Water consumption & allocation strategies along the river oases of Tarim River based on large-scale hydrological modeling

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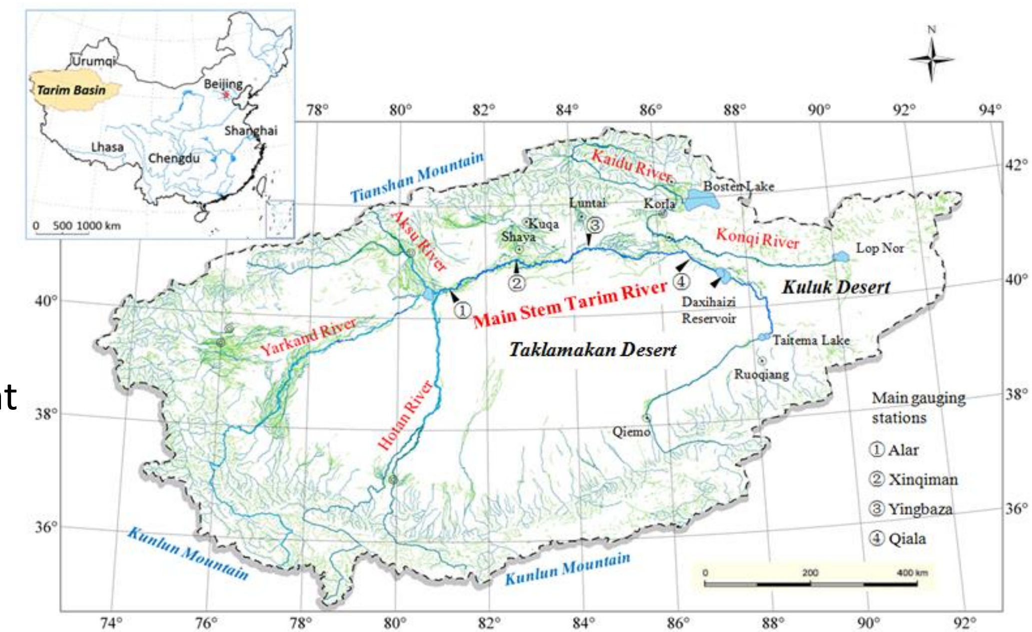
Scenario: Discharge 5.4 billion m^3 (year 2012)

Goal: Cotton production at 90%

Investigate: farmland area & water allocation strategy

Model conditions:

- GW model: sigle-layer
- Deficit distibution: equal shortage
- Crop model: FAO56 DualCropCoefficient
- Climate, soil, routing method,etc.



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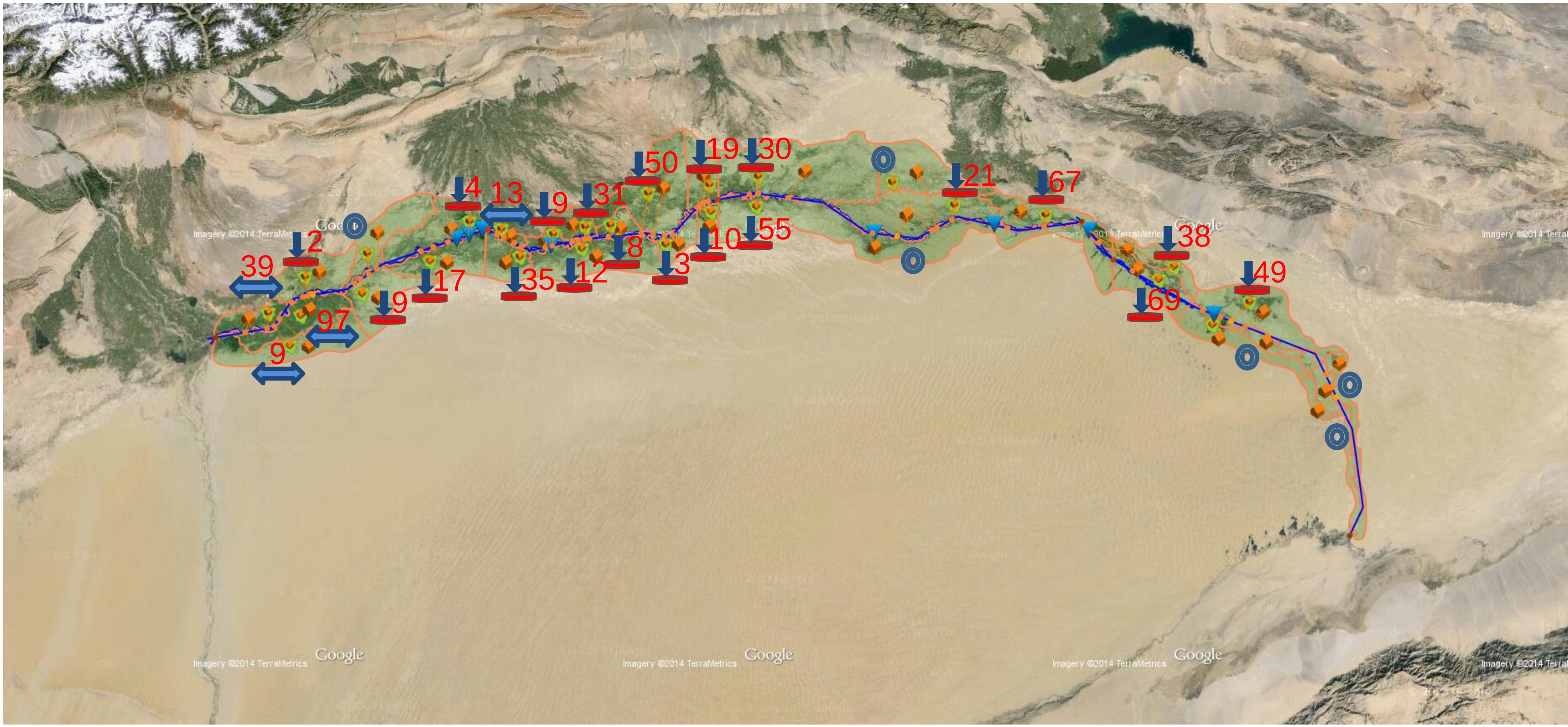
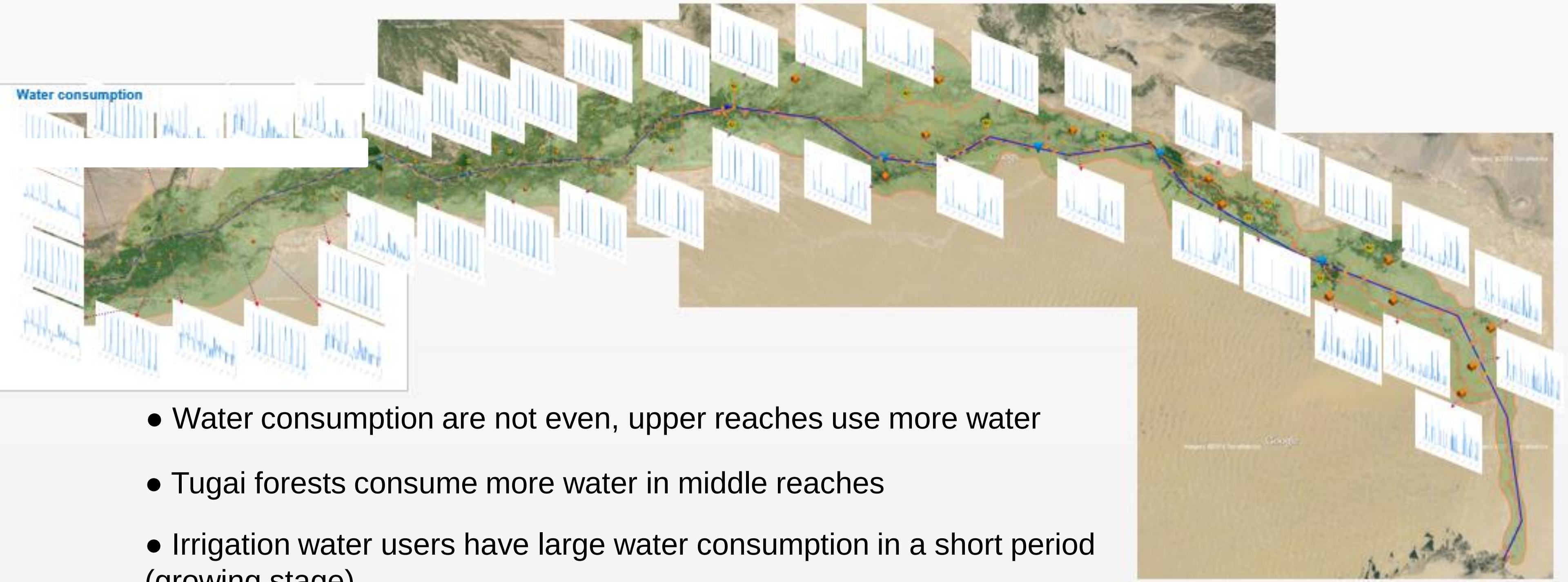
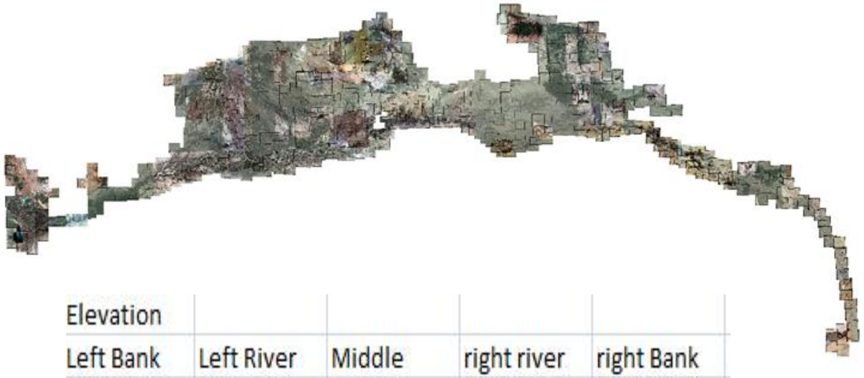
Farmland area reduced to (km^2) Maintain None

