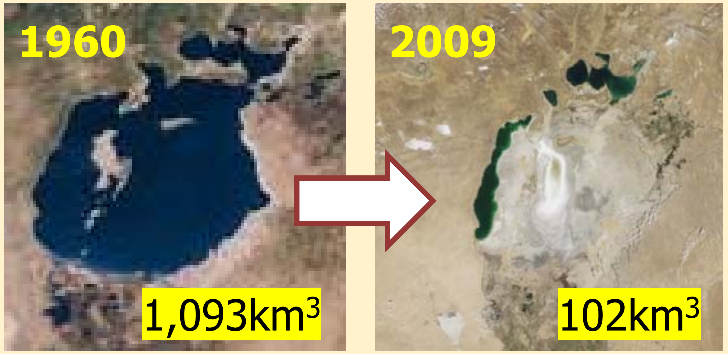
Developing Hydrological Model in the Aral Sea Basin which can consider Human Impact and Climate Change

Tohoku University
Yoshiya Touge

The Aral Sea

One of inland lakes without outflowing river.
(Water inflow is same with evaporation.)

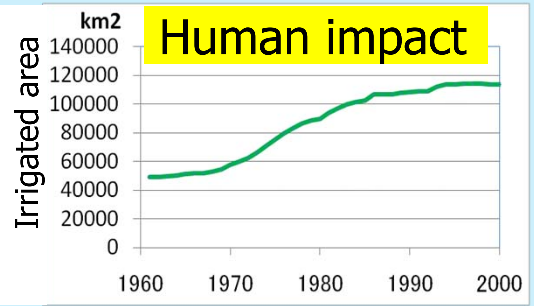
It has drastically reduced to less than 10% in volume since 1960, due to changes in the water balance in the basin.



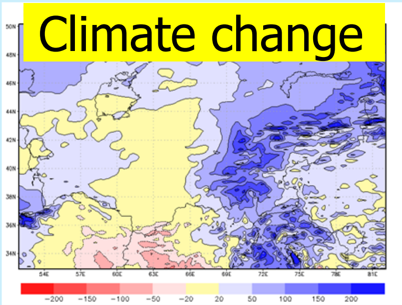
Desiccation of the Aral Sea (NASA)

The research target to be simulated

1. Historical water balance in whole basin
2. Human impact and climate change



Change in irrigated area in whole basin



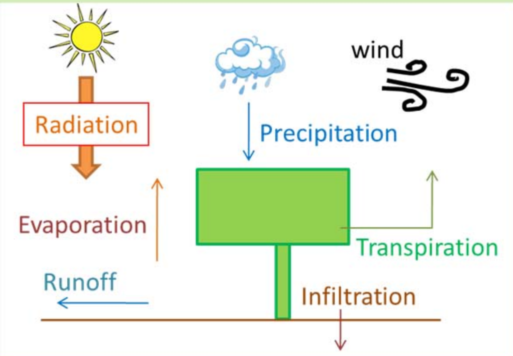
Precipitation change until end century

Aral Sea Basin (Micklin 2006)

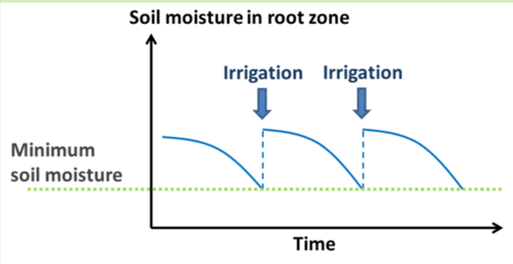
■ Hydrological model : Terrestrial water circulation model

- Physical water circulation model was developed.
  - It was integrated by several models.

Land Surface Model : SiBUC



Land surface model



Irrigation scheme in SiBUC

Vertical Water and Heat balance in mesh
"Mesh to River"

Input data

- Climatic data
  Present / Future climate
- Land Surface Parameter
  Irrigated area / crops

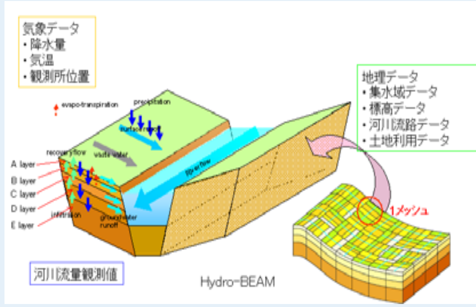
Output data

- Runoff to river
- Irrigation water needed

River Discharge Model : Hydro-BEAM

Horizontal water movement in river

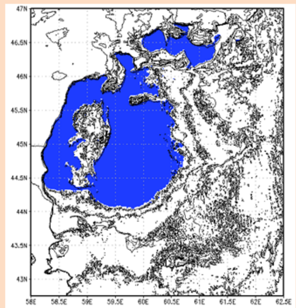
- Input
  Runoff to river
- Output
  River discharge



River Discharge Model

Aral Sea shrinkage model

Estimate Aral Sea changes by basin scale hydrological process.



Sea Bathymetry

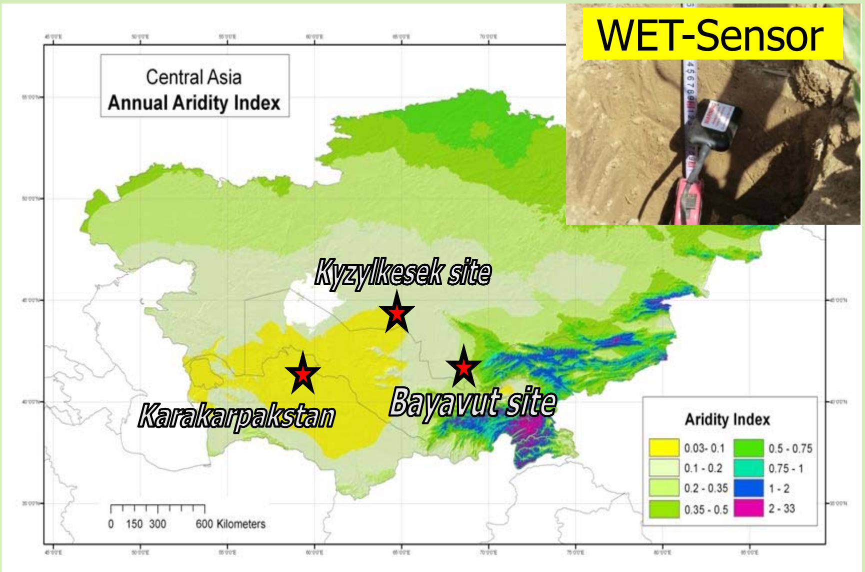
■ Observation : In situ measurement in Irrigate farms

- In situ measurement for irrigation regime.
  - Validation for human operation and hydrological process at irrigated farm.

Sites for irrigated farm

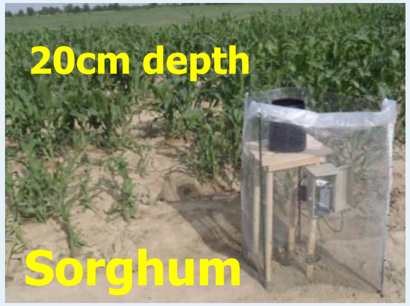
- Bayavut site (Semi-arid)
- Kyzylkesec site (Arid)

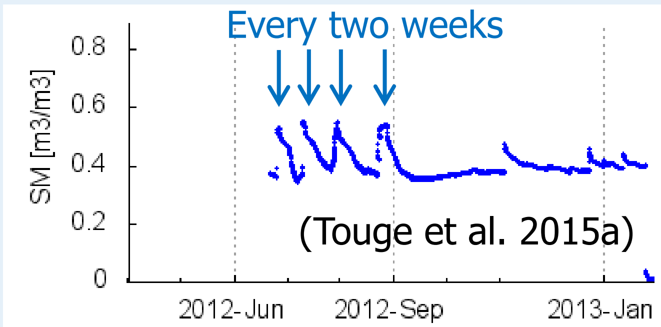
Under different climatic condition



Results in Bayavut site

Large irrigated farm in semi-arid.





■ Hydrological model : Irrigation scheme

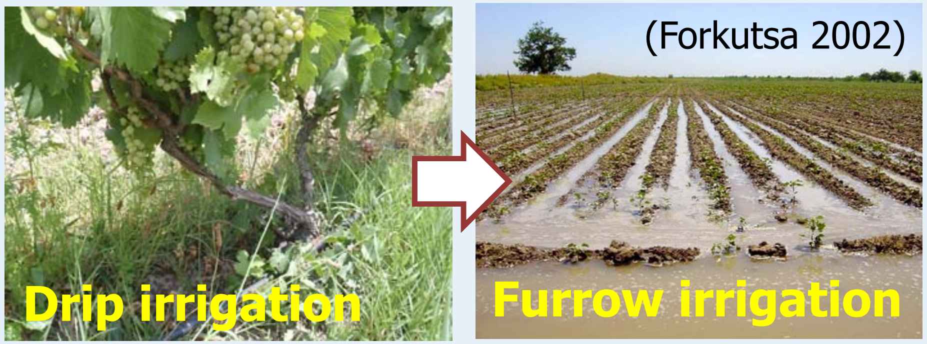
- In situ measurement for irrigation regime.
  - Validation for human operation and hydrological process at irrigated farm.

