see section 5 of this document)

`BEAMflowOut.csv` - a comma-separated file containing output data on agricultural model results

`BEAMflowOut.csv` - a comma-separated file containing output data water flow model results

`BEAMoutput.xls` - aspreadsheet reading data from **`BEAMflowOut.csv`** and **`BEAMagriOut.csv`** and presenting an overview of these data

The model can be run by entering the directory where the BEAM files are placed by typing

```
c:\BEAM\> gams.exe beam.gms
```

The macro creating the .inc files can be activated by pressing the button named "Write sets and data" in the frontpage sheet of **`BEAM.xls`**. If running very old versions of GAMS, it may be necessary to place the **`.gms`** and **`.inc`** files in the root directory of the GAMS installation.

4 OPERATIONAL UNITS IN THE MODEL

GAMS models operates by applying equations and inequalities to operational units. Each operational unit is represented by en element from a set. In this chapter the most important sets are described.

- The set *B* describes all nodes in the model. This can be parts of the river, reservoirs, planning zones or seas. Subsets of B describe which bodies that belong to these categories.

- A number of two-dimensional sets (combinations of two bodies) describe arcs

- The set *J* describes crop types

- The set *K* describes input into agricultural production

- Two sets *Y* and *M* describing year and months

Below these sets are described in greater detail.

4.1 Node types describing water bodies and planning zones

The model distinguishes between several types of nodes

- **Water source nodes:** These are the origin of river water. All water flowing into a source node must continue its flow to a downstream node.

- **River nodes:** River nodes are supplied by water sources, reservoirs and return water. All water flowing into a source node must continue its flow to a downstream node..

- **Reservoir nodes:** Reservoir nodes have the ability to store water in a volume between the reservoir minimum and maximum storage capacity. Reservoirs nodes can also operate in fixed mode, meaning that the ability to store water is not used, so that all inflows are immediately discharged.

- **Sea nodes:** Sea nodes are end nodes with no arcs to lower nodes. Technically they have the ability to store water leading to rising sea levels.

- **Planning zone nodes:** These nodes are the destination of all human water use for agriculture, industrial and household use.

4.2 Arcs connecting nodes

The model distinguishes between several type of arcs.

- **Discharge arcs** (in the model a variable named *DIS* describes these flows) linking reservoirs to downstream nodes. The monthly volume flowing through discharge arcs are optimised according to downstream water needs and hydro power production from water flowing through the discharge arc

- **Intake arcs** (in the model a variable named *ITK*) linking river nodes to planning zone nodes. Intakes equals the plannign zones water demand.

- **Flow arcs** (in the model a variable named *FLW*) linking river nodes to other river, sea and reservoir nodes. The water volume in flow arcs can be thought of as residuals when

The flow arcs are illustrated together with all nodes in appendix A.

4.3 Agricultural crops and inputs

Agriculture have seven crops: Cotton, wheat, rice, vegetables, fruit, alfalfa and other crops. These crops are contained in the set *J={cot, wht, ric, veg, fru, alf, oth}*.

Agricultural costs are divided into land, water, labor, capital and other costs (covering e.g. diesel and fertiliser). These inputs are contained in the set *K={land,watr,labr,cptl,othr}*.

4.4 Sets related to time

The set for years are denoted by $y \in Y$. At present the model data is prepared for only one full year (chosen by the user) consisting of 12 months $\in M = \{m01, ..., m12\}$. Generally, the year starts in October (*m10*) and ends in September (*m09*) the following year.

5 THE ECONOMIC VALUE OF LAND AND WATER

This chapter specifies the demand functions by sectors, thereby providing information about the key variables and data requirements (see also Appendix A).

5.1 Nature

For natures demand for water it is proposed that a fixed, price-inelastic demand is used. This means that the nature sector will demand the same amount of water regardless of the water price. This reflects that nature demand for water is a consequence of the water planning decisions made by humans.

Technically, water demand from nature is a fixed GAMS parameter callend *minFlow(bd,bo)* (where *bo* designates the upstream node and *bd* the downstream node) describing nature demand for water from each sub-region. The sub-regional nature water demand will be determined using data on actual use for nature purposes, like e.g.

$$FLW(bd, bo, m, y) \geq minFlow(bd, bo, m) \; \forall \; bo, bd \in B$$

It is also possible to specify an annual inflow, in case the exact distribution across months is less important to the environment compared to the total annual inflow.

$$\sum_{y} FLW(bd, bo, m, y) \geq minFlowA(bd, bo) \forall \; bo, bd \in B$$

The cost of protecting the nature in the Aral Sea Basin can be evaluated by changing the water demand for that purpose. The quantification of the benefits of doing so is outside the scope of the model analysis.

Water quality (e.g. content of salts etc.) is outside currently the scope of the model, although some preparations for later inclusion has been made.

5.2 Drinking water

The demand for drinking water is caused by usage for drinking, hygiene etc. These purposes are essential and are likely not to react very much to differences in water prices. It is thus assumed that the households' demand for drinking water is a given monthly parameter based on observed data.

5.3 Industrial demand

The demand for industrial water depends on industrial production. The water's share of industrial input cost is rather low, so the demand is not likely to react much on price signals or other planning incentives. It is thus assumed that the industry demand for water is a given monthly parameter based on observed data.

5.4 Agriculture

Agricultural production of crops are described as a Leontief production function. This means that a 1 % change in output is associated with a 1 % change in the inputs of K = *{ land, water, labour, capital, other }* and other inputs such as diesel, fertilizer etc.

The model denotes agricultural activity in so-called index form, meaning that the variables describing inputs (*iINPUT*) and outputs (*iOUTPUT*) in the baseline are equal to 1. Thus, if a production variable end up being 1,15, the production has increased by 15 %. The physical amounts of crops, water, land etc. can be found by multiplying the index variable with the base year physical production or use.

Letting the index $k \in K$ denote these inputs, the Leontief identity can be written as

$$iOUTPUT(b,j,y) = iINPUT(b,j,k,y) \forall j \in J, k \in K, y \in Y, b \in bPlz$$

where $j \in J = \{cotton, wheat, rice, alfalfa, fruit, vegetables, other\}$. This identity is applied for all crops *j* in planning zones $b \in bZ$ where there is a positive base year use of input *k*.

The total monthly water use in agriculture is thus

$$iINPUT(b,j,k,y) * qWater0(b,j,m)$$

where *qWater0* is the base year monthly water use for crop *j* in planning zone *b*. This water use enters into the water balance of the planning zone.

For some crops it is assumed that the land use of that crop is fixed, e.g. for fruits from plantations. The fixed crops represented by the set *jAX*. For these, the model constraint is

$$iOUTPUT(b,j,y) = 1 \forall j \in jAX, y \in Y, b \in bPlz$$

The remaining crops (called flexible crops, denoted in the set *jAF*) are not constrained to a specific land use. It is, however, assumed that the base year land use pattern reflects various limitation on the flexibility of the crops. For instance, combine harvesters may not be available in sufficient numbers to accomodate a lot more wheat, or soil quality may inhibit increased use of certain crops. Also the farmers' knowledge of the individual crops may be restraining the scope for crop pattern changes.

To reflect these limitations it is assumed that the flexible crops are subject to a so-called transformation frontier[4]. This means that changing from a cropping pattern of e.g. 60 % cotton and 40 % wheat to 50/50 % causes a drop in yields of both crops of a certain magnitude. The functional form of the transformation frontier is assumed to be of the CET type (Constant Elasticity of Transformation) and is represented by the relation

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[4] See Mas-Collell, Whinston and Green (1995), proposition XX.X.X

$$\sum_{j \in jAX} \left(oShare0(h,j) * tOUTPUT(h,j,y)^{rL} \right)^{\frac{1}{rL}} = 1 \ \forall \, y \in Y, h \in hPtz$$

The parameter *rL<0* describes how "sluggish" the flexible crops are. A value close to zero indicates very sluggish transformation, while a numerically large value indicate large flexibility. The parameter *oShare0* describes the percentage distribution of crop sales (flexible crops only) by value for that particular zone.

The magnitude of *rL* is not directly observable, rather it relies on an educated guess by the modeller accomplished by proper sensitity analyses. The value of rL has been chosen such that a change from 50 / 50 % shares of wheat and cotton to a 60 / 40 % share is accompanied by a yield loss of 5 %. This gives *rL* = -1.5. A change to a 70 /30 share would imply a yield drop of 19 %.

MIKR: ADD DERIVASION OF FIRST ORDER CONDITIONS AND FURTHER EXPLENATIONS

5.5 Hydro power and reservoir management

An important aspect of hydropower generation and reservoir management is that the electricity generation per cubic metre of water depends on the height difference between the reservoir water surface and the surface of the receiving water body (or the reservoir water outlet after the turbine). This height is known as the so-called "head". A larger head leads to larger electricity production. In turn, the head depends on the level of the reservoir, so a reservoir with a level close to its maximum produces more power per cubic metre of water than one with a level close to its minimum.