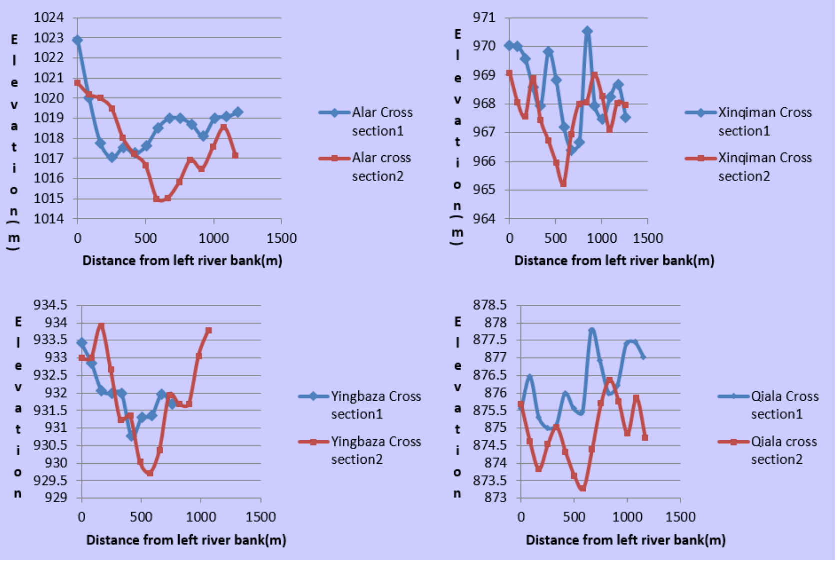


Water allocation strategy

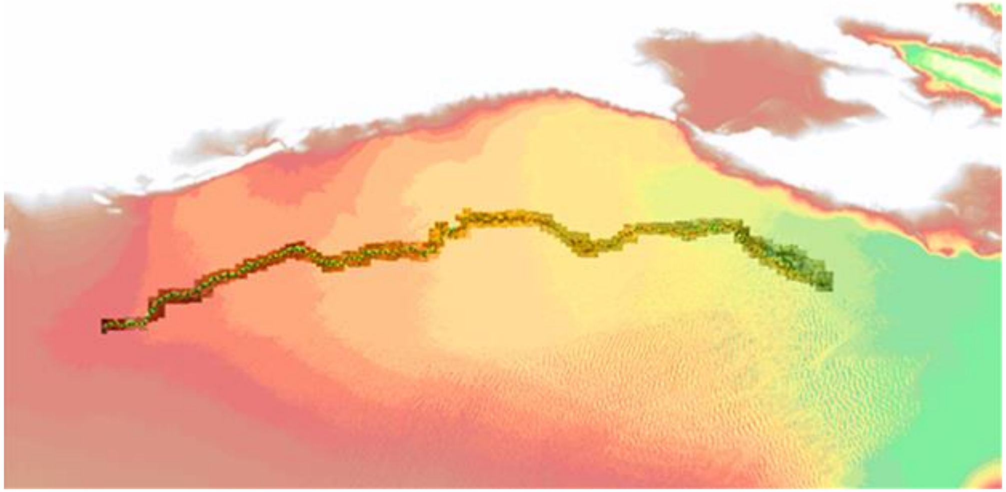


- Water consumption are not even, upper reaches use more water
- Tugai forests consume more water in middle reaches
- Irrigation water users have large water consumption in a short period (growing stage)





Elevation				
Left Bank	Left River	Middle	right river	right Bank
1025	1021	1019	1021	1025
1023	1019	1017	1019	1023
1021	1017	1015	1017	1021
1020	1016	1014	1016	1020
1018	1014	1012	1014	1018
1018	1014	1012	1014	1018
1015	1011	1009	1011	1015
1012	1008	1006	1008	1012
1012	1008	1006	1008	1012
1012	1008	1006	1008	1012
1011	1007	1005	1007	1011
1010	1006	1004	1006	1010
1008	1004	1002	1004	1008
1007	1003	1001	1003	1007
1005	1001	999	1001	1005