Irrigation schemes

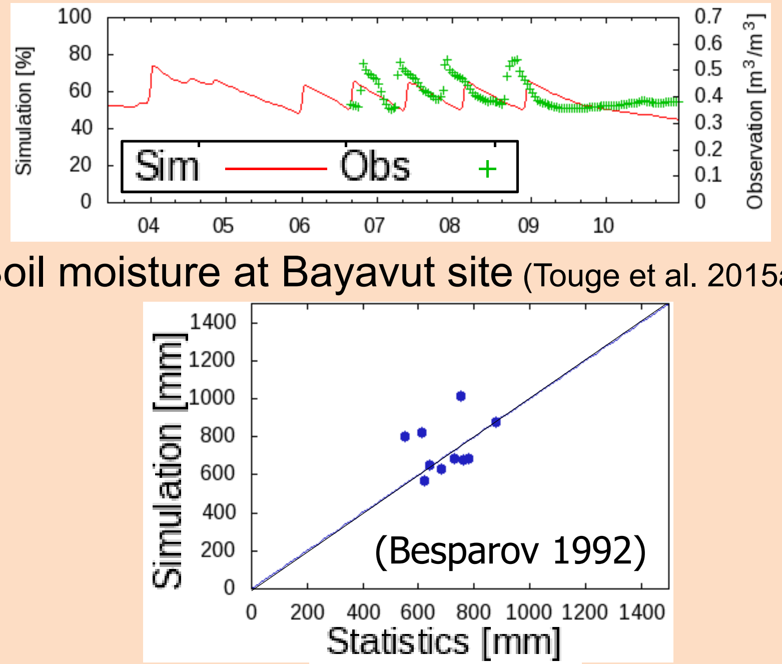
Improvement for irrigation efficiency

* Drip irrigation scheme
Soil moisture is efficiently controlled.

* Furrow irrigation scheme
A lot of water is supplied infrequently.



Validation



Soil moisture at Bayavut site (Touge et al. 2015a)

Representative water requirement of cotton at main cities in Uzbekistan

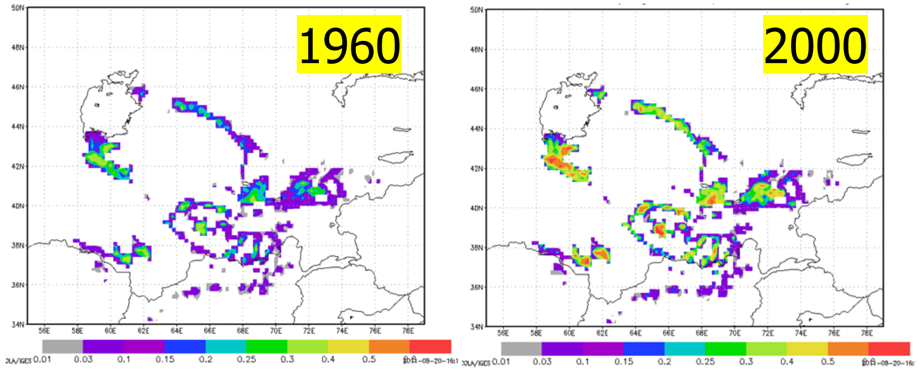
■ Human impact : Results of the inland lake model

- Physical water circulation model was developed.
  - It was integrated by several models.

Historical change of irrigated area

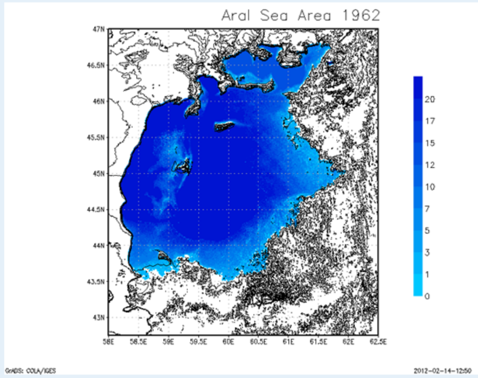
Irrigated area in the whole basin [km²]

Year	1960	1970	1980	1990	2000
Area	45100	51500	69200	76000	78900

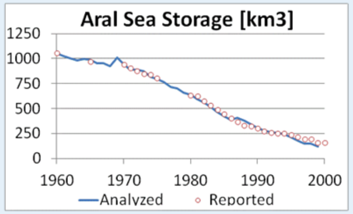


Irrigated area fraction in each mesh [%]

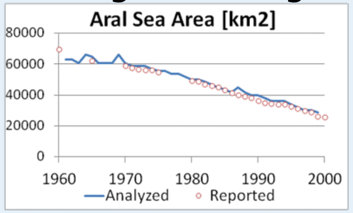
Aral Sea Desiccation Model



Aral Sea Area
(Touge et al. 2013)



Change in storage

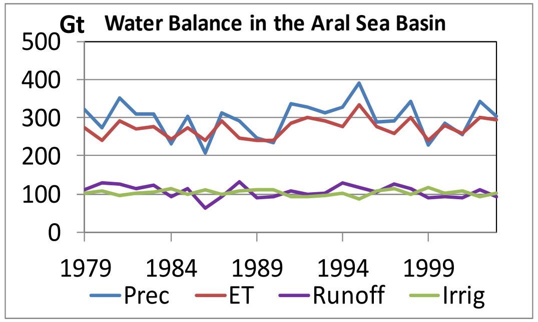


Change in area

Through basin scale water circulation analysis, considering climate variability and human impact, shrinkage of the Aral Sea was accurately reproduced in numerical analysis.

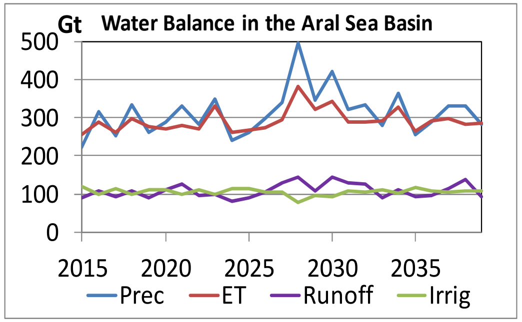
■ Climate Change : Total Water Balance

present (1979-2003)



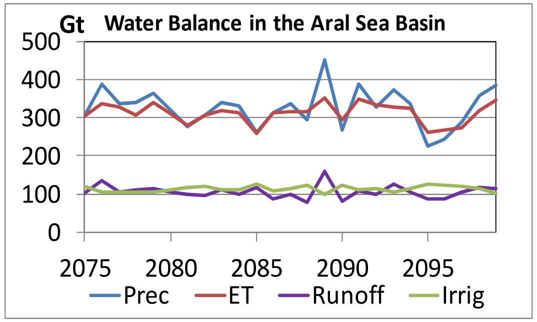
Basin water balance

near future (2015-2039)



Basin water balance

end century (2075-2099)



Basin water balance

Averaged annual water balance [Gt/yr]

	Discharge	Prec	ET	Tveg	Runoff	Irrig	Rain	Snow
Present	10.24	296.99	272.96	46.34	106.53	103.21	167.79	129.19
Near Future	11.66	313.14	291.66	51.14	108.69	105.63	191.39	121.75
End Century	5.77	326.07	311.94	59.49	106.25	113.48	212.84	113.23

Water resource will not change. Water demand will increase.

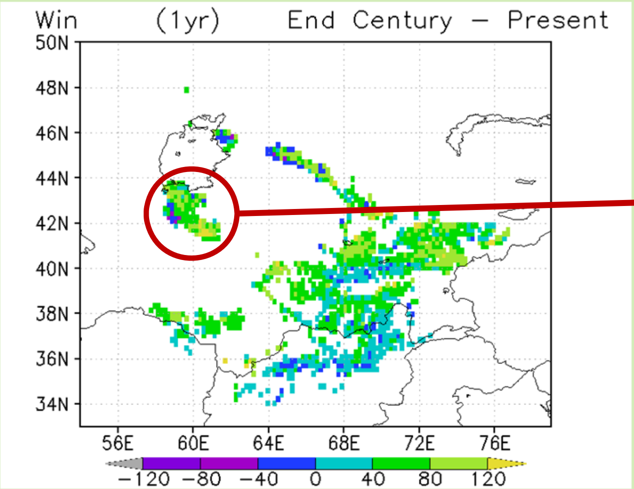
Water demand will increase, while resource will not change.
Drought situation will be more serious by climate change.