The relation between the head and the reservoir level depends on the specific topography of the reservoir, but in general the graph describing head as a function of reservoir volume is convex and upwardssloping (i.e. a 10 % decrease in the volume of an almost filled reservoir has little impact on the head, while a 10 % decrease in the volume of an almost empty reservoir has a large impact).

The functional form has been estimated by a polynomical regression on 6-8 estimated points for each reservoir relating volume to head. The functional form of the head/volume relation in the model is thus

$$HEAD(b,y,m) = a(b) + b(b) * VOL(b,y,m) + c(b) * VOL(b,y,m)^2$$

where *VOL* is the reservoir volume in million cubic metres and *HEAD* is the head in metres. The electricity production *ELY* is then

$$ELY(b,y,m) = \sum_{b} g * \rho * \eta(b) * HEAD(b,y,m) * DIS(b,y,m)$$

where *g* is the gravity constant (9,82 m/s^2), ρ is the density of water (1 kg/liter), and *η(b)* is the electric efficiency of the generators.

5.6 Overall criteria function

The overall criteria of the model is to maximise the total value of land and water returns.

$$\sum_{b,y} aSALES(b,y) - aCOSTS(b,y) + eSALES(b,y)$$

where the agricultural sales and costs and electricity sales are

$$aSALES(b,y) = \sum_{j} iOUTPUT(b,j,y) * qOutput0(b,j,y) * pOutput(j)$$

$$aCOSTS(b,y) = \sum_{j,kT} iINPUT(b,j,kT,y) * qInput0(b,j,kT,y) * pInput(j,kT)$$

$$eSALES(b,y) = \sum_{m} ELY(b,m,y) * pEly(m,y)$$

Base year agricultural output (measured in tonnes per year) is *qOutput*, the crop prices are pOutput, base year inputs are *qInput0* and input prices are *pInput*. Electricity price is *pEly*, which may vary across months Note that the agriculutral costs concerns only the traded inputs capital, labour and other inputs (denoted by the set *kT*), while water and land is allocated by the model in order to maximise the value added from these two inputs.

6 HYDROLOGICAL CONSTRAINTS

The hydrological constraints consists of equations and inequalities describing water bodies in the basin (technically described as nodes) and connections between these (technically described as arcs).

6.1 Water balance

All nodes in the model,whether they are planning zones, river sections, reservoirs or sources are constrained by a common water balance equation. This ensures that all water will keep flowing downstream.

```
WBALANCE(s,b,y,m)..
    SUM(bd$intk(bd,b), ITK(s,bd,b,y,m))
  + SUM(bd$flow(bd,b), FLW(s,bd,b,y,m))
  + STO(s,b,y,m)$(sea(b) OR bRes(b))
  + SUM(j, iINPUT(b,j,"watr",y)*qAWater(b,j)*agriSeason(b,j,m))
  + qIWater(b,m) + qHWater(b,m)
 =e=
    ( SUM(bo$intk(b,bo), ITK(s,b,bo,y,m))
     +SUM(bo$resv(b,bo), DIS(s,b,bo,y,m))
     +SUM(bo$flow(b,bo), FLW(s,b,bo,y,m))
     +sup(s,b,m) + gwCorr(b,m)
     +rtn0(b,m)
    ) * (1-loss(b,m))
```

MIKR: Add a bit further explenation

6.2 Reservoirs

Reservoirs stores and discharge water at different times, so an intertemporal balance must also be kept.

```
* Reservoir is calculated at end of body and end of season
RESVOL(s,b,y,m)$bRes(b)..
   VOL(s,b,y,m) =e= SUM((yy,mm)$mLast(y,m,yy,mm), VOL(s,b,yy,mm)) +
STO(s,b,y,m) - SUM(bd$resv(bd,b), DIS(s,bd,b,y,m));

* Sea volumes are not restricted to primo level =e= ultimo level
SEAVOL(s,b,y,m)$sea(b)..
   VOL(s,b,y,m) =e= SUM((yy,mm)$mLast(y,m,yy,mm), VOL(s,b,yy,mm))$(ord(m) gt 1)
+ STO(s,b,y,m) - SUM(bd$resv(bd,b), DIS(s,bd,b,y,m));
```

The amount stored must be in the interval of minium and maximum storage volume. Reservoirs running in fixed operation mode will have their minimum storage volume set equal to their maximum storage volume.

```
* Maximum reservoir volume
RESVOLMAX(b,y,m)$bRes(b)..
   SUM(s$sW(s), VOL(s,b,y,m)) =l= reservoirs(b,"max");

* Minimum reservoir volume
RESVOLMIN(b,y,m)$bRes(b)..
   SUM(s$sW(s), VOL(s,b,y,m)) =g= reservoirs(b,"min");
```

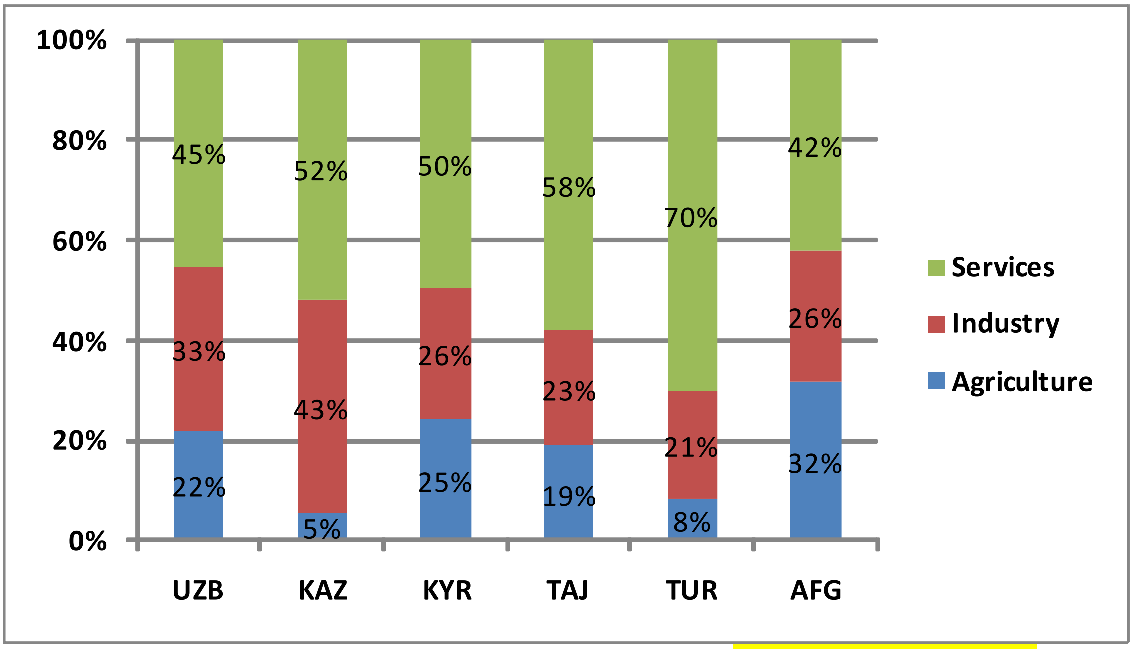
7 OVERVIEW OF DATA

7.1 Composition of GDP

The economical model relies on a transition mechanism that is deeply dependent on the relative value shares of production input in the water using sectors. Presenting such data will give an immediate impression of the expected effects of water price changes.

First is presented overall data on the composition of GDP across agriculture, industry and service in the six countries, c.f. Figure 3.

Figure 3 GDP by sector and country, 2010



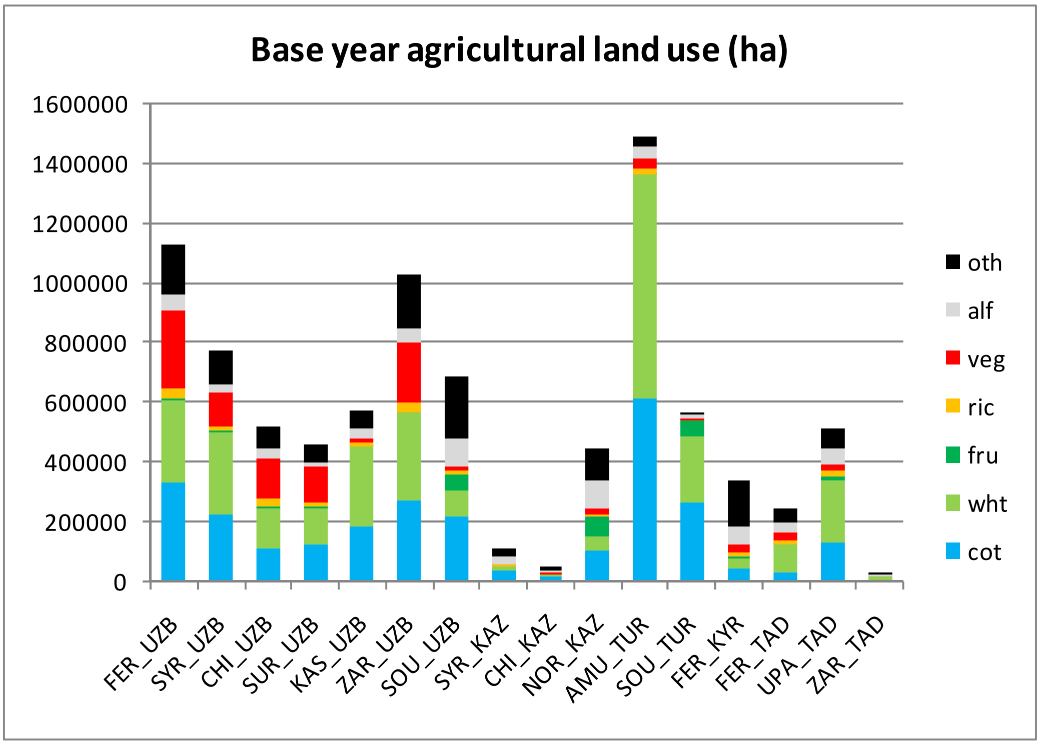
Source: CIA Factbook as presented by http://www.indexmundi.com/ UPDATE with national data?