MIKE HYDRO 2014 and model setup

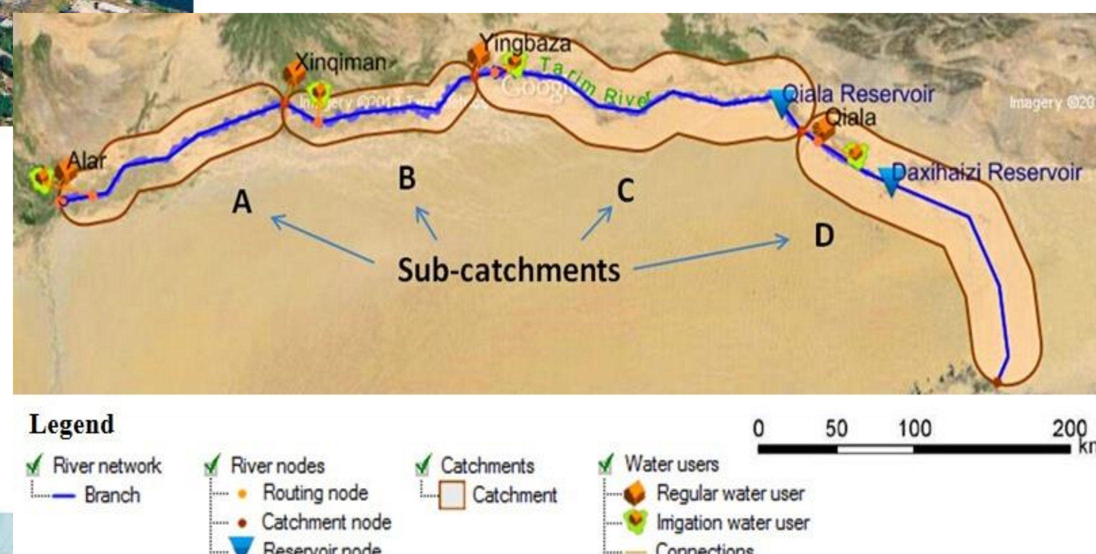
MIKE HYDRO release 2014

Typical basin module applications:

- Integrated Water Resources Management (IWRM) studies
- Provision of multi-sector solution alternatives to water allocation and water shortage problems
- Reservoir and hydropower operation optimization
- Exploration of conjunctive use of groundwater and surface water
- Irrigation scheme performance improvements

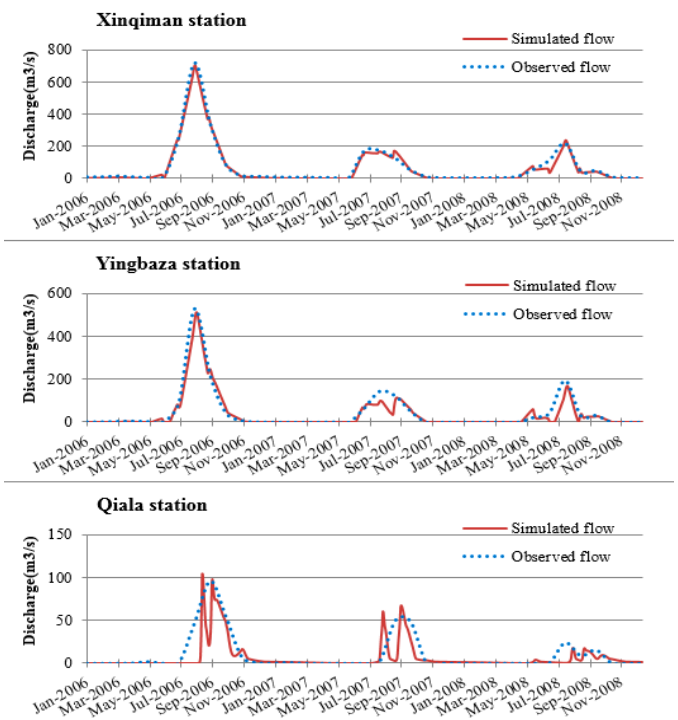
The study area was divided into four sub-regions:

- Alar-Xinqiman (A)
- Xinqiman-Yingbaza (B)
- Yingbaza-Qiala (C)
- Qiala-Taitema Lake (D)



Discharge and calibration

Simulated & Observed Discharge



Four error indices:

$$NSE = 1 - \frac{\sum_{t=1}^{t=n}[(Q_{sim})_t - (Q_{obs})_t]^2}{\sum_{t=1}^{t=n}\left[(Q_{obs})_t - \left(\overline{Q_{obs}}\right)_t\right]^2} \quad (1)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{t=1}^{t=n}[(Q_{sim})_t - (Q_{obs})_t]^2} \quad (2)$$

$$RSR = \frac{RMSE}{\sqrt{\frac{1}{n}\sum_{t=1}^{t=n}\left[(Q_{obs})_t - \left(\overline{Q_{obs}}\right)_t\right]^2}} \quad (3)$$

$$\%\ Bias = \frac{\sum_{t=1}^{t=n}[(Q_{sim})_t - (Q_{obs})_t]}{\sum_{t=1}^{t=n}(Q_{obs})_t} \times 100 \quad (4)$$

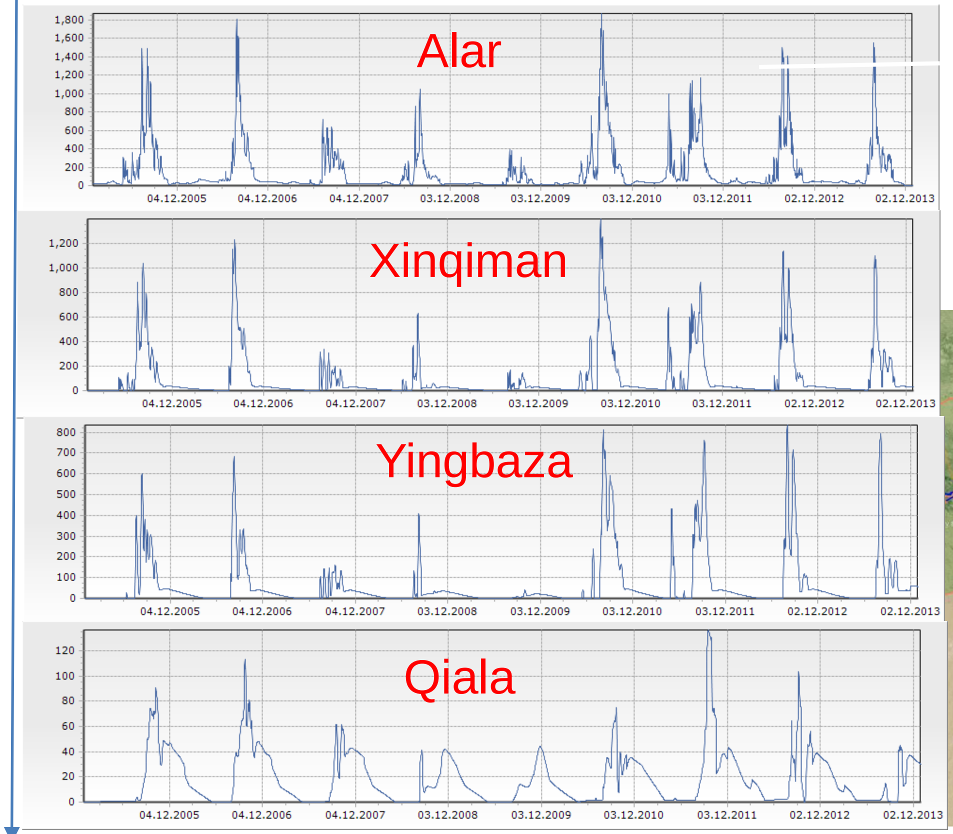
Evaluation of calibration performance.