(Touge et al. 2015b)

■ Climate Change : Water demand in farms

- Irrigation water requirement will be higher in the future.
  - Plants needs more water under warmer climate.
  - Required water will increase especially in drier zone.

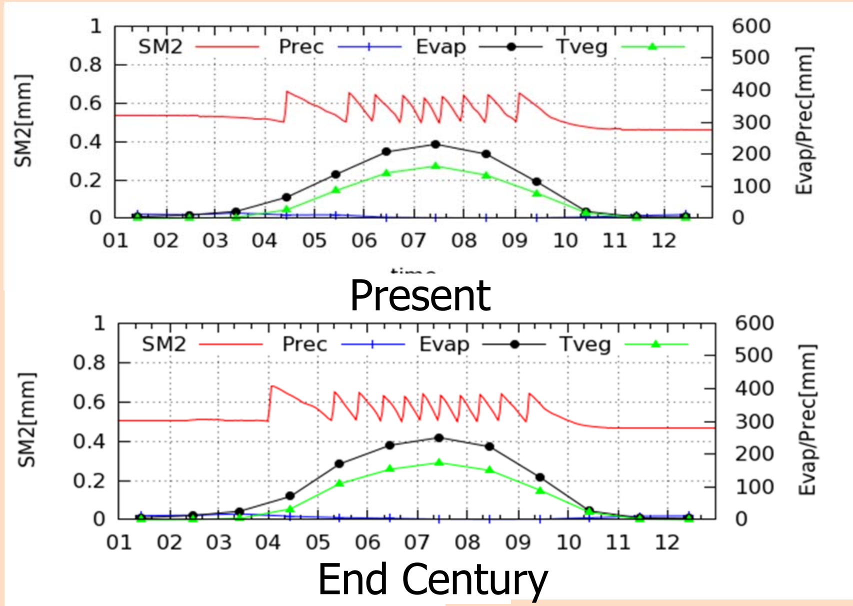
Analysis in whole basin



Changes of annual irrigation water requirement

Irrigation water requirement will increase in whole basin.

Climate change impacts on seasonal change



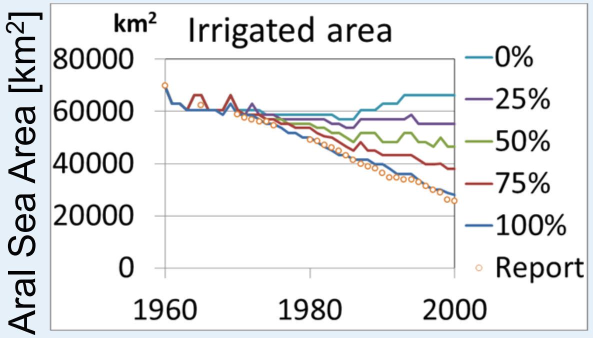
Amudarya Delta (Touge et al. 2015b)

Human impact : Irrigation scenario for drought mitigation

- Scenario analysis was conducted in different irrigation scenario.
  - 1. Smaller irrigated area scenario
  - 2. Drip irrigation scenario
  - 3. Improving canal irrigation efficiency scenario

1. Smaller irrigated area

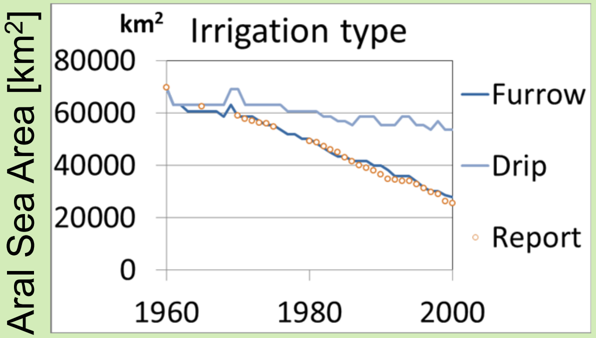
- "No-expansion" saves 23Gt/yr.
  => 1960s level of Aral Sea
- "50% expansion" saves 10Gt/yr.
  => 1982 level of Aral Sea



Annual change of Aral Sea area

2. Drip irrigation

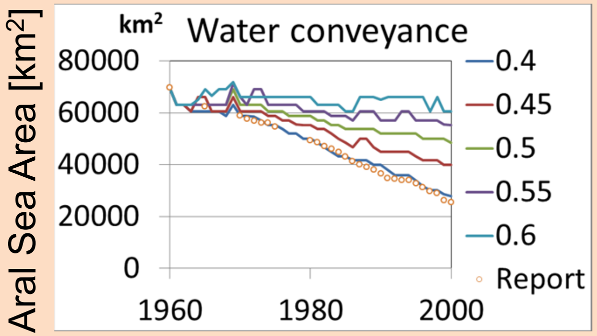
- "Drip Irrigation" saves 16Gt/yr.
  => 1976s level of Aral Sea



Annual change of Aral Sea area

3. Canal irrigation efficiency

- "10% improvement" : 12Gt/yr.
  => 1980 level of Aral Sea
- "20% improvement" : 22Gt/yr.
  => 1967 level of Aral Sea



Annual change of Aral Sea area

(Touge et al. 2012)

Conclusion : Basin water balance

- **Hydrological modeling**
  - Hydrological model was developed using land surface model.
  - It can simulate water resource and water demand in basin scale.
  - The model was validated based on in situ measurement in Uzbekistan and the Aral Sea desiccation.

- **Irrigation scenarios**
  - Potential impacts on virtual adaptation plans were quantitatively assessed.
  - Irrigation efficiency will have a significant impacts on water balance, which was comparable to irrigated area.

- **Future climate scenarios**
  - Water resource will not change, but irrigation water demand will increase, so water scarcity will be much serious.
  - Amudarya delta region is one of the area where irrigation water demand will significantly increase.

ЎЗБЕКИСТОН РЕСПУБЛИКАСИ
СУВ ХЎЖАЛИГИ ВАЗИРЛИГИ

ИРРИГАЦИЯ ВА СУВ МУАММОЛАРИ
ИЛМИЙ-ТАДҚИҚОТ ИНСТИТУТИ

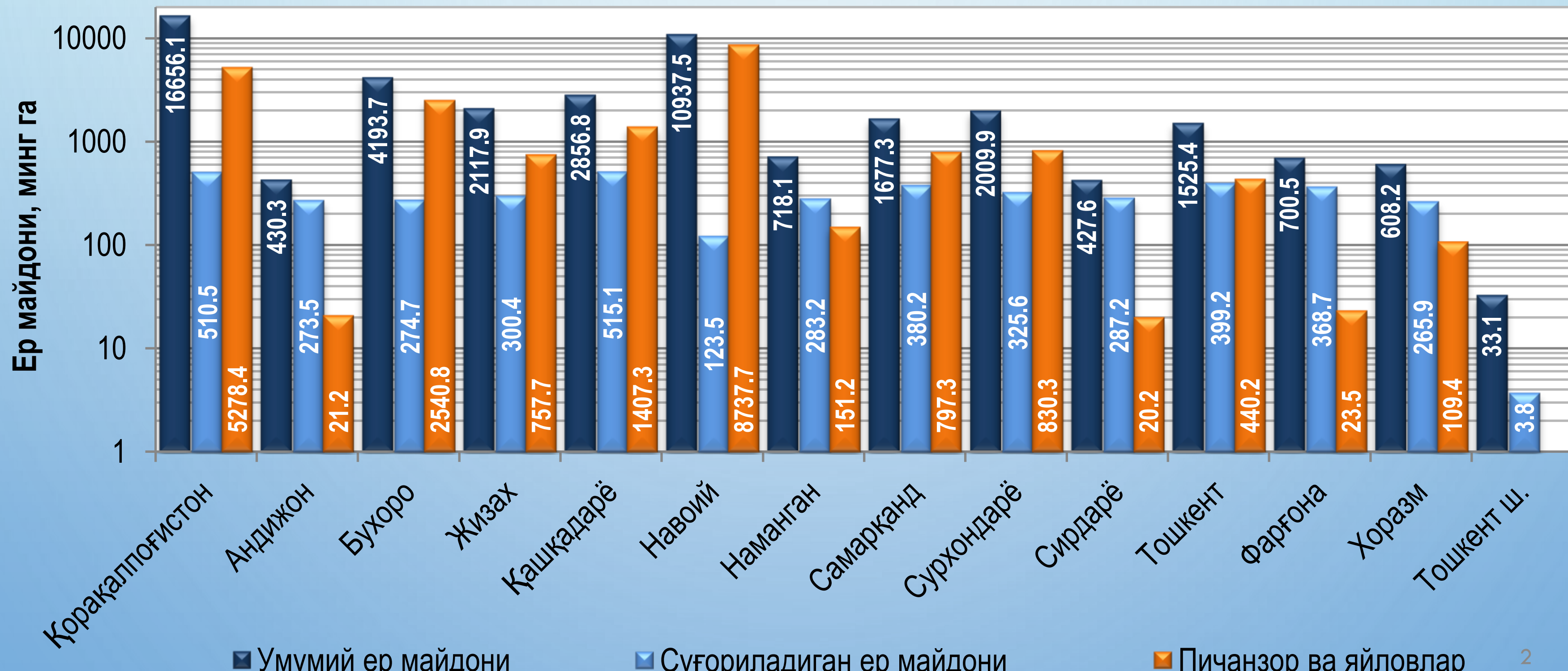
«Water, soil and society in Central Asia and the Caucasus»

QUESTION OF ENVIRONMENTAL PROBLEMS ASSOCIATED WITH WATER AND SOIL AND THEIR IMPACT

GENERAL INFORMATION: TOTAL LAND AREA

- Total area– 44.9 млн.га
- Irrigated land area– 4.3 млн. га
- Pastures and hayfields – 21.2 млн. га

Hayfields and pastures - a reserve of additional irrigated lands!