The different sectors' prevalence in the region's individual countries is also of interest. Such data will give an immediate impression of the effect on the individual countries of altering the distribution of water.

7.2 Agriculture

In Figure 4 the agricultural land use by crop is shown. It can be seen that cotton and wheat are dominant crops in most of the countries, and that Uzbekistan and Turkmenistan are the major wheat and cotton producers in the region. The third most important crop is vegetables.

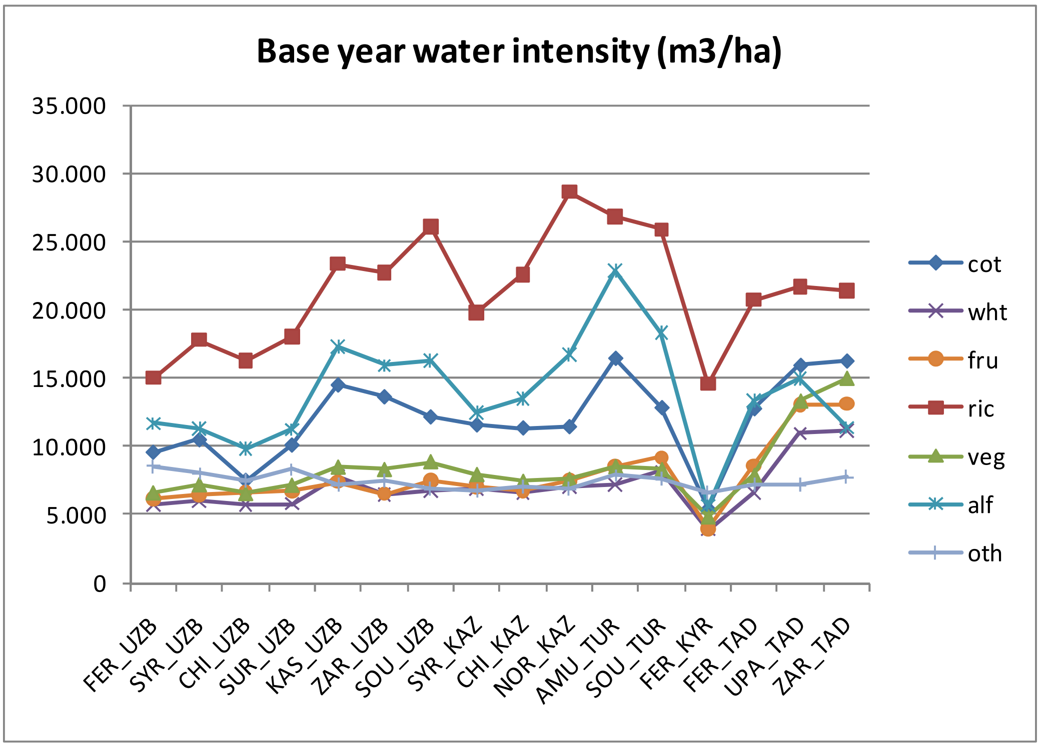
Figure 4 Agricultural land use by crop type, 2009



Source: PLEASE INSERT SOURCE. PLEASE VERIFY VERY HIGH SHARE OF LAND USE FOR VEGETABLES IN UZB RELATIVE TO OTHER COUNTRIES

The different crops have differing water needs. Rice, cotton and alfalfa are relatively thirsty crops with water intensities typically above 10.000 m3/ha. The crops wheat vegetables and other crops are typically below 10.000 m3/ha., c.f. Figure 5. PLEASE CHECK FER_KYR (TOO LOW?) AND *_TAD (TOO HIGH?)

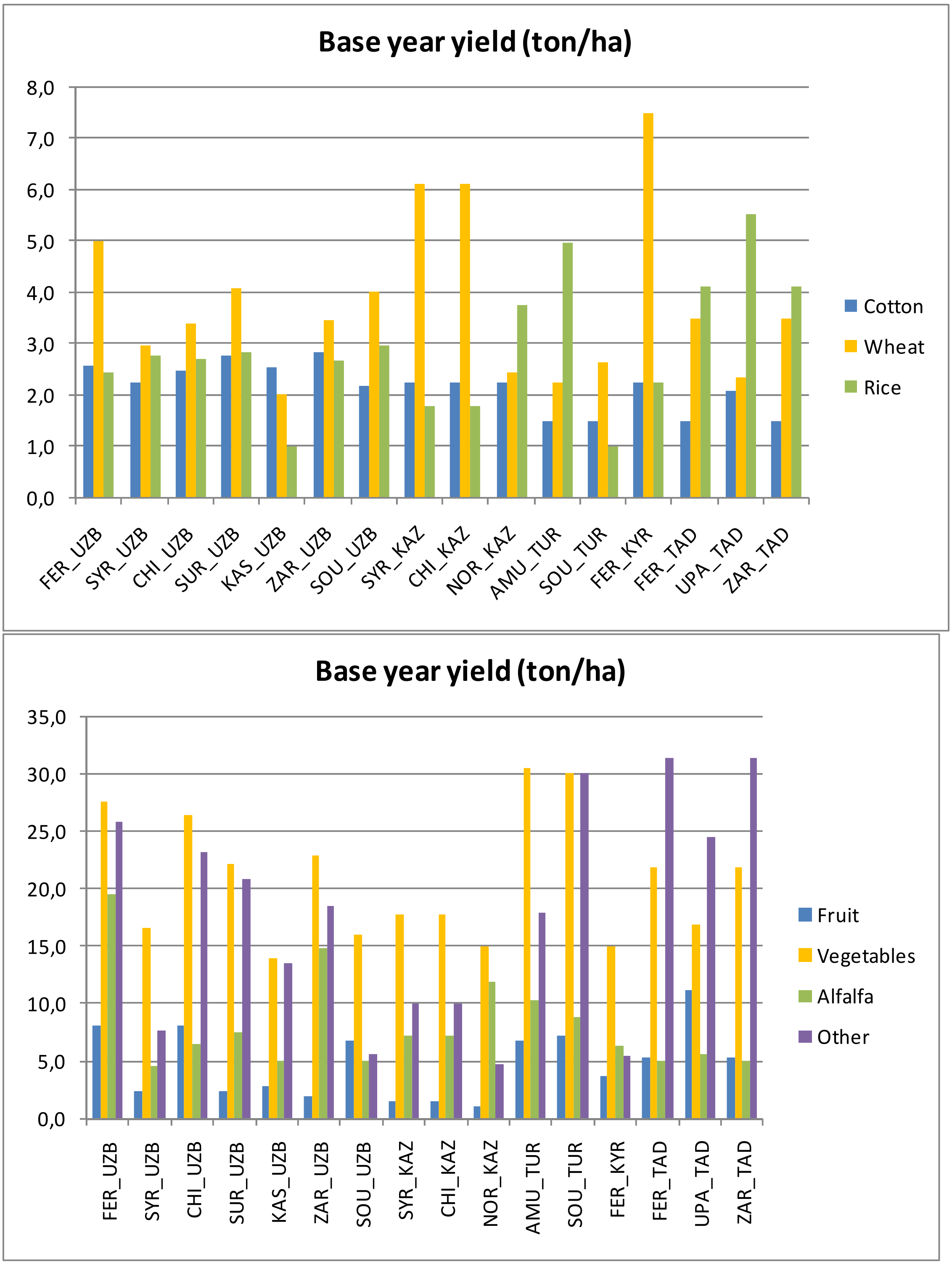
Figure 5 Agricultural water intensity



Source: PLEASE INSERT SOURCE

The crop yields are shown in Figure 6. The data has been supplied by PLEASE INSERT SOURCE. Corrections to the yields have been made, so that no yield is lower than 1.5 ton/ha for wheat, 2,0 ton/ha for cotton and 1.0 ton/ha for rice.