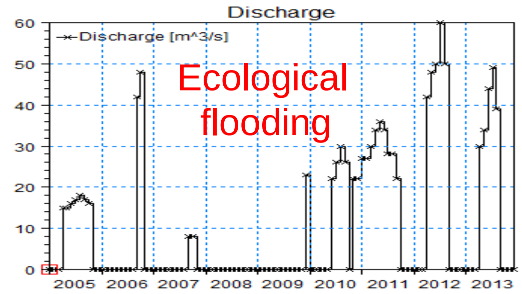
Gauging stations	NSE	RMSE (m^3/s)	RSR	% Bias
Xinqiman	0.88	14.7	0.11	-2.41
Yingbaza	0.86	11.53	0.12	-3.42
Qiala	0.92	3.58	0.10	-8.24

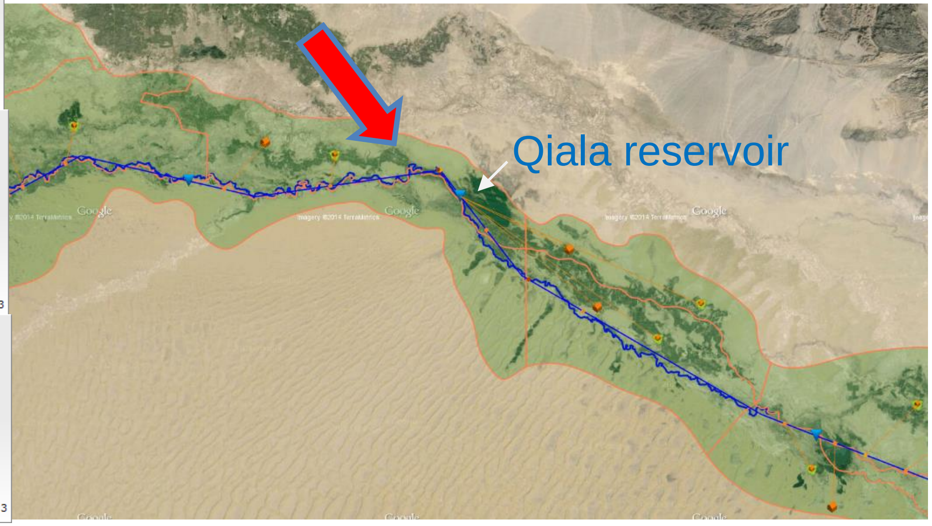
The model adequately reproduced the patterns of observed discharges and their magnitudes, although the simulated flow was underestimated. Because the efficiency coefficient was sensitive to extreme values, the high values of the NSE (0.88, 0.86 and 0.92) indicated a good match of simulated and observed discharges. RMSE, RSR and % Bias values all represented good ratings.

Simulated streamflow on several locations

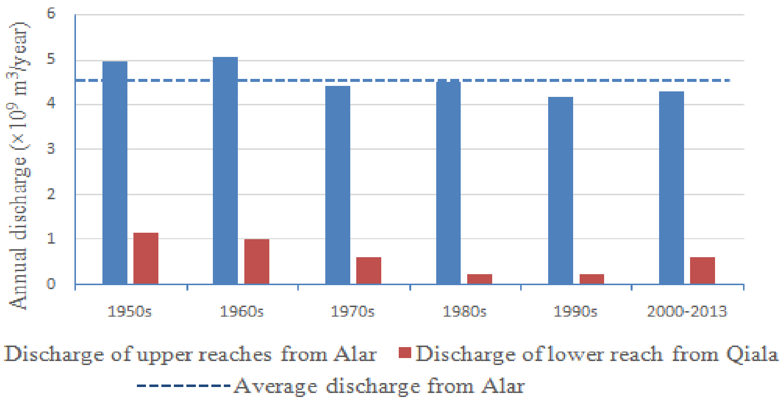
Simulation period: 2005-2013
Time step: daily







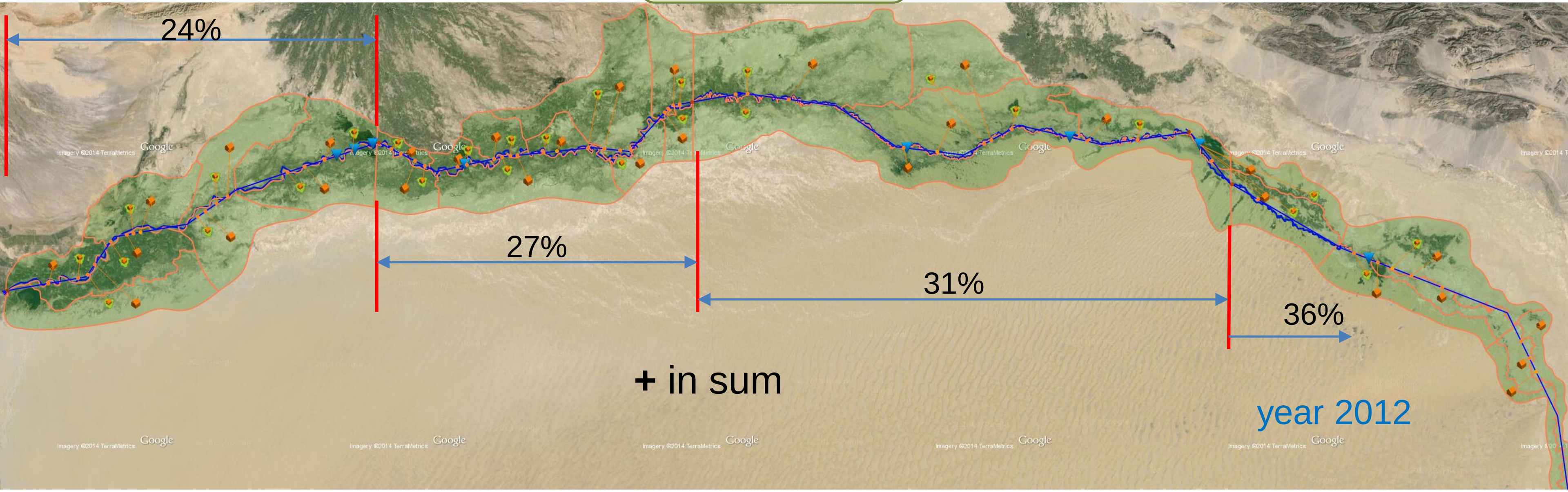
YU, Yang
München, 11. Dec. 2015



Since the 1970s, less than 1/4 of the discharge from the main stem of the Tarim River has been reaching the downstream areas.