Source: Cadastral Agency under the State Tax Committee,, 2021 y. (http://kadastr.uz/uz/yer-hisobi-yo'nalishi)

WATER RESOURCES ARE ITS FORMATION

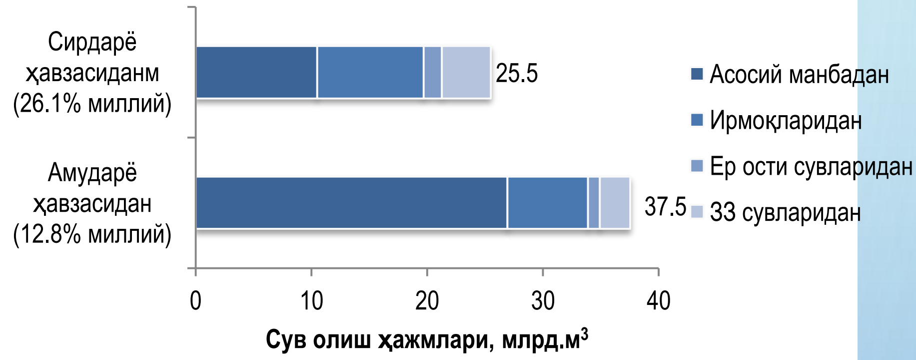
Экономика Узбекистана зависит от внешних водных ресурсов!

- Source of water resources of the Republic of Uzbekistan:
- External (transboundary) water resources:

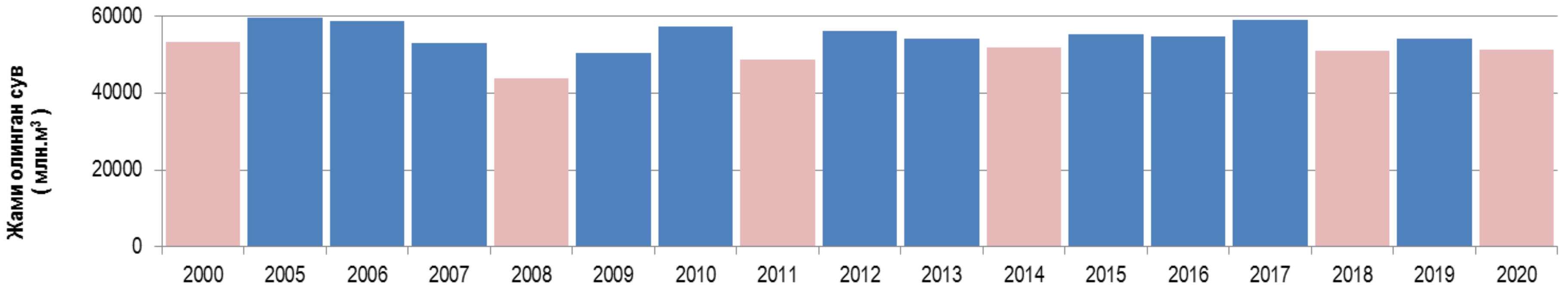
  – 80% (51.6 км^3)

2. Domestic (national) water resources :

   – 20% (11.5 км^3)



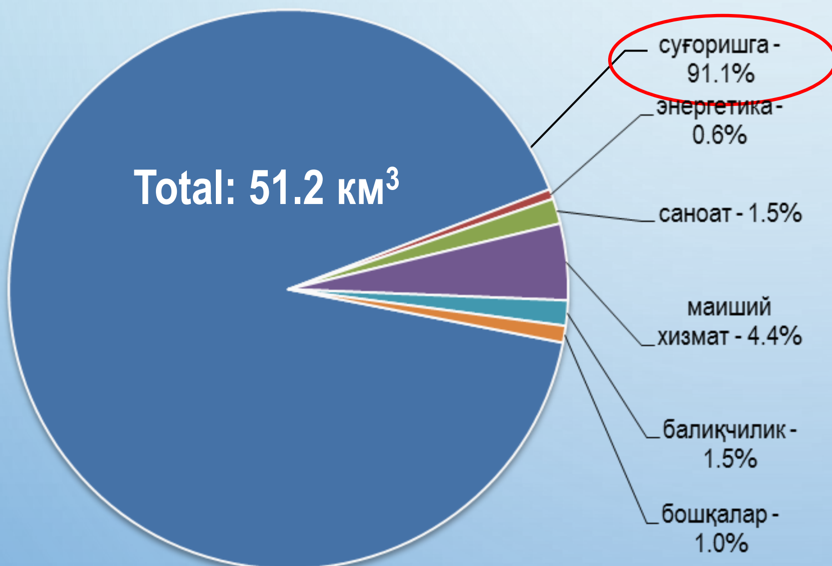
- Climate change, the length of dry seasons, the reduction of snow reserves in the mountains, the frequency of dry years are increasing, which, in turn, leads to an increase in the risk of low water:



Source:
UNDP, 2007. Water is a vital resource for the future of Uzbekistan. Tashkent, p.127. Ministry of Water Resources of the Republic of Uzbekistan, 2021

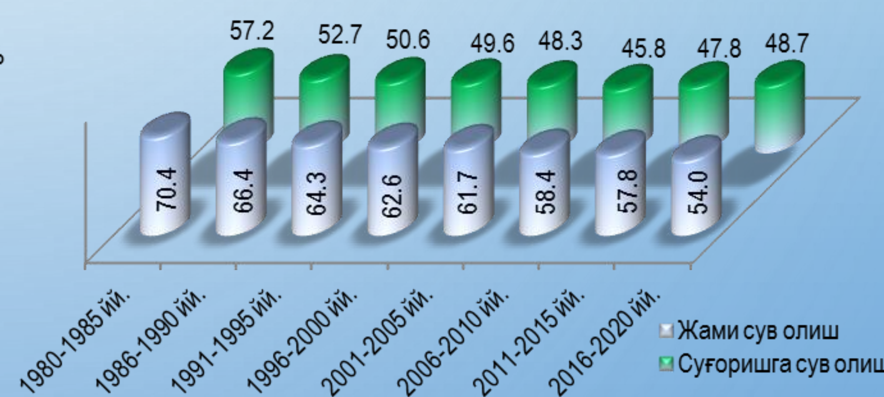
TOTAL WATER CONSUMPTION IN IRRIGATED AGRICULTURE

- In sectors of the economy, agriculture is the most water-intensive industry
- The volume of water, water withdrawal for irrigation, is ~10 billion compared to 1980. decreased by more than m3 in the Amudaryo and Syrdarya basins, the water withdrawal limit was reduced by 20% compared to the SRKFvaMQ schemes (an average long-term limit is 64 km3).



Water use in sectors of the economy (for 2020, in %)