Figure 6 Base year crop yields, 2009.



Source: PLEASE INSERT SOURCE

The farmers' choice of crops will also depend on crop prices and costs. These are shown in table

Table 1 Crop input costs and prices

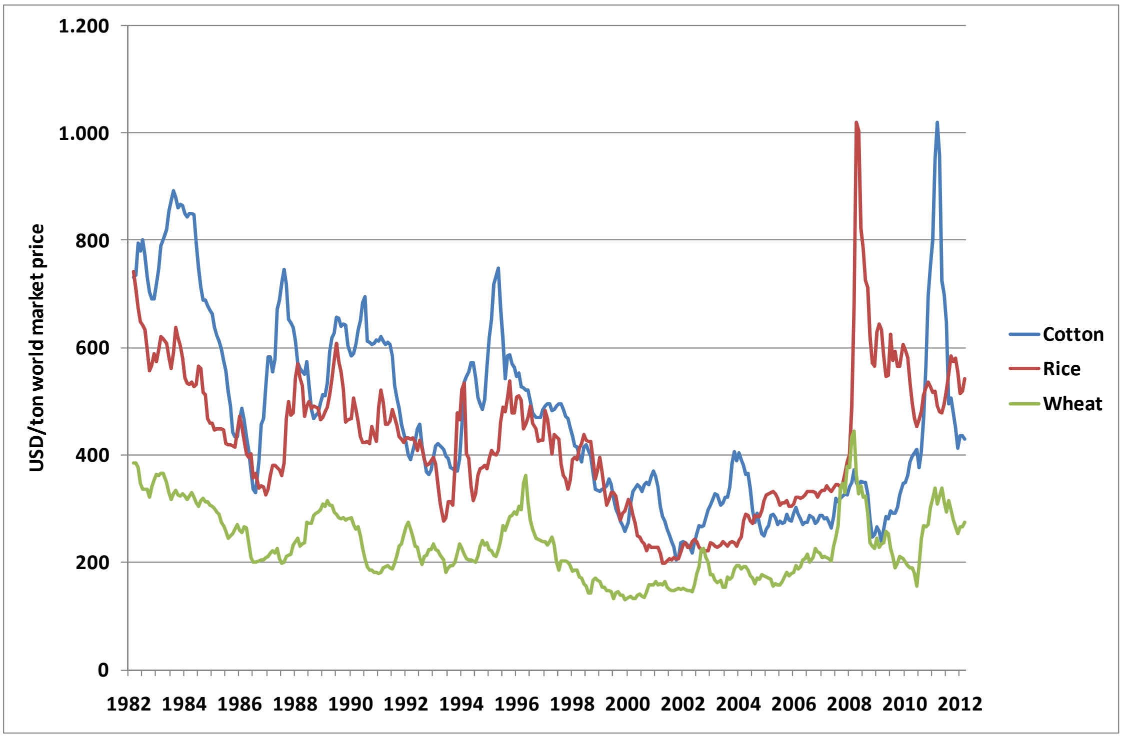
	Cotton	Wheat	Fruit	Rice	Vegetables	Alfalfa	Other

Labor	USD/ha	240	160	80	240	160	80	120
Capital	USD/ha	18	18	14	14	14	12	12
Other inputs	USD/ha	360	240	120	360	240	120	180
Crop price	USD/ton	467	232	450	422	50	100	75
Zero profit yeild	ton/ha	1,3	1,8	0,5	1,5	8,3	2,1	4,2

Source: Crop input prices PLEASE PROVIDE SOURCE; Prices for wheat, cotton and rice is average since 1982 in real terms, see below; other crop prices: Assumptions leading to comparable profits.

Cotton, wheat and rice are products traded on the world market. The prices for these crops are easily accessible. Time series for these crops show that the price is rather volatile (in particular for rice and cotton), fluctuating between -50 % and +100 % under and above the average. These prices are shown in Figure 7.

Figure 7 Historical real (2009 level) prices for wheat, cotton and rice, 1982-2012, USD/ton

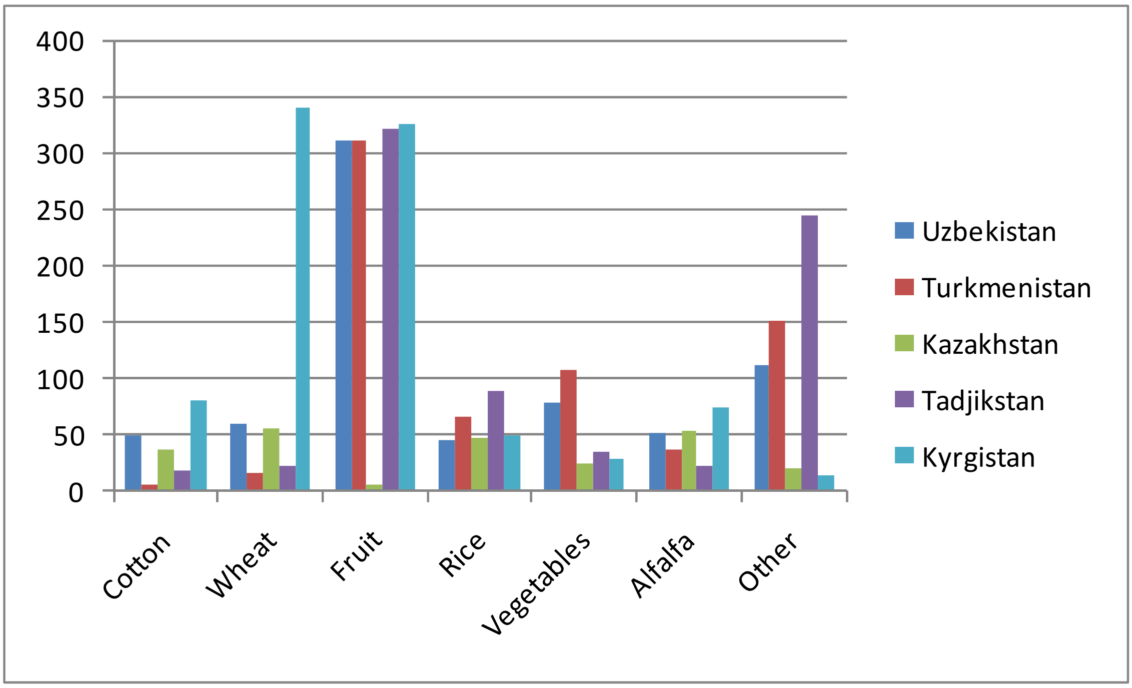


Source: www.indexmundi.com

The prices for the remaining crops are much more dependent on local market conditions, as they are not as easily transported across the world.

A rough measure of the economic value of water can be illustrated by relating the agricultural value added (sales value minus costs of capital, labor and other inputs) to water use, c.f. Figure 8.

Figure 8 Economical efficiency of water by crop, 2009, USD/1000m3.



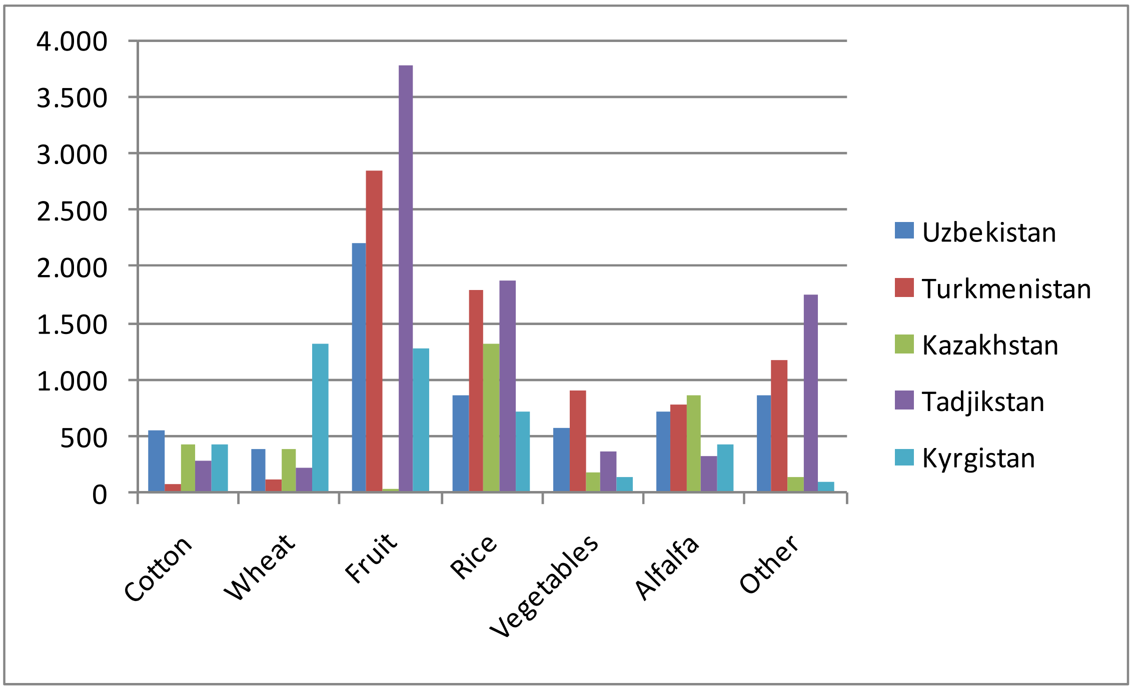
Source: Calculations on yields, water intensity and land use shown in this chapter

Most of these values are in the order of 25-75 USD/1000m3, although fruits and other crops are outliers. The high value for fruits may be explained by the large investments in plantations, which should be attributed to land rather than water (as the value added in the present calculation can be attributed to either land or water). Fruit in Kazakhstan is an outlier because the fruit yield is only around 1-1.5 ton/ha compared to 5-10 ton/ha for the other countries. PLEASE EXPLAIN THIS DIFFERENCE.