Simulation results

Water deficit



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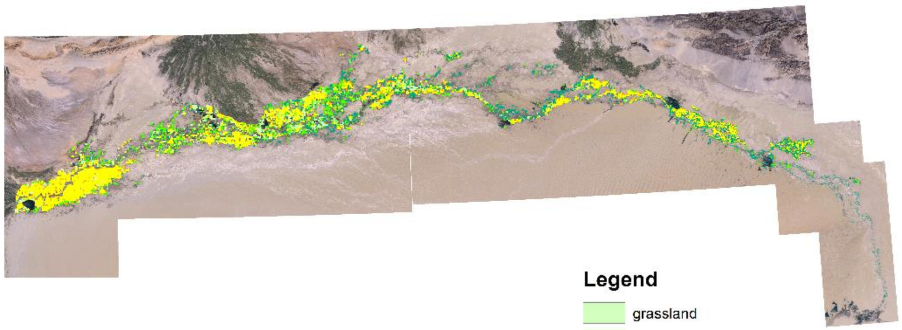
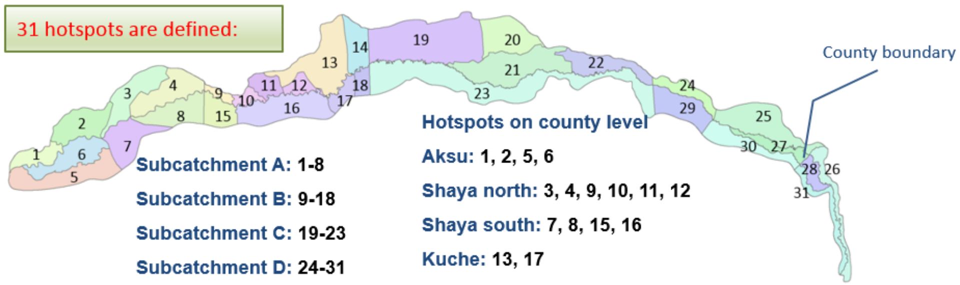
Landuse distribution:



Source: Created by Prof. Dr. Joachim Hill, Universität Trier,
modified by Philipp Huttner, TUM, SuMaRiO

31 hotspots are defined:



Subcatchment A: 1-8
Subcatchment B: 9-18
Subcatchment C: 19-23
Subcatchment D: 24-31

Hotspots on county level
Aksu: 1, 2, 5, 6
Shaya north: 3, 4, 9, 10, 11, 12
Shaya south: 7, 8, 15, 16
Kuche: 13, 17
Luntai: 14, 19, 20

Farmland area, Tugai forest area,etc.

	Grassland	Natural Vegetation	Tugai forest	Urban vegetation	Low dense Tugai	Cotton	Other agriculture
Subcatchment 1	387.8	493.3	97.1	4.6	497.1	1125.1	129.0
hotspot_1	30.6	20.92		3.9825	11.5025	259.1125	32.08
hotspot_2	106.0	71.5825	20.305		82.1925	7.86	3.245
hotspot_3	11.7	15.54	2.1925		36.535	0.0025	
hotspot_4	108.7	148.4625	37.5325		155.6325	25.45	3.2475
hotspot_5	34.9	53.3825	0.8		36.2025	30.7425	12.0625
hotspot_6	42.7	33.725	0.9025	0.5975	5.86	643.615	52.14
hotspot_7	12.5	25.585	5		40.0225	46.2375	14.245
hotspot_8	40.6	124.125	30.365		129.2	112.1275	11.9975
Σ	387.8	493.3	97.1	4.6	497.1	1125.1	129.0
Subcatchment 2	359.3	626.1	382.2	4.0	829.6	810.3	140.8
hotspot_9	18.7	18.0575		0.575	4.4675	58.9425	6.125
hotspot_10	40.6	41.0875	3.56		8.075	34.9725	8.1025
hotspot_11	42.0	61.7525	11.535		43.465	139.865	17.175
hotspot_12	42.5	52.735	29.6375		48.4625	32.365	6.935
hotspot_13	63.8	251.9975	196.2175	3.42	389.0325	208.845	40.86
hotspot_14	12.7	21.055	30.045		68.785	70.13	18.46
hotspot_15	33.0	30.66	6.5725		40.31	164.215	16.8525
hotspot_16	96.3	126.1975	82.355		212.505	56.39	7.5275
hotspot_17	2.3	12.6925	6.0275		12.1225	12.1375	4.365
hotspot_18	7.3	9.835	16.205		2.3975	32.465	14.385
Σ	359.3	626.1	382.2	4.0	829.6	810.3	140.8
Subcatchment 3	180.2	251.7	500.5	0.6	1218.3	466.3	167.1
hotspot_19	78.9	82.2625	131.23		403.3575	70.9525	38.3275
hotspot_20	8.3	31.9525			150.215	0.0475	
hotspot_21	36.4	55.7025	177.7525		403.18	57.275	19.92
hotspot_22	16.0	16.4075	63.665	0.56	72.185	184.285	60.7975
hotspot_23	40.6	65.375	127.8525		189.4	153.725	48.005
Σ	180.2	251.7	500.5	0.6	1218.3	466.3	167.1
Subcatchment 4	28.3	76.5	473.1	15.2	42.9	296.5	93.0
hotspot_24	8.8	8.175	36.5475	1.11	1.64	65.955	28.3475
hotspot_25	6.3	18.4075	160.39	7.67	13.765	92.675	31.66
hotspot_26		4.755	34.6175				
hotspot_27	0.2	11.585	51.6575		3.2525		
hotspot_28			19.455				
hotspot_29	12.5	25.645	114.7675	6.4475	12.03	137.8525	32.9525
hotspot_30	0.6	7.9175	38.8225		12.2275		0.045
hotspot_31			16.8475				
Σ	28.3	76.5	473.1	15.2	42.9	296.5	93.0