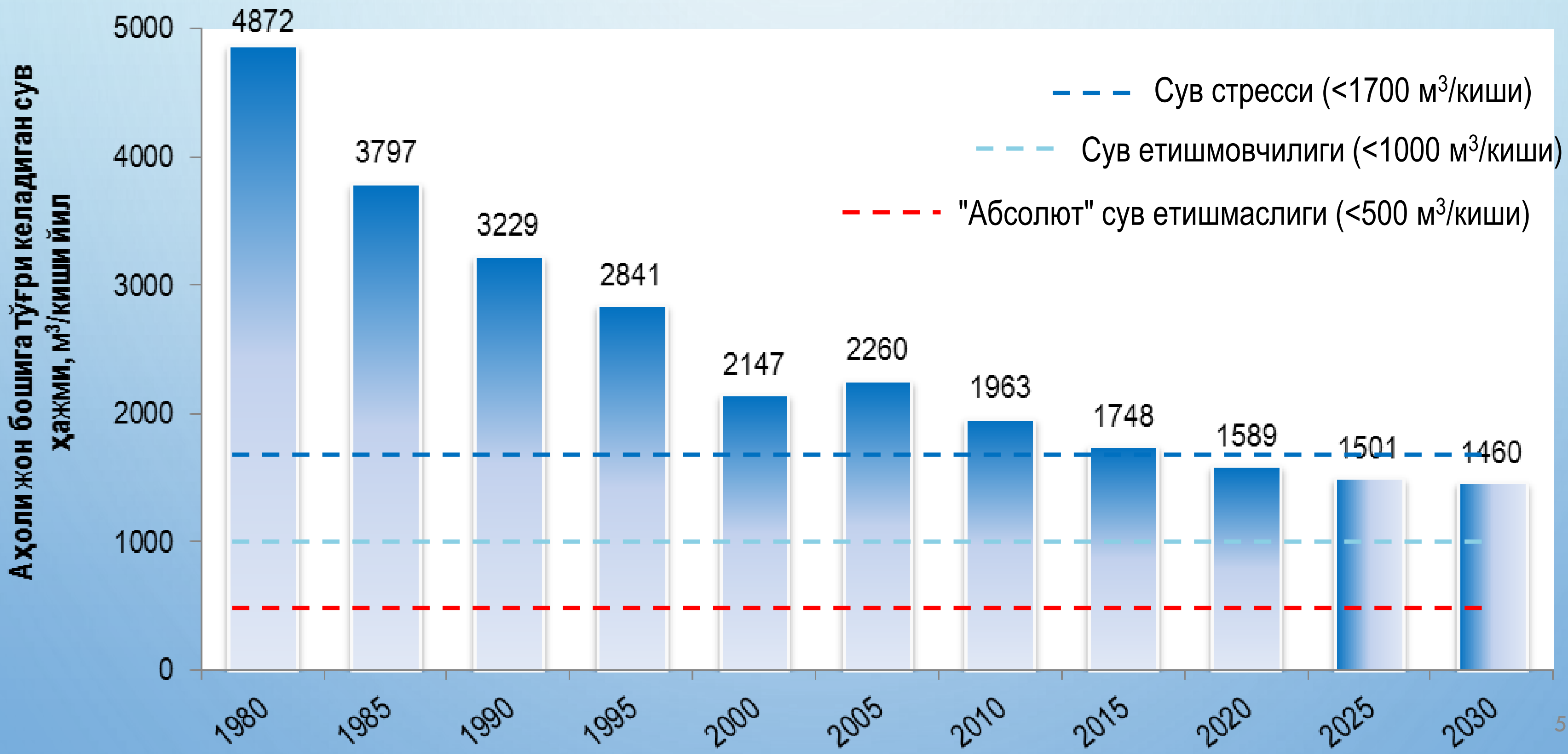
Saving water for irrigation is a hot topic!



SIC ICWC, 2017 y. (http://www.cawater-info.net)
Source Ministry of Water Resources of the Republic of Uzbekistan., 2021 y.

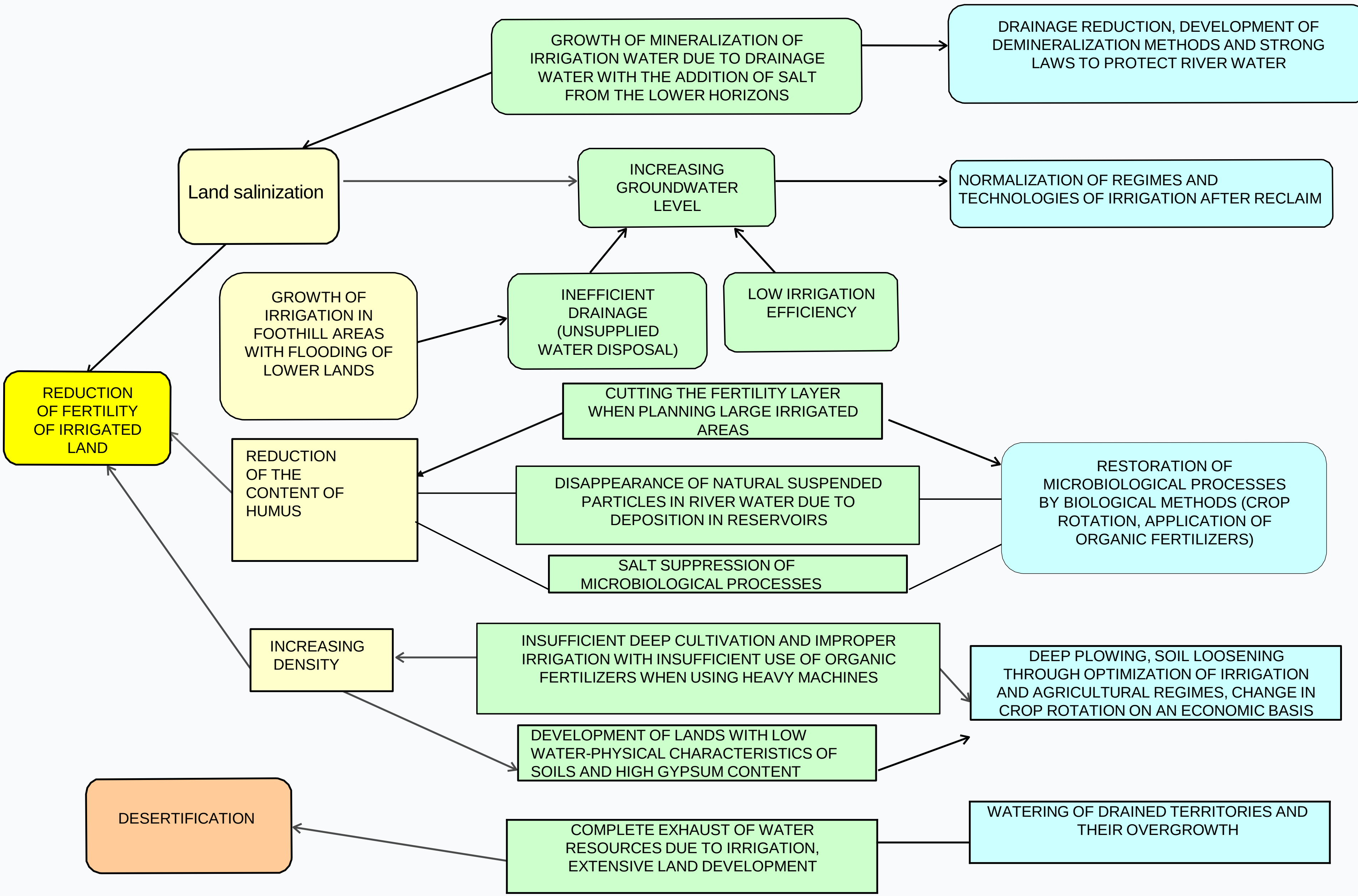
GROWING DEMAND FOR WATER

- Global climate change (increase in air temperature, change in precipitation);
- Change in water flow regime (irrigation energy); →
- Growing demand for water (Afghanistan, population growth).



Source: Authors' reports; State Committee on Statistics of the Republic of Uzbekistan, 2021 y (https://stat.uz)
Concept for the development of water management for 2020-2030, 2020 y; ООН, 2018 год (http://www.un.org/waterforlifedecade/scarcity.shtml)

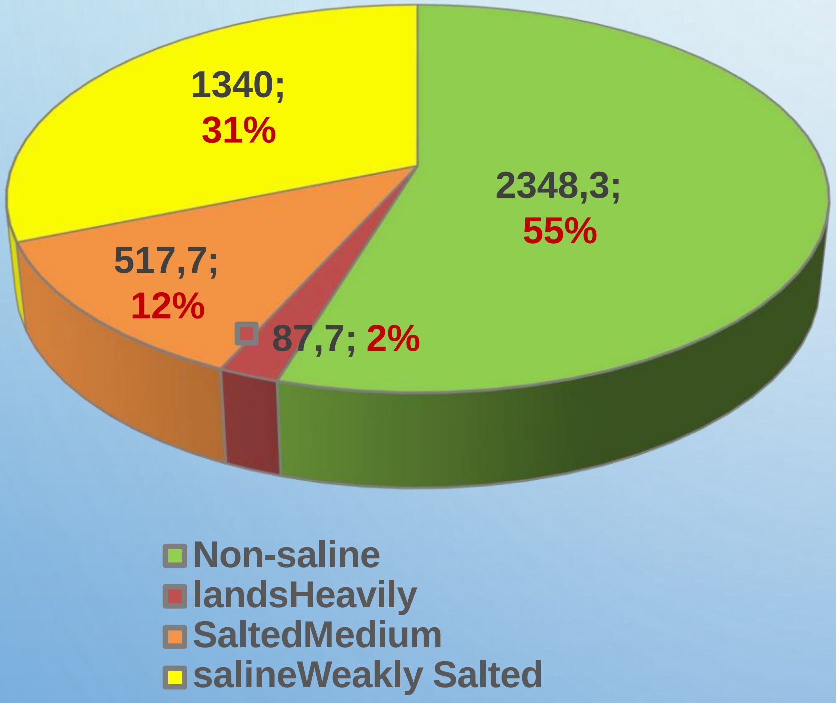
MAIN CAUSES OF SOIL DEGRADATION AND NECESSARY MEASURES TO IMPROVE THE SOIL AND RECLAIM SITUATION