The same may be the case for "other" crops, where the economic value added relative to water is high in Uzbekistan, Turkmenistan and Tadjikstan (caused by yields above 10 ton/ha) and low in Kazakhstan and Kyrgistan (caused by yields below 10 ton/ha).

The value added can also be related to land use. The general picture here is the same as when relating to water use.

Figure 9 Value added relative to land use, USD/ha.



Source: Calculations on yields, water intensity and land use shown in this chapter

Not surprisingly, those crops with high yields add more value than those with low yield. This underlines the importance of having very reliable data on crop yields.

7.3 Agricultural diversification

While it at first sight may seem more efficient to diversify irrigation needs and land use across the seasons, it has been observed[5] that a more extensive use of the irrigation and drainage (I&D) system for the combination of the two crops may lead to a lower maintenance level, as there is then no off-season for repairs and cleaning, at least with current maintenance practices.

It is also observed that a diversification into more types of agricultural products will decrease the economic risks. This may certainly be true regarding technical/agricultural risks (pests, drought). However, historical data suggests that agricultural product prices seem to move somewhat in tandem, c.f. Figure 7, so the risk diversification in this respect does also have its limits (note that the figure is not adjusted for inflation and reflect U.S. prices only).

7.4 Reservoirs

Data on reservoirs are described in appendix A.

PLEASE PROVIDE DATA SOURCE ON RESERVOIR DATA

---

[55] I. Abdullaev et. al. (2009)

7.5 Irrigation efficiency investments

Irrigation efficiency investments are modelled as a user choice in the user interface. Selecting among several options, the user can add improved irrigation efficiency to the model simulations, at the cost of money related to hectares or water quantities covered by the investments. The efficiency improvements and their costs are shown in the table below:

	Efficiency increase %	Area cost USD/ha	Volume cost USD/m3
Option 0	0	0	0,000
Option 1	0	30	0,001
Option 2	0	70	0,002
Option 3	0	200	0,004

PLEASE PROVIDE DATA AND DESCRIPTION FOR VARIOUS OPTIONS

QUALITATIVE QUESTIONS

Q1: What would it cost to bring e.g. Uzbek cotton water consumption to internationally comparable levels (in USD/m^3 or USD/ha)?

Q2: What is the limiting factor to an increase in agricultural output: water, land, management or capital?

Q3: Which types of irrigation are used in the 5 countries?

Q4: Are there any sub-categories for flooding?

Q5: What is the current water use efficiency of each technology applied?

PLEASE PROVIDE ANSWERS FOR QUESTIONS ABOVE

7.6 Water sources

Ground and surface water sources data is presented in appendix A.

7.7 Return water

PLEASE VERIFY THAT THE DESCRIPTION BELOW IS SUFFICIENT FOR RETURN WATER CALCULATIONS. PLEASE COMPARE WITH DATA FOR RETURN WATER SENT BY VADIM SOKOLOV.

Return water (collector runoff from irrigated arrays and domestic and industrial waste water), which is formed in the planning zones Wret, should be divided into three components:

- return water going back to into river network Wret_river - are shown in the consolidated data file,
- return water reused for irrigation Wret_ir (as additional source); initially, this component was present in the list of input data recommended by regional expert; however it is not in the model; so it should be included as a function of water intake to the planning zone
- return water, discharged to lakes (water ecosystems) and into natural depressions (evaporators) Wret_lake – in the model, for example, they are considered as collector flows, entering the Golden Lake of Turkmenistan.

Return water can be represented as follows:

Wret (m, b) = b*Wint(b)/6.0

Wret_river (m, b) = c*Wint(b)/6.0

Wret_ir (m, b) = d*Wint(b)/6.0

Where: Wret (m, b) – return water flow [mln.cub.m], Wret_river (m, b) – return water volume discharged to river network [mln.cub.m] , Wret_ir (m, b) – volume of return water reused in irrigation [mln.cub.m], Wint(pz) – water intake to planning zone – total annual water supply from rivers and groundwater [mln.cub.m], – month (only for the growing season, i.e. for April - September) , pz – planning zone, b, c, d – coefficients

The coefficients are presented below (the same for one month of the season).

Planning zone	Coefficient **b** for the calculation of Wret (i, pz)		Coefficient **c** For calculation of Wret_river (i, pz)		Coefficient **d** For calculation of Wret_ir (i, pz)	
	October-March	April-September	October-March	April-September	October-March	April-September
FER_KYR	0.044	0.140	0.044	0.130	0.00	0.010
FER_TAD	0.080	0.160	0.080	0.100	0.00	0.060
UPA_TAD	0.007	0.080	0.007	0.070	0.00	0.010
ZAR_TAD	0.009	0.080	0.009	0.030	0.00	0.050
AMU_TUR	0.072	0.130	0.013	0.020	0.00	0.000
SOU_TUR	0.077	0.230	0.00	0.000	0.00	0.010
FER_UZB	0.360	0.330	0.358	0.250	0.00	0.070
SYR_UZB	0.193	0.290	0.055	0.080	0.00	0.010
CHI_UZB	0.315	0.340	0.260	0.160	0.00	0.120
SUR_UZB	0.168	0.230	0.168	0.140	0.00	0.090
KAS_UZB	0.130	0.200	0.072	0.110	0.00	0.040
ZAR_UZB	0.207	0.250	0.145	0.180	0.00	0.030
SOU_UZB	0.149	0.230	0.025	0.040	0.00	0.010
SYR_KAZ	0.117	0.120	0.000	0.000	0.00	0.060
CHI_KAZ	0.117	0.100	0.117	0.040	0.00	0.060

NOR_KAZ	0.045	0.130	0.045	0.130	0.000	0.000

PLEASE PROVIDE SOURCE AND RATIONALE FOR THAT THESE VALUES WILL BE CONSISTENT WITH CHANGE IN WATER USE

8 MODEL LIMITATIONS

A number of issues have been considered but not included in the model.

8.1 Water stress and yield

It is well known that crop yield decreases if less water than the norm is delivered. In the model it is assumed that crop choice and water is allocated so that crop needs are always fulfilled. However, particular in dry years it may be the case that it could be optimal to irrigate the crops with less water than the norm, because more profitable, but also more water intensive crops could be planted.

This would require model functionality for yield with less than optimal irrigation water. This may be a topic for future enhancement of the model.

8.2 Salts

Salination of the water is an important issue in the area around the Aral Sea. Not only has salination detrimental environmental effects, but it also affects the crop yield. This topic may also be handled in future versions of the model.

8.3 Multiyear drought risk management

The model is not well suited to handle multiyear drouhgt risk management. This topic should be analysed by the use of some sort of stochastic programming in order to derive efficient strategies for storing and discharging water in different sequences of dry, normal and wet years.

For computational reasons, it would probably be better to do away with a simpler flow schematic,consisting of a reservoir zone, an agricultural zone and a sea zone. However, the CET function for land allocation would probably be relevant for reuse.

8.4 Value added from crop processing

The model does not include "downstream" economic activities related to refinement of crops, e.g. textile industry. To the extent that such industries enjoy supernormal profits caused by the national production of crops, the model may underestimate the extent of costs related to changes in crop patterns. This may be the case if export, labour and/or capital markets are less than perfectly mobile.

On the longer term, it is a standard assumption is that factors are perfectly mobile and that competetition will erode supernormal profits. Following such arguments, the omission of "downstream" industries is not a concern for the reliability of the results.

However, interesting results concerning labour migration could be obtained by including various industries. This would however, require a CGE like database for production and factor use in the relevant countries.

8.5 Electricity markets

The impact of hydro power generation and water alloctaion choices on the electricity market is not modelled. Consequently, neither is the impact of electricity markets on water allocation. One particularly interesting impact of electricity market effects could be a large scale extension of Combined Heat/Power (CHP) generation. In electricity systems with significant amounts of CHP, electricity prices can tend to be lower in the winter, as a large heat demand tends to cause large production of electricity from CHP plants.