By proportion of crop areas in each sub-catchment based on the landuse map

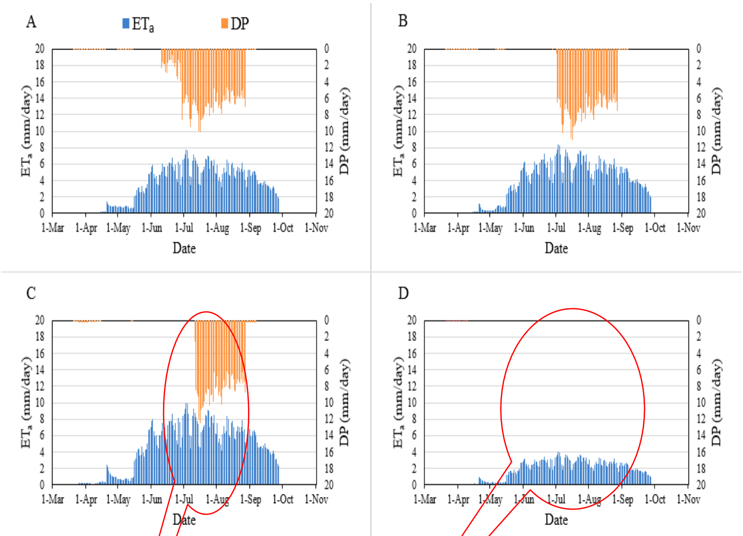
Irrigation Scheme

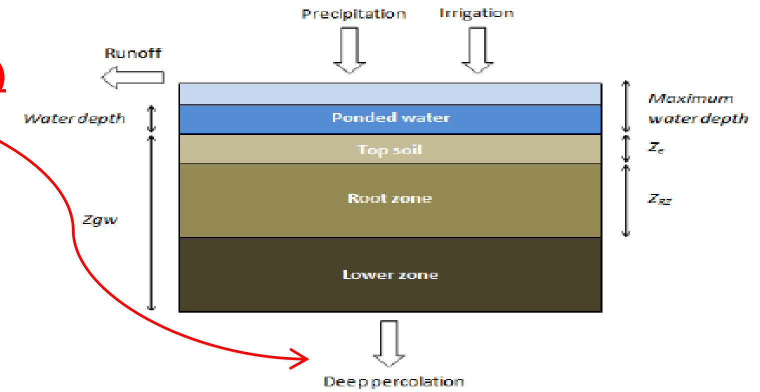
The *Irrigation scheme tab includes definition of three types of information:*

- Climate model
- Deficit distribution method
- Use a soil and runoff model for all fields

Crop evapotranspiration & crop factors

Crop evapotranspiration (ET_a) & deep percolation (DP)





The total ET_a for 2006 in sub-catchments A, B, C and D was 666, 709, 864 and 190 mm. This reflected **high water stress** in the lower reach of sub-catchment D.
The highest levels of ET_a and DP both occurred in sub-catchment C during July.
High water consumption for irrigation in this district.

The relationships of reference evapotranspiration (ET_o), crop evapotranspiration (ET_c) and actual evapotranspiration (ET_a)

$$ET_c = K_{cb} \times ET_0$$

$$ET_a = K_s \times ET_c$$

K_S : water stress coefficient that describes the effect of water stress on crop transpiration.
ET_o : From FAO-56 Penman-Monteith method.

Crop factors and growth stages in study area

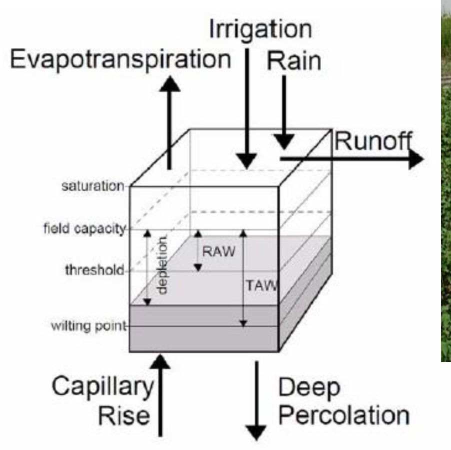
Crops	Share (%)	Sowing day	Length (days) INI	DEV	MID	LAT	RD (mm)	MH (m)	Kcb INI	MID	LAT
Wheat	2.7	03.21	15	25	40	20	1500	1	0.4	1.2	0.5
Maize	1.6	04.16	20	25	60	15	1700	2	0.4	1.2	0.7
Sugarbeet	5.1	03.26	25	35	60	45	1200	0.5	0.5	1.2	0.8
Bean	1.7	04.21	20	30	30	10	700	0.4	0.4	1.1	0.9
Melon	2.1	04.01	25	35	40	20	1500	0.4	0.5	1	0.8
Cotton	82.6	04.21	25	45	50	40	1700	1.5	0.5	1.2	0.8
Tomato	2.1	04.11	35	40	50	25	1500	0.6	0.5	1.2	0.8

Total Available Water (TAW) Scenarios

- TAW in the root zone is the difference between the water content at field capacity and the wilting point.

The design of the TAW scenarios assumed that irrigation starts when soil moisture content reaches the specified fraction of TAW. From TAW = 0.7 to TAW = 0.1, seven scenarios were investigated to show the yield performance by different crops. As crop yield declined with the decrease of TAW,
the primary purpose of the scenarios was to find the suitable fraction of TAW for each crop at which less water is consumed while maintaining a relatively high crop yield.

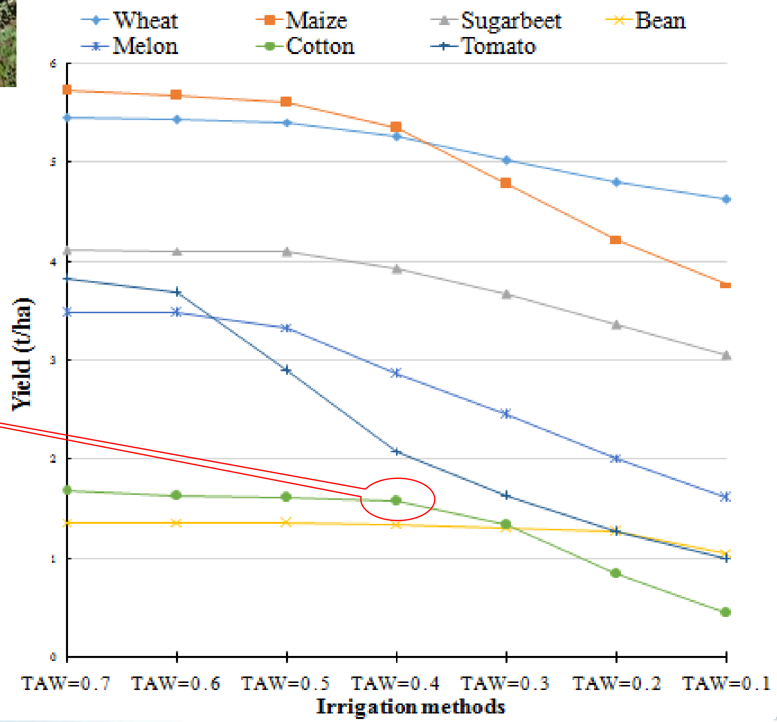
Yield performance of crops based on TAW



Water use-yield relationship:

$$(1 - \frac{Y_a}{Y_m}) = K_y\,(1 - \frac{ET_a}{ET_c})$$

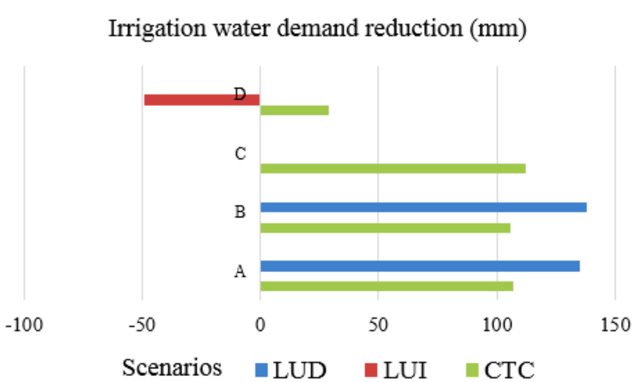
Yield performance of crops based on fraction of total available water (TAW)

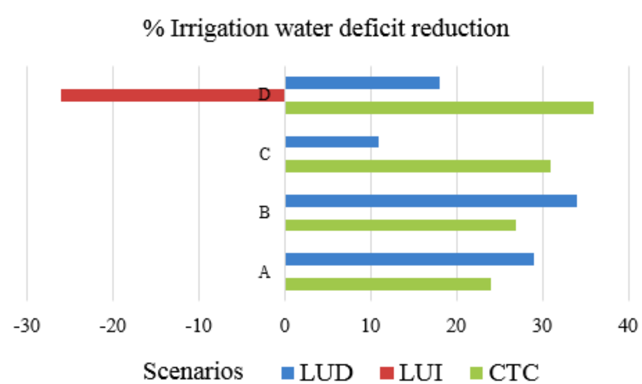


Analyzing crop yields under water scarcity represents the highly differing susceptibility of crop types to water stress. Cotton demonstrates a robust yield performance with a reduction in TAW. To maintain cotton production while reducing water use, TAW 0.4 is recommended.