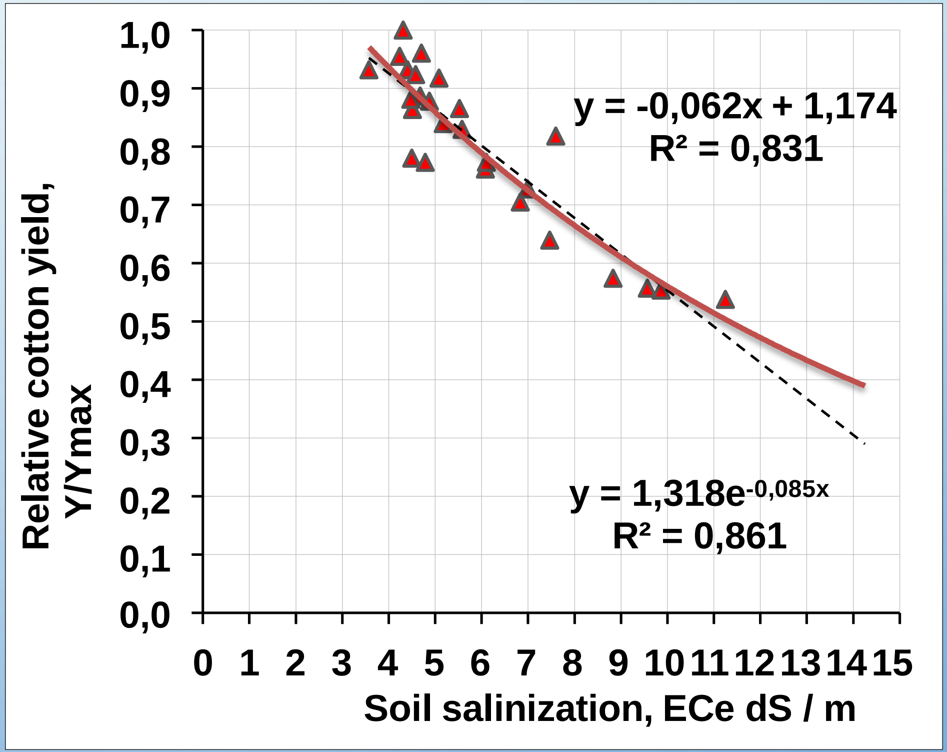


RISKS FACING AGRICULTURE IN UZBEKISTAN

- Natural disasters (sand and destructive dust storms, droughts, frosts - early spring frosts and uncomfortable autumn, rains and hail, hurricanes, etc.)
- Emergencies (lightning and fires, earthquakes and floods, floods and landslides, pests and diseases, etc.)
- and other natural disasters and catastrophes:
  - ✓ destruction of crops and perennial fruit trees and total or partial loss of crops in agriculture;
  - ✓ disease and death of livestock, poultry and fish, complete or partial;
  - ✓ Agricultural equipment, buildings and structures can be completely or partially damaged or destroyed.

DUE TO THE SPREAD OF SOIL SALINIZATION IN THE IRRIGATED TERRITORY OF THE REPUBLIC THERE IS A SHORTAGE OF AGRICULTURAL CROPS





MEASURES TAKEN BY THE GOVERNMENT OF THE REPUBLIC OF UZBEKISTAN

- Due to global climate change, the constant increase in the population and the growing demand for water, the shortage of water resources is increasing in Uzbekistan from year to year, which can become the main limiting factor for the development of the country in the future;

- In order to ensure the water and food security of the country, by organizing the effective management of water resources and their rational use in the medium and long term, reforming the water sector and introducing market principles and mechanisms, information and communication technologies into the sphere, as well as the effective use of scientific potential in sphere, the "CONCEPT OF THE DEVELOPMENT OF THE WATER ECONOMY OF THE REPUBLIC OF UZBEKISTAN FOR 2020-2030" was approved

MEASURES TAKEN BY THE GOVERNMENT OF THE REPUBLIC OF UZBEKISTAN

STRATEGY FOR WATER MANAGEMENT AND DEVELOPMENT OF THE IRRIGATION SECTOR IN THE REPUBLIC OF UZBEKISTAN FOR 2021-2023:

- ✓ increase from 35% to 38% of the share of canals with concrete pavement;
- ✓ increasing the efficiency of irrigation networks from 0.63 to 0.66;
- ✓ bringing the introduction of TSA irrigation from 308 thousand hectares to 1.1 million hectares, including drip irrigation technologies - from 121 thousand hectares to 822 thousand hectares;
- ✓ reduction from 1,926 thousand hectares to 1,888 thousand hectares of the area of saline lands, including medium and highly saline ones, from 581 thousand hectares to 532 thousand hectares;
- ✓ reduction from 988 thousand hectares to 900 thousand hectares of irrigated land areas with a critical level of groundwater (0 - 2 meters);
- ✓ re-introduction into circulation of 232 thousand hectares of irrigated land that have left agricultural circulation;
- ✓ bringing to 18,576 units the number of water management facilities that record water based on the digital technology "Smart Water" ("Smart Water");
- ✓ monitoring at 2,100 operating reclamation observation wells using digital technologies;
- ✓ implementation of a total of 124 projects in the water sector based on PPP.

DIRECTION OF JOINT ACTION

To create a favorable reclamation regime in specific conditions, with the rational use of water, it is necessary:

- Maintaining drainage systems (and especially drainage collectors) in working order (use of shallow drainage)
- laser land leveling (especially in rice fields)
- reliable information on the distribution of lands with varying degrees of salinity (using GIS and remote sensing data)
- use of science-based flushing technologies, in conjunction with the degree of initial salinity and mechanical composition of soils
- introduction of water- and resource-saving technologies for irrigation of agricultural crops
- crop diversification (transplantation & new varieties of rice)

Executive Board of the International Fund for saving the Aral Sea in the Republic of Kazakhstan

The experts meeting “Environmental issues in Central Asia and the Caucasus – the role of Japan”

Co-hosted by Ministry of Foreign Affairs of Japan and Slavic – Eurasian Research Center, Hokkaido University

Developing the potential of sub-regional cooperation to ensure resilience to climate change and natural disasters in the Aral Sea Basin