While there could be some benefits in an integrated model of water and energy generation, it is also possible to analyse monthly electricity price patterns with an electricity market model and feed the resulting electricity prices into BEAM,

In its current version the farmers always get the amount of water that the crop needs. This assumption requires a system whereby farmers can "buy" or otherwise acquire a guarantee for water delivery then they have to make their crop choice for the year (in October).

9

APPENDICES

APPENDIX A

Data collection, Excel file

10 COLLECTED DATA

This appendix outlines the most important data collected.

10.1 Model set labels

Planning zones

FER_UZB	'Planning zone of Fergana Valley region (includes provinces of Uzbekistan - Fergana, Andijan and Namangan)'
SYR_UZB	'Planning zone of Middle reach of Syrdarya (includes provinces of Uzbekistan - Syrdarya and Djizak)'
CHI_UZB	'Planning zone of Chirchik basin (includes Tashkent province of Uzbekistan)'
SUR_UZB	'Planning zone of Surkhandarya basin (includes Surkhandarya province of Uzbekistan)'
KAS_UZB	'Planning zone of Kashkadarya basin (includes kashkadarya province of Uzbekistan)'
ZAR_UZB	'Planning zone of Zaravshan basin (includes provinces of Uzbekistan - Bukhara, Navoi and Samarkand)'
SOU_UZB	'Planning zone of Low reach of Amudarya (includes provinces of Uzbekistan - Khorezm and Karakalpakstan)'
SYR_KAZ	'Planning zone of Middle reach of Syrdarya (includes Goldostepe zone of South Kakzakhstan province of Kazakhstan)'
CHI_KAZ	'Planning zone of Chirchik basin (includes CHAKIR zone of South Kakzakhstan province of Kazakhstan)'
NOR_KAZ	'Planning zone of Low reach of Syrdarya (includes ARTUR and Kyzylkum zones of South Kakzakhstan province and Kyzyl-Orda province of Kazakhstan)'
AMU_TUR	'Planning zone of Middle reach of Amudarya (includes Lebap, Mary, Akhal and Balkan provinces of Turkmenistan) '
SOU_TUR	'Planning zone of Low reach of Amudarya (includes Dashkhovuz province of Turkmenistan)'
FER_KYR	'Planning zone of Fergana valley (includes Osh, Djalalabad and Naryn provinces of Kyrgyz Republic) '
FER_TAD	'Planning zone of Fergana valley (includes Sogd province of Tajikistan without Zeravshan part) '
UPA_TAD	'Planning zone of Uppersteram of Amudarya (Includes Khatlon and Gorno-Badakhshan provinces and rayons of republican subordination of Tadjikistan)'
ZAR_TAD	'Planning zone of Zaravshan basin (includes Zeravshan part of Sogd province of Tadjikistan)'
UPA_AFG	'Planning zone of Uppersteram of Amudarya (includes Afghanistan)'

Reservoirs

Res_KAM	'Kambarata-1 (ky) (new)'
Res_TOK	'Toktogul (ky)'
Res_AND	'Andijan (uz)'
Res_KAR	'Kairakkum (tj)'
Res_CHA	'Charvak (uz), followed by (but not including) Chirchic cascade'
Res_SHA	'Shardara (kz)'
Res_ROG	'Rogun (tj) (new)'
Res_NUR	'Nurek (tj)'
Res_TMP	'Tuyamyun with HEPS (uz)'
Res_DAS	'Dashtijum (tj)'
Res_ZAR	'Yavan (tj)'
Res_FER	'reservoirs in Fergana valley (ky, uz)'
Res_TMR	'Tuyamyun, big reservoir w.o. HEPS (uz)'
Res_AHA	'reservoirs in Akhangaran basin (uz)'

Res_ARN	'Arnasay (uz)'
Res_KOK	'Koksarek (kz)'
Res_ARY	'reservoirs in Arys basin (kz)'
Res_KAF	'reservoirs in Kafirnigan basin (tj)'
Res_ZD	'Zeid in Karakum canal (tu)'
Res_TUR	'reservoirs in rivers of Turkmenistan (tu)'
Res_SUR	'reservoirs in Surkhandarya basin (uz)'
Res_KAS	'reservoirs in Kashkadarya basin (uz)'
Res_TAL	'Talimardjan in Karshi canal (uz)'
Res_BUK	'reservoirs in Bukhara province (uz)'
Res_NAR	'Naryn cascade of HEPS: Kurpsay, Tashkumyr, Shamaldysay, Uchkurgan, Kambarata2 (ky)'
Res_FAR	'Farkhad (uz)'
Res_VAH	'Vakhsh cascade of HEPS: Baipaza, Perepadnaya, Central, Golovnaya, Sangtuda2 (tj)'
Res_CHI	'Chirchik cascade of HEPS: Khodjikent, Gazalkent (uz), below Charvak'

Water sources

Src_TOK	'River flow of the Naryn river - inflow to Toktogul reservoir'
Src_NAR	'River flow of tributaries to Naryn river below Toktogul reservoir'
Src_AND	'River flow of Karadarya river - inflow to Andijan reservoir'
Src_KAR	'River flow of tributaries to Karadarya river below Andijan reservoir'
Src_FER	'River flow of small rivers in the Fergana Valley '
Src_SYR	'River flow of small rivers in Middle reach of Syrdarya'
Src_AHA	'River flow of the Akhangaran river'
Src_CHI	'River flow of the Chirchik river'
Src_KEL	'River flow of the Keles river'
Src_ARY	'River flow of the Arys river'
Src_ROG	'River flow of the Vakhsh river at the Rogun HEPS '
Src_VAH	'River flow of tributaries to Vakhsh below Rogun HEPS'
Src_PYD	'River flow of the Pyandj river'
Src_KAF	'River flow of the Kafirnigan river '
Src_ZAR	'River flow of the Zaravshan river'
Src_SUR	'River flow of the Surkhandarys river '
Src_KAS	'River flow of the Kashkadarya river'
Src_AFG	'River flow of tributaries from Afghanistan to Pyandj and Amudarya '
Src_TUR	'River flow of rivers in Turkmenistan'

River and sea nodes

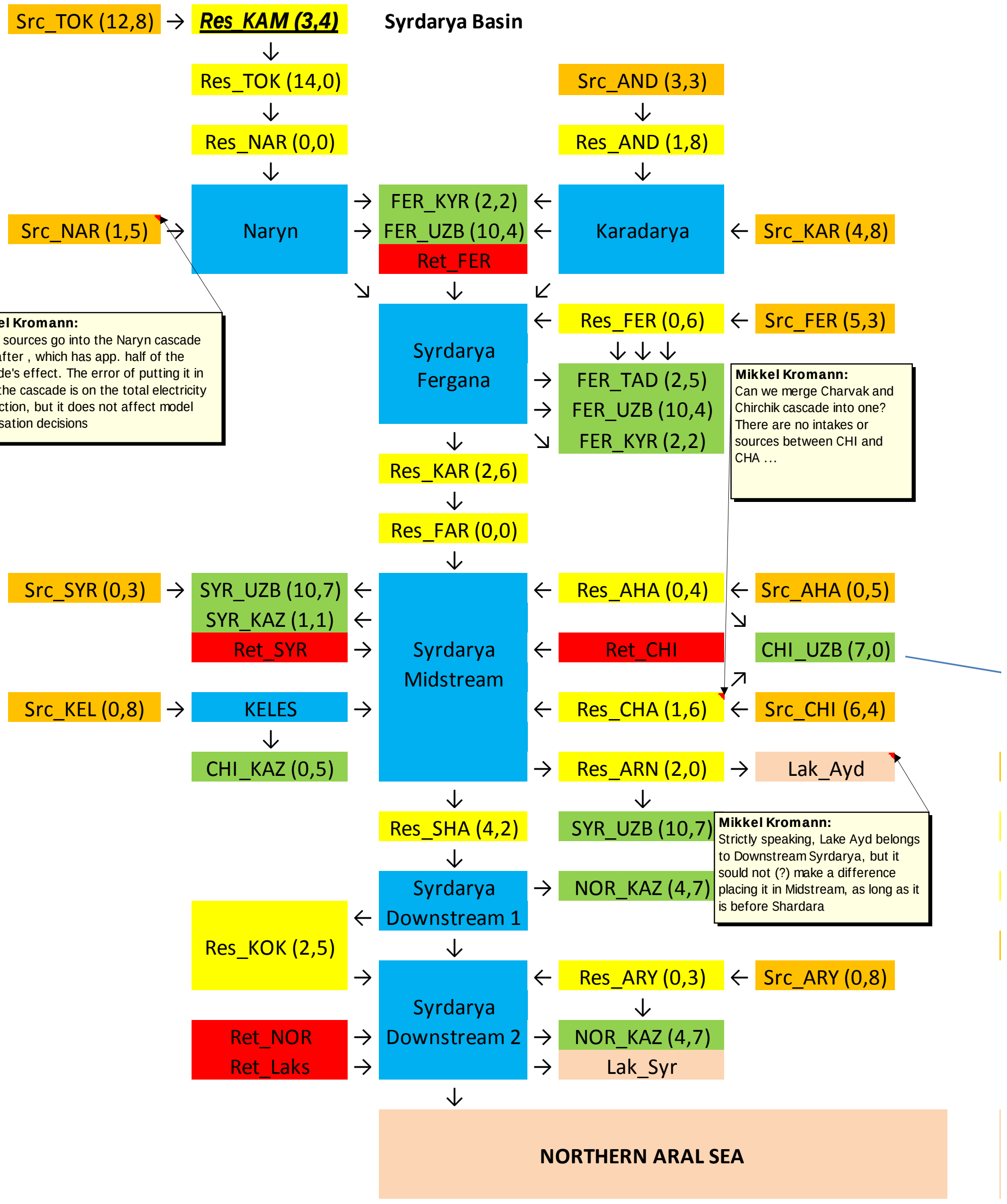
NARYN	'Naryn River'
KRDRYA	'Karadarya River'
SYRFER	'Syrdaria in Fergana Valley'
SYRMID	'Syrdaria below Kairakum '
KELES	'Keles River'
SYRDW1	'Syrdaria below Shardara'
SYRDW2	'Syrdaria below Koksarek'
VAKHSH	'Vakhsh River'
PYANDJ	'Pyandj River'
KUNDUZ	'Kunduz River'
KARFIR	'Karfirnigan River'
AMUUPS	'Amudarya below Vakhsh '
AMUMID	'Amudarya below Karfirnigan'