Wheat, maize, sugar beet, bean, melon and cotton all showed high compatibility with water stress. Tomatoes should be considered in areas where the supply of irrigation water is ensured.

Land use scenarios





LUD: land use decrease scenario

LUI: land use increase scenario

CTC : crop type change scenario

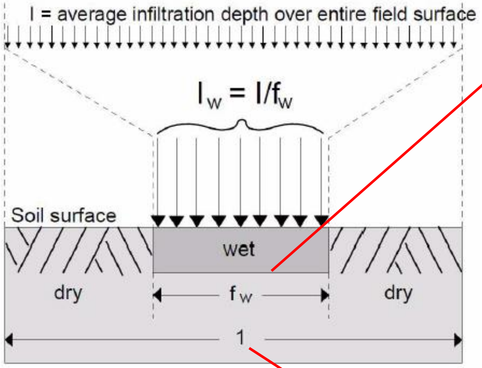
Simulation results & conclusions:

In LUD scenario, the reduction of farmland in sub-catchments A and B (upper reaches) indicates a positive effect on the reduction of irrigation water demand.
In LUI scenario, the increase of farmland in the lower reach was found to be harmful to the water saving purpose.
In CTC scenario, rotation of crop types (cotton ⇨ apocynum) can be an effective approach to reduce irrigation water demand and deficit.

Water-Saving Irrigation Scenarios

Drip irrigation under mulch (DIUM)

By applying DIUM method in the irrigation fields, spray loss (SL) and wetting fraction (WF) will be significantly reduced compared with sprinkler irrigation.



- **Wetting fraction time series**. The irrigation model requires a wetting fraction that determines the fraction of the field surface that is being wetted during irrigation. For example, in sprinkler irrigation this fraction will be close to 1, whereas for drip irrigation it may be as low as 0.1. The wetting fraction is also an important factor for determining how much irrigation water is required before the surface soil storage is filled and hence when the root zone starts to fill. Results of modelling revealed that a considerable amount of water could be saved by the water-saving irrigation.

Five DIUM scenarios and simulation results.

% DIUM	% SL	% WF	% WS	% RWDD
10	46	91	6	5
30	38	73	17	12
50	30	55	25	16
70	22	37	32	22
100	10	10	40	30

% DIUM: percentage of applied drip irrigation under mulch in the field.

% SL: percentage of spray losses.

% WF: percentage of wetting fraction.

% WS: percentage of water saving.

% RWDD: percentage of reduction of water demand deficit.

Possible Scenarios:

Alar discharge (2008, 2010, 2012?)

Goal: Yield production (water deficit) on certain lever

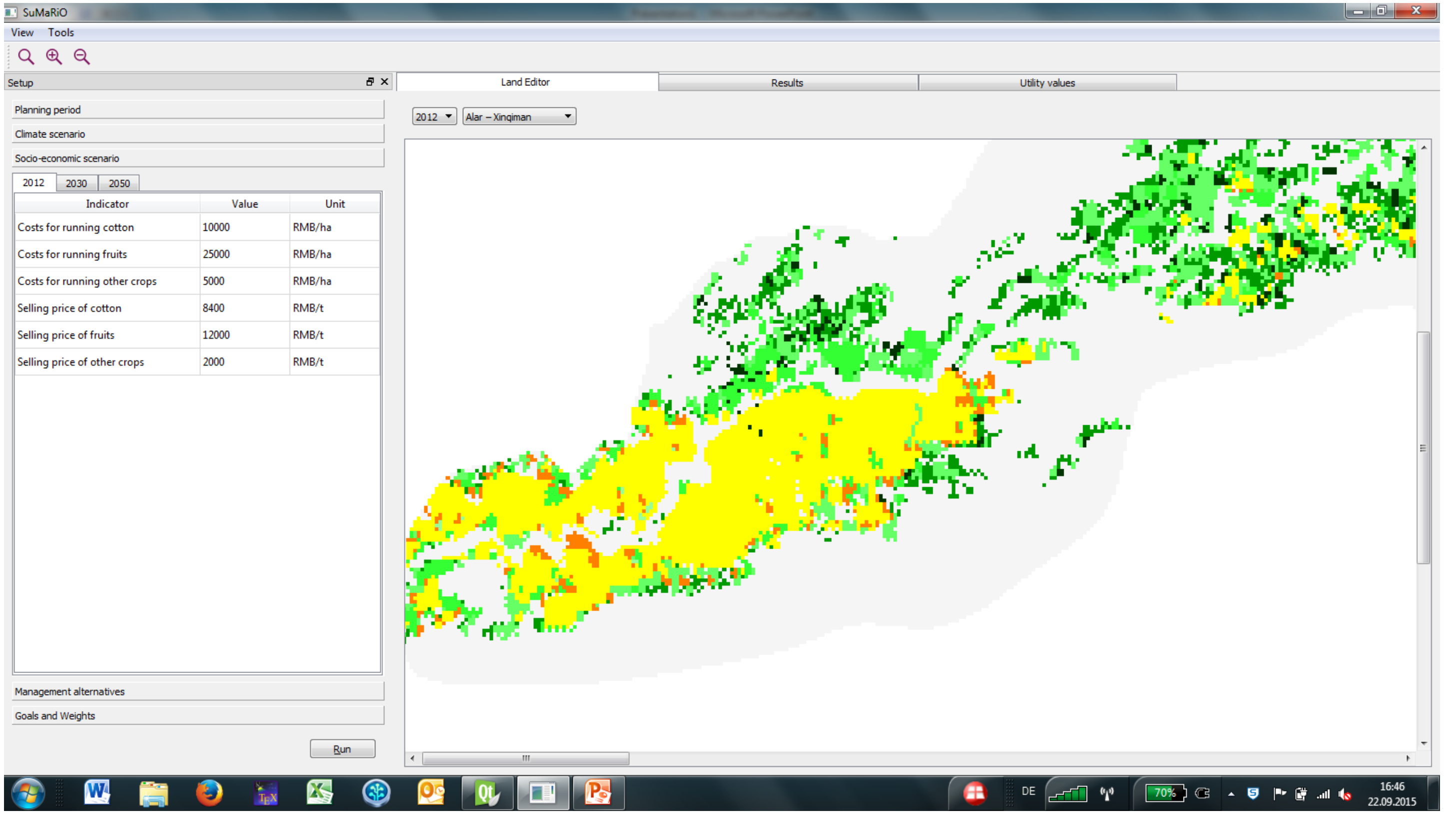
Optimized:

Farmland area (unchanged/changed)

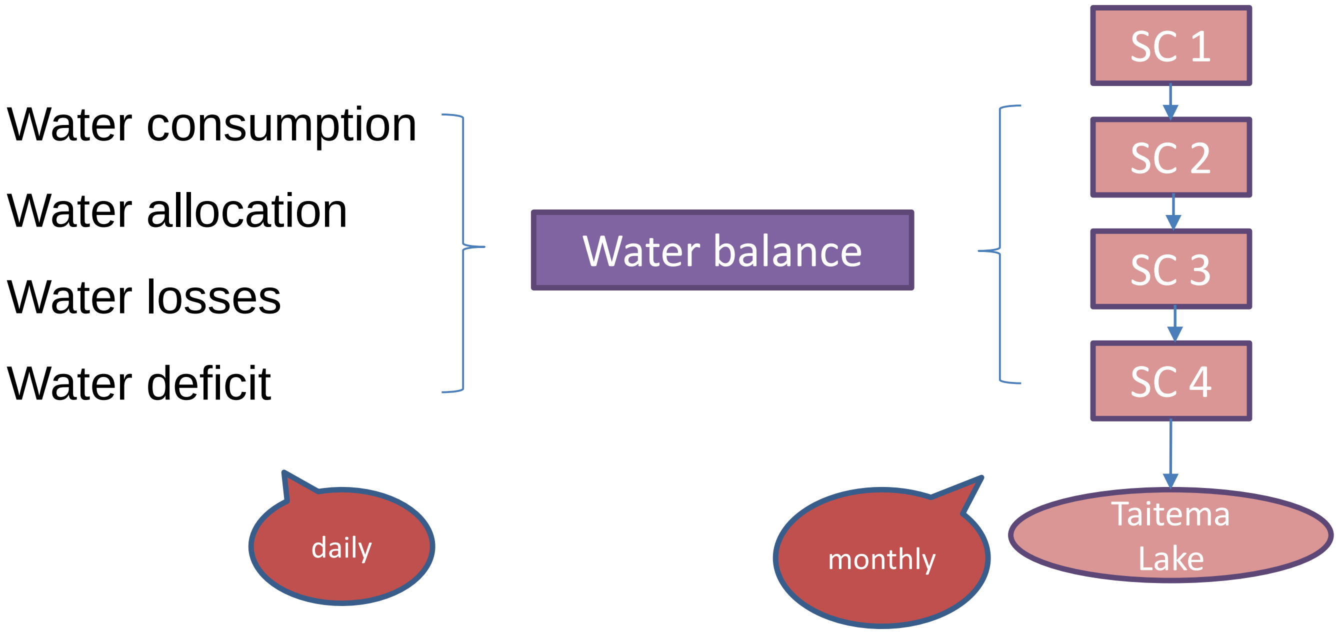
Water allocation strategies

More populus in the hotspots?

- DSS serves the decision-making, operations, and planning levels of sustainable management of water and land use in the Tarim River basin.



Coupling between MIKE HYDRO & DSS (1)



Coupling between MIKE HYDRO & DSS (2)

Mike hydro

DSS

Water demand for crops

Km^2 of crops in each SC

No. of cells for each crop

Each cell water demand (monthly)

Coupling between MIKE HYDRO & DSS (3)

$$\left(1-\frac{Y_a}{Y_m}\right)=K_y\left(1-\frac{ET_a}{ET_c}\right)$$

Output:
Y_a

Inputs:

Y_m: fixed value

K_y: fixed value

ET_c: fixed value

ET_a: Output of Mike Hydro in initial year, then

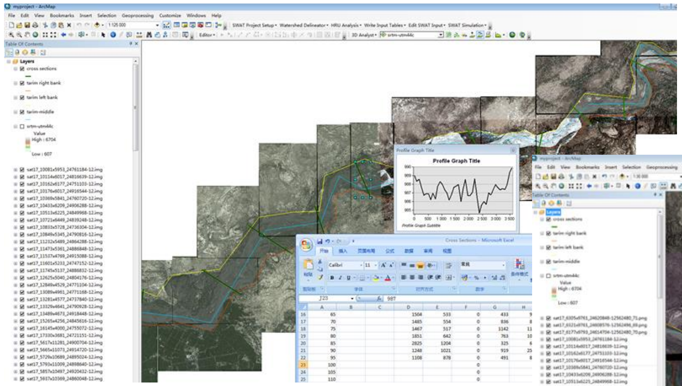
Modflow

Coupling between MIKE HYDRO & DSS (the others)

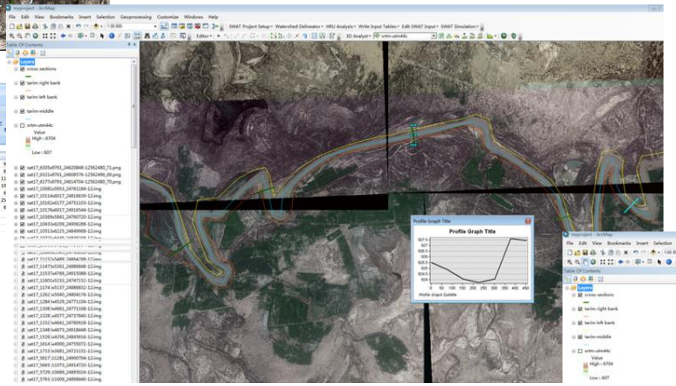
- Agricultural water that is needed for maximal production (million m^3)
- Water availability for agriculture (million m^3)
- Water availability for natural vegetation (million m^3)
- Membership functions: (fuzzy logic)
  flooding in each SC: high/medium/low
- TAW (under consideration)

Latest news

Upper reach



Middle reach



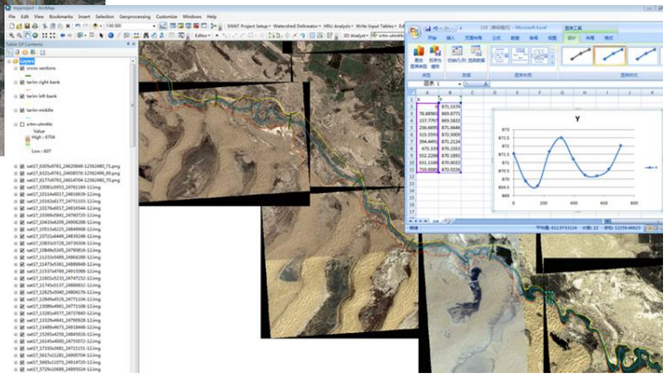
✦ Nov.2015: 16th ecological flooding

461 million m^3 water released.

In Kaerdayi station, GL ⬆ 1.7m

(compared with last year)

Lower reach



✦ Oct.2015, the discharge Alar reached 5 billion m^3 of water.

✦ Oct.2015: groundwater exlpoitation project accomplished.

⬆ 6 million m^3/y groundwater use in Aksu.

Thank You 谢谢！

Danke schön!

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Chair of Hydrology and River Basin Managment (Prof. Markus Disse)