Marat Narbayev – Doctor of geographical sciences, deputy director EB IFAS in RK

16 March, 2022

Aral Sea adjacent area – indicator of environmental aspects of Central Asia

Sand storm emergence at the FASB

Akespe village on the northwest of NAS

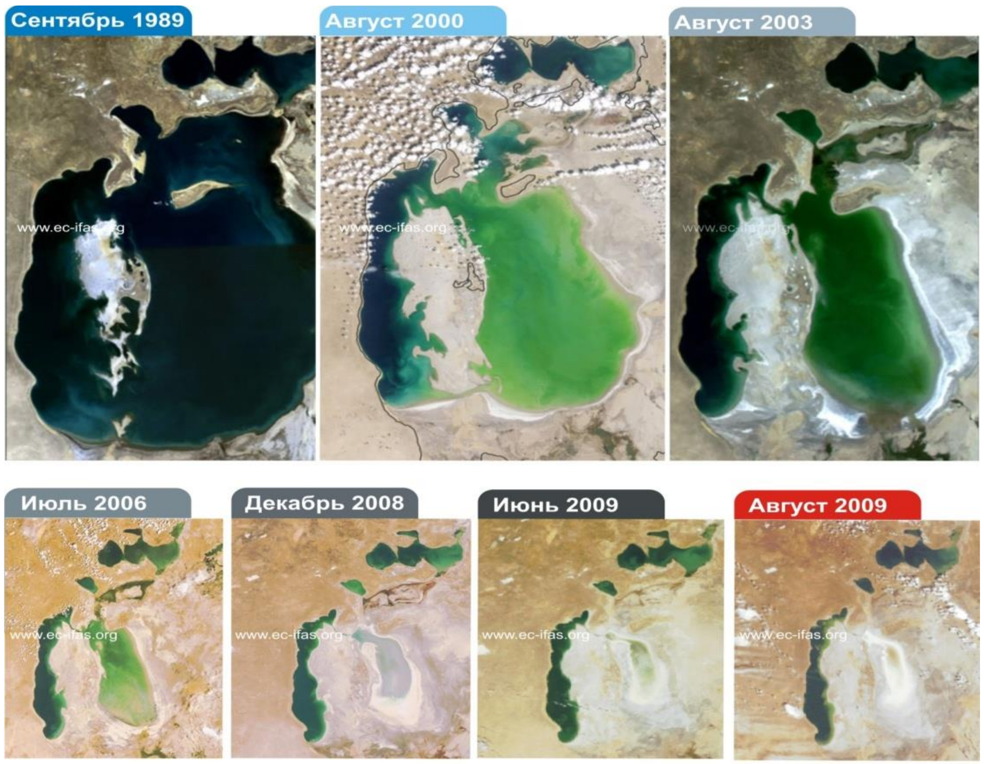
Abandoned ships on Vozrozhdenie Island

Desertification in Akespe village

https://kazaral.org/

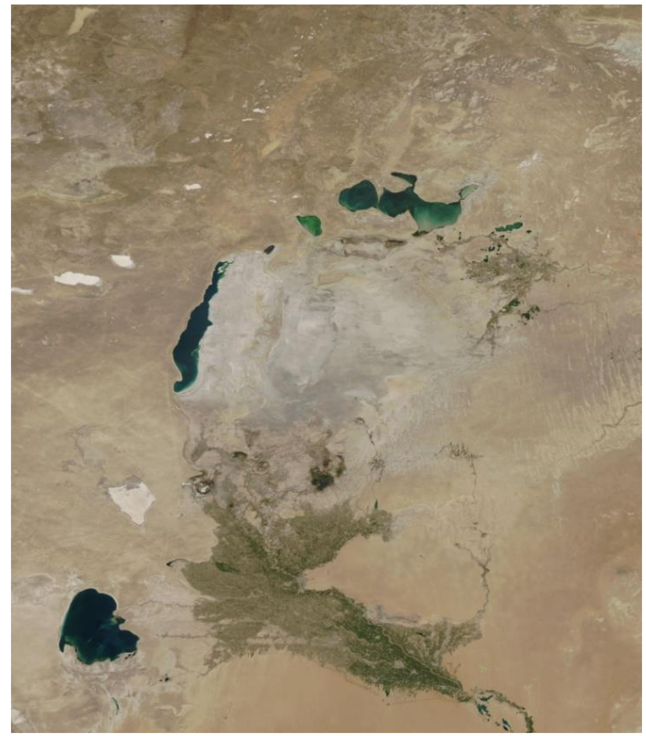
Aral Sea environmental catastrophe

September 1989 August 2000 August 2003



July 2006 December 2008 June 2008 August 2009

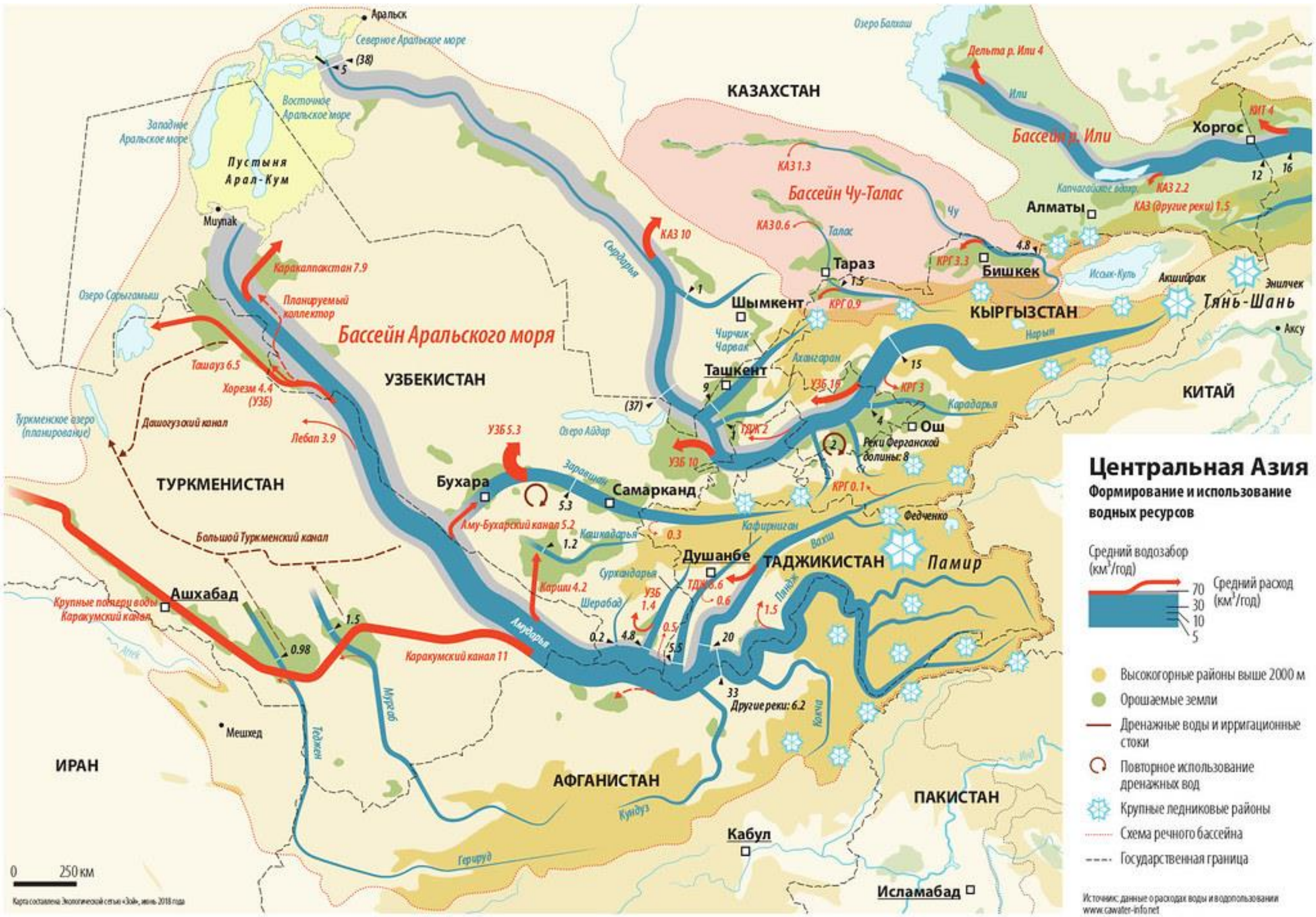
2021



Source: https://kazaral.org/

In December 2021 the volume of the North Aral Sea was 20 km3, and water salinity was 10 g/l.
West Aral Sea is about 42 km3, with mineralization rate of 170 g/l,
Tushebas lake is 1,7 km3, with water salinity rate at 90 g/l.

Aral Sea basin water resources



Central Asia

Forming and use of water resources

Average water abstraction (km3/year)

average discharge (km3/year)

Alpine districts higher than 2000 m

Irrigated lands

Drainage waters and irrigation runoffs

Reclaimed drainage water use

Large glacial districts

River basin scheme

State border

Data source on volumetric flow rate and Water use is www.cawater-info.net

Source: http://cawater-info.net/aral/index.htm

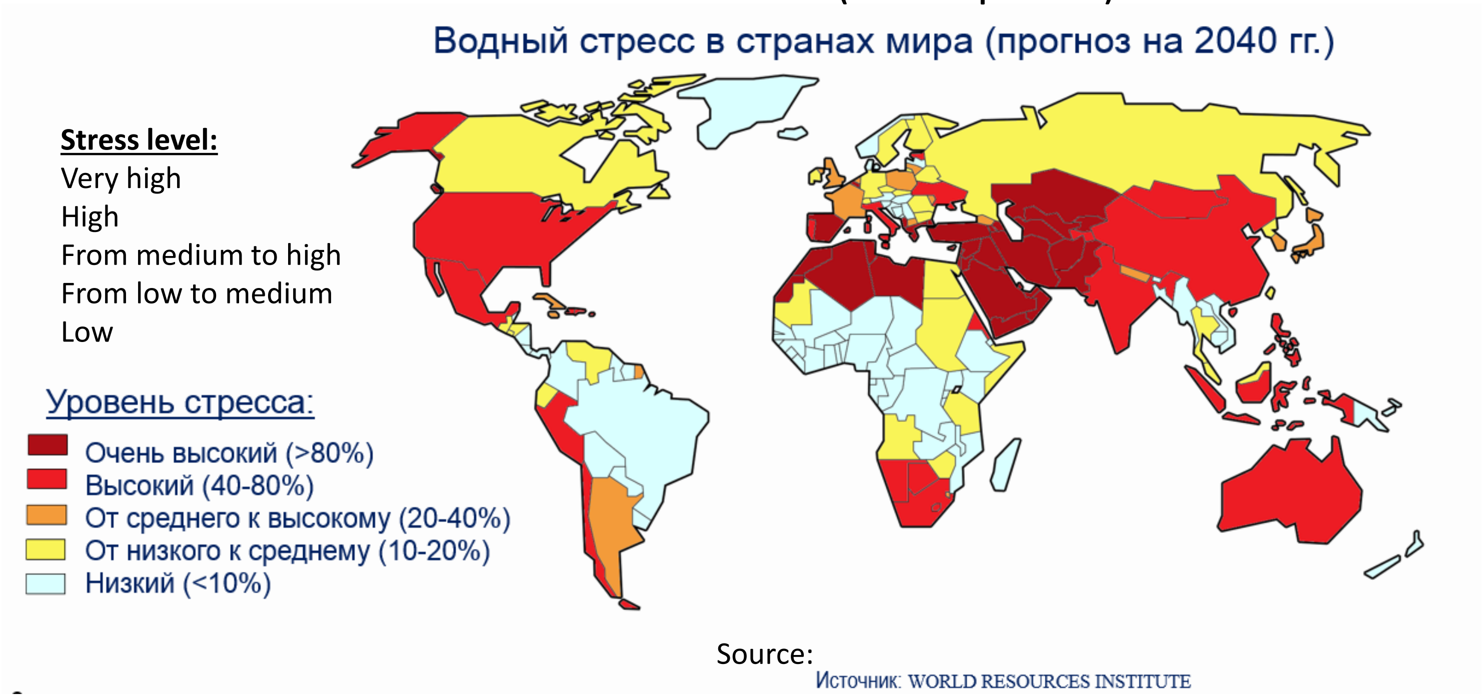
Aral Sea basin water availability

Water resources load level, % 2018 (SDG 6.4.2)