AMUDWN	'Amudarya below Tuyamun'
Lak_AYD	'Aidarkul lake'
Lak_SYR	'Lakes in Syrdarya delta'
Lak_GOL	'Golden age Lake'
Lak_AMU	'Lakes in Amudarya delta'
Lak_ARS	'Southern Aral Sea'
Lak_ARN	'Northern Aral Sea'

10.2 Water network and river topography

Figure 10 Syr Darya topography

Differences between left and right side of rivers are not shown.
Numbers in parentheses describe water and reservoir volumes.

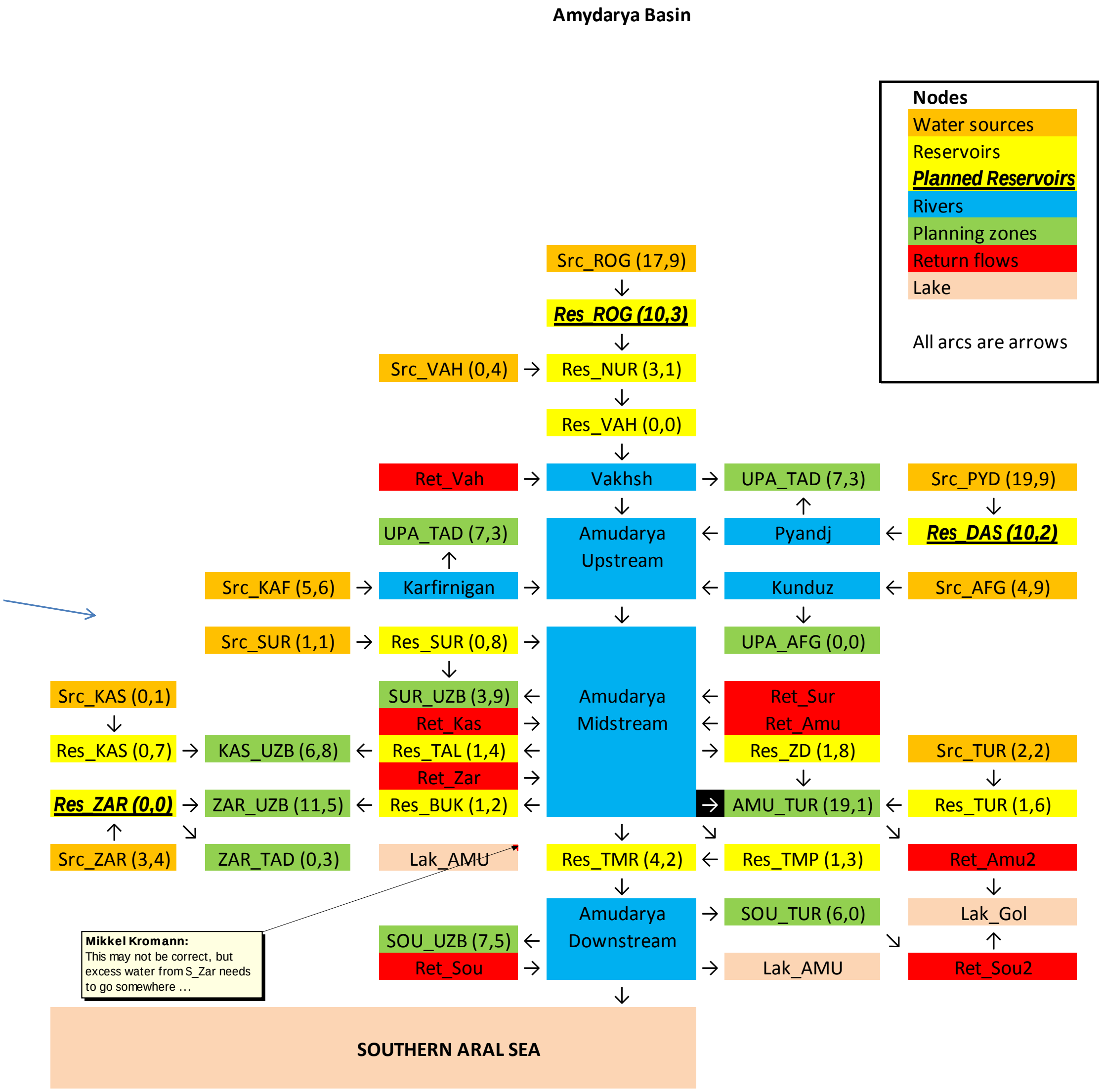


Mikkel Kromann: Naryn sources go into the Naryn cascade right after , which has app. half of the cascade's effect. The error of putting it in after the cascade is on the total electricity production, but it does not affect model optimisation decisions

Mikkel Kromann: Can we merge Charvak and Chirchik cascade into one? There are no intakes or sources between CHI and CHA …

Mikkel Kromann: Strictly speaking, Lake Ayd belongs to Downstream Syrdarya, but it sould not (?) make a difference placing it in Midstream, as long as it is before Shardara

Figure 11 *Amu Darya topography*



10.3 Data on agricultural production and water use

The construction of the agricultural water demand functions rely on both physical data and economical data.

Base year yield (ton/ha)							
	cot	wht	fru	ric	veg	alf	oth
FER_UZB	2,6	5,0	8,1	2,4	27,5	19,5	25,9
SYR_UZB	2,3	3,0	2,4	2,8	16,6	4,6	7,7
CHI_UZB	2,5	3,4	8,1	2,7	26,5	6,5	23,2
SUR_UZB	2,8	4,1	2,4	2,8	22,2	7,5	20,9
KAS_UZB	2,5	2,0	2,9	1,0	13,9	5,0	13,5
ZAR_UZB	2,8	3,4	2,0	2,7	22,8	14,8	18,5

SOU_UZB	2,2	4,0	6,8	3,0	16,0	5,0	5,6
SYR_KAZ	2,2	6,1	1,5	1,8	17,8	7,2	10,0
CHI_KAZ	2,2	6,1	1,5	1,8	17,8	7,2	10,0
NOR_KAZ	2,2	2,4	1,0	3,8	15,0	11,8	4,7
AMU_TUR	1,5	2,3	6,8	5,0	30,4	10,4	17,9
SOU_TUR	1,5	2,6	7,3	1,0	30,0	8,8	30,0
FER_KYR	2,3	7,5	3,8	2,2	15,0	6,3	5,4
FER_TAD	1,5	3,5	5,3	4,1	21,8	5,0	31,4
UPA_TAD	2,1	2,4	11,1	5,5	16,8	5,5	24,6
ZAR_TAD	1,5	3,5	5,3	4,1	21,8	5,0	31,4
UPA_AFG	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Note: Yellow cells indicates out-of-range values that have been corrected.

Base year agricultural land use (ha)

	cot	wht	fru	ric	veg	alf	oth
FER_UZB	331200	274800	3200	37500	257500	56500	165610
SYR_UZB	225000	273000	8300	12200	110600	32000	113610
CHI_UZB	111000	133000	7000	28000	133000	33000	73200
SUR_UZB	125000	117000	11000	10000	121000	15000	62000
KAS_UZB	182000	269000	800	12000	17000	33000	56140
ZAR_UZB	272000	291000	820	33700	202100	46000	181030
SOU_UZB	217000	90200	49000	14600	12600	92000	211200
SYR_KAZ	39215	12658	1241	447	5957	22089	25440
CHI_KAZ	17636	5693	558	201	2679	9934	11441
NOR_KAZ	101148	46649	71201	8152	16664	95976	104518
AMU_TUR	612000	749000	2020	18600	36000	40000	31490
SOU_TUR	263000	219000	58000	1000	4200	13000	6330
FER_KYR	40500	37400	5500	13300	26361	57700	154968
FER_TAD	29797	92099	4515	11738	26185	35214	43503
UPA_TAD	133000	208000	11010	19800	21710	53000	64310
ZAR_TAD	3203	9901	485	1262	2815	3786	4677
UPA_AFG	0	0	0	0	0	0	0

Base year water intensity (m3/ha)

	cot	wht	fru	ric	veg	alf	oth
FER_UZB	9.561	5.757	6.117	15.010	6.580	11.658	8.500
SYR_UZB	10.476	5.956	6.474	17.774	7.180	11.300	8.000
CHI_UZB	7.511	5.715	6.641	16.220	6.532	9.852	7.429
SUR_UZB	10.089	5.781	6.688	18.024	7.142	11.223	8.286
KAS_UZB	14.474	7.783	7.373	23.349	8.466	17.273	7.143
ZAR_UZB	13.609	6.443	6.509	22.748	8.284	15.911	7.429
SOU_UZB	12.143	6.714	7.429	26.043	8.857	16.214	6.857
SYR_KAZ	11.558	6.883	7.013	19.739	7.922	12.467	6.714
CHI_KAZ	11.338	6.631	6.763	22.544	7.426	13.460	7.000
NOR_KAZ	11.429	7.000	7.429	28.629	7.571	16.714	6.857
AMU_TUR	16.418	7.183	8.502	26.826	8.502	22.857	7.857
SOU_TUR	12.817	8.138	9.155	25.867	8.283	18.310	7.571
FER_KYR	5.429	3.878	3.930	14.565	4.826	5.619	6.571
FER_TAD	12.743	6.543	8.571	20.714	7.857	13.286	7.143
UPA_TAD	15.902	10.918	13.054	21.714	13.292	14.953	7.143
ZAR_TAD	16.218	11.115	13.092	21.429	14.962	11.371	7.714
UPA_AFG	0	0	0	0	0	0	0

Crop water use, share by month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cotton	12%	15%	0%	0%	7%	25%	19%	19%	2%	0%	0%	0%
Wheat	0%	0%	0%	24%	30%	25%	0%	0%	0%	3%	18%	0%
Vegetables	0%	22%	0%	10%	14%	16%	20%	14%	5%	0%	0%	0%
Fruits	0%	0%	5%	0%	15%	25%	23%	20%	12%	0%	0%	0%
Rice	6%	9%	0%	11%	17%	19%	20%	17%	0%	0%	0%	0%
Alfalfa	9%	12%	0%	2%	10%	13%	17%	17%	12%	7%	0%	0%
Other	0%	0%	0%	0%	15%	19%	21%	22%	23%	0%	0%	0%

10.4 Data on nature, household and industrial water needs

Annual planning zone demand, mm3/year

		Industry			**Households**	
	Demand	Oct-Mar	Apr-Sep	Demand	Oct-Mar	Apr-Sep
FER_UZB	1.058	550	508	870	333	537
SYR_UZB	2.807	1.520	1.287	3.247	933	2.314
CHI_UZB	5.237	2.711	2.526	1.036	476	560
SUR_UZB	38	20	18	147	67	80
KAS_UZB	1.258	671	587	123	63	60
ZAR_UZB	2.427	1.251	1.176	440	216	224
SOU_UZB	832	438	394	134	63	72
SYR_KAZ	10	5	5	4	2	2
CHI_KAZ	11	6	5	5	2	2
NOR_KAZ	74	39	35	18	9	9
AMU_TUR	3.447	1.783	1.664	236	118	118
SOU_TUR	15	8	7	6	3	3
FER_KYR	99	51	48	147	74	74
FER_TAD	281	146	135	182	90	92
UPA_TAD	686	356	331	469	230	239
ZAR_TAD	28	14	13	18	9	9
UPA_AFG	0	0	0	0	0	0

Nature needs, km3/season

		2000-2001(dry)		2008-2009 (normal)	
Region	Country	Non-veg	Veg.	Non-veg	Veg.
lak_Ayd	Syr	0,0	0,0	1,1	0,1
lak_Syr	Syr	0,0	0,5	0,5	1,5
Lak_gol	Amu	1,1	1,8	1,5	2,8
lak_Amu	Amu	1,0	1,5	1,5	2,5
Aral_sou	Amu	1,0	1,0	2,0	6,0
Aral_nor	Syr	1,0	0,5	1,5	2,5

10.5 Data on Hydro Electric Power Stations and reservoirs

	Max Vol.	Min Vol.	Yield	Effect	Capacity	Head	Efficiency	Coefficients cf. explenation		
	mm3	mm3	MWh/mm3	MW	m3/s	meter	η %	a	b	c
Res_KAM	4.650	1.220	516	1.900	960	210	90%	85,28	2,68E-02	
Res_TOK	19.500	5.500	422	1.200	960	182	85%	86,62	6,50E-03	-8,00E-08
Res_AND	1.900	150	230	100	140	99	85%	31,09	7,67E-02	-2,00E-05
Res_KAR	3.350	750	46	126	720	21	80%	10,51	4,50E-03	-4,00E-07
Res_CHA	2.010	430	323	600	550	148	80%	72,44	5,48E-02	-9,00E-06
Res_SHA	5.200	970	53	100	780	23	85%	10,69	3,50E-03	-3,00E-07
Res_ROG	13.300	3.040	822	3.600	1.550	335	90%	85,72	2,05E-02	-6,00E-07
Res_NUR	7.130	4.000	491	3.000	1.500	225	80%	-32,65	9,50E-02	-9,00E-06
Res_TMP	1.290	40	33	150	1.500	15	80%	5,54	1,62E-02	-7,00E-06
Res_DAS	17.600	7.400	737	4.000	1.700	300	90%	54,71	8,80E-03	
Res_ZAR	50	20	209	120	190	85	90%			
Res_FER	595	45	0	0	0	0				
Res_TMR	6.510	2.268	0	0	0	0				
Res_AHA	450	31	0	0	0	0				
Res_ARN	3.000	1.000	0	0	0	0				
Res_KOK	3.000	500	0	0	0	0				
Res_ARY	350	10	0	0	0	0				
Res_KAF	940	320	0	0	0	0				
Res_ZD	2.200	400	0	0	0	0				
Res_TUR	2.000	400	0	0	0	0				
Res_SUR	883	116	0	0	0	0				
Res_KAS	803	70	0	0	0	0				
Res_TAL	1.525	125	0	0	0	0				
Res_BUK	1.879	664	0	0	0	0				
Res_NAR	0	0	0	0	0	0				
Res_FAR	0	0	72	126	0	31	85%			
Res_VAH	0	0	0	0	0	0				
Res_CHI	0	0	153	305	0	66	85%			

10.6 Data on water sources

Water supply, mm3/month

	m01	m02	m03	m04	m05	m06	m07	m08	m09	m10	m11	m12
Src_TOK	459	384	563	849	2107	2323	1661	1461	979	795	660	558
Src_NAR	70	58	91	207	279	238	174	94	78	75	83	83
Src_AND	173	160	146	228	550	634	230	178	141	273	335	216
Src_KAR	379	385	485	390	307	348	138	315	334	555	633	546
Src_FER	184	161	189	250	564	909	1088	782	440	316	242	223
Src_SYR	12	16	21	46	57	46	46	37	17	14	13	13
Src_AHA	13	12	46	122	170	60	19	18	15	33	21	18
Src_CHI	214	165	293	665	1287	1402	736	487	362	329	276	234
Src_KEL	97	68	85	89	25	22	23	68	52	75	97	111
Src_ARY	51	172	258	138	37	27	28	24	20	6	11	8

Src_ROG	429	332	555	1101	2086	3442	3727	2776	1439	812	610	548
Src_VAH	15	17	32	65	57	53	46	30	23	14	14	13
Src_PYD	546	451	480	706	1271	3805	4996	3607	1706	1010	740	557
Src_KAF	76	73	398	719	1250	1126	908	557	199	143	103	92
Src_ZAR	107	98	106	107	381	727	686	483	265	164	131	134
Src_SUR	118	91	79	70	195	152	41	47	48	81	93	107
Src_KAS	26	35	17	7	1	6	4	1	3	9	6	22
Src_AFG	235	372	263	372	664	964	627	303	245	275	280	286

Ground water sources (mm3/half year)

	oct-mar	apr-sep
FER_UZB	500	600
SYR_UZB	100	200
CHI_UZB	300	400
SUR_UZB	100	150
KAS_UZB	200	250
ZAR_UZB	300	400
SOU_UZB	0	0
SYR_KAZ	0	0
CHI_KAZ	0	0
NOR_KAZ	50	50
AMU_TUR	0	0
SOU_TUR	0	0
FER_KYR	100	150
FER_TAD	100	150
UPA_TAD	300	350
ZAR_TAD	0	0

APPENDIX B

References

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