KZ	KG	TJ	TM	UZ	CA	WORLD
33	50	62	89,9	169	76	18,4
Low	Low	Moderate	High	Critical	Hich	No stress

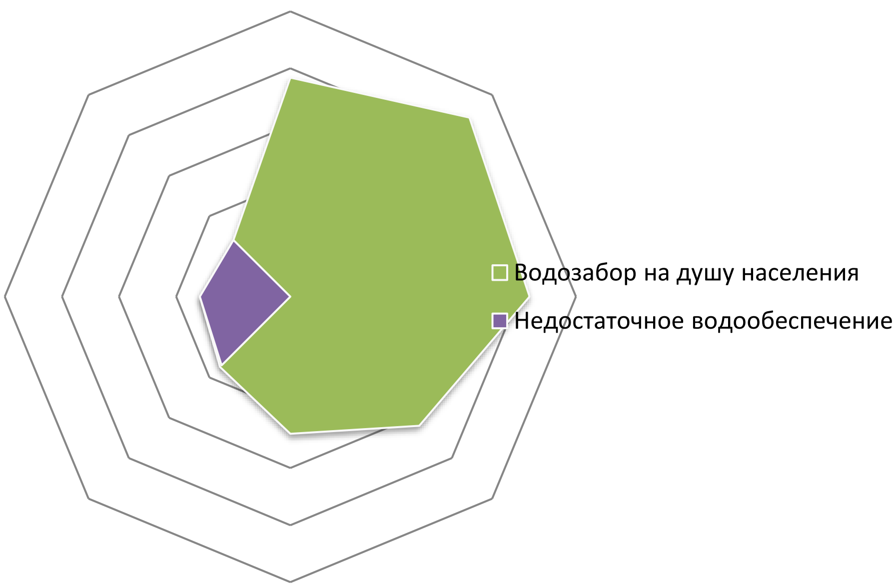
Source: FAO, 2021, (www.fao.org); EC IFAS, 2022 (https://ecifas-tj.org);

Water stress worldwide (forecast up to 2040)



Water and land resources of Aral Sea basin

On Aral Sea basin	1960	1990	2000	2020	2030	2050
Population, mil. People	15,8	36,4	43,7	60,0	67,8	75,6
Total arable lands, ha.	4510	7421	8038	8040	8100	8200
Water supply per capita, km3/capita per year	3836	3194	2403	**1743**	**1586**	**1406**



Water supply per capita
Insufficient water availability

Macroeconomic indicators of the Central Asian states

CA States	GDP-2020 ($)	Human Development Index – 2020	Production of power per capita (kWh per person)	Production of grain crop per capita (kg/person)
KZ	9060	0,82 (51 places)	5812	1081
KG	1148	0,69 (120 places)	2369	280
TJ	733	0,66 (125 places)	2129	140
TM	8074	0,71 (111 places)	4328	266
UZ	1694	0,72 (106 places)	1907	223

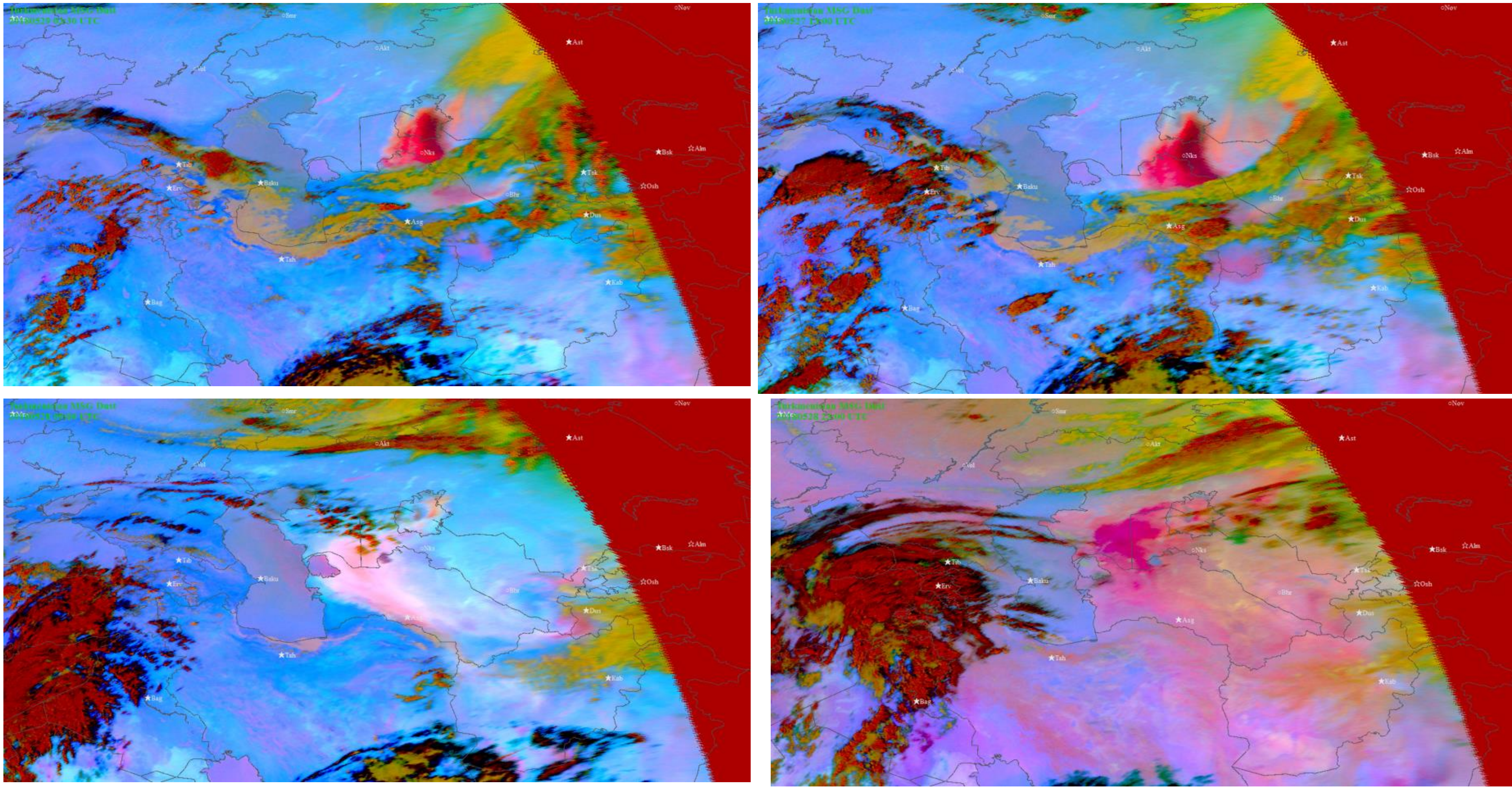
Source: Statkom CIS, EAEU 2020

Total goods turnover between CA states was $12.2 bil., foreign trade turnover was $145.5 bil. in 2020

Extensive withdrawal of water from Amudarya and Syrdarya

- **According to the World Bank,** salinization of arable lands in the Aral Sea basin poses a threat “of fundamental and difficult nature” for all the security aspects (food, water resources, environmental, social etc.) of states of the region.
- **According to the Japan Global Investment Fund (GIF Japan),** the main reason of the Aral crisis is the same reason that destroyed civilizations of Mesopotamia and Mohenjo-daro. Catastrophic phenomena which humanity have faced in the past is happening again in modern world. Aral catastrophe is a result of mistakes in infrastructure development of states of the region. Illdesigned policy of large-scale modification of barren deserted land into irrigated lands by full irretrievable withdrawal of water for these objectives from Amudarya and Syrdarya rivers.

Dust storm in the Aral Sea basin
26-28 May 2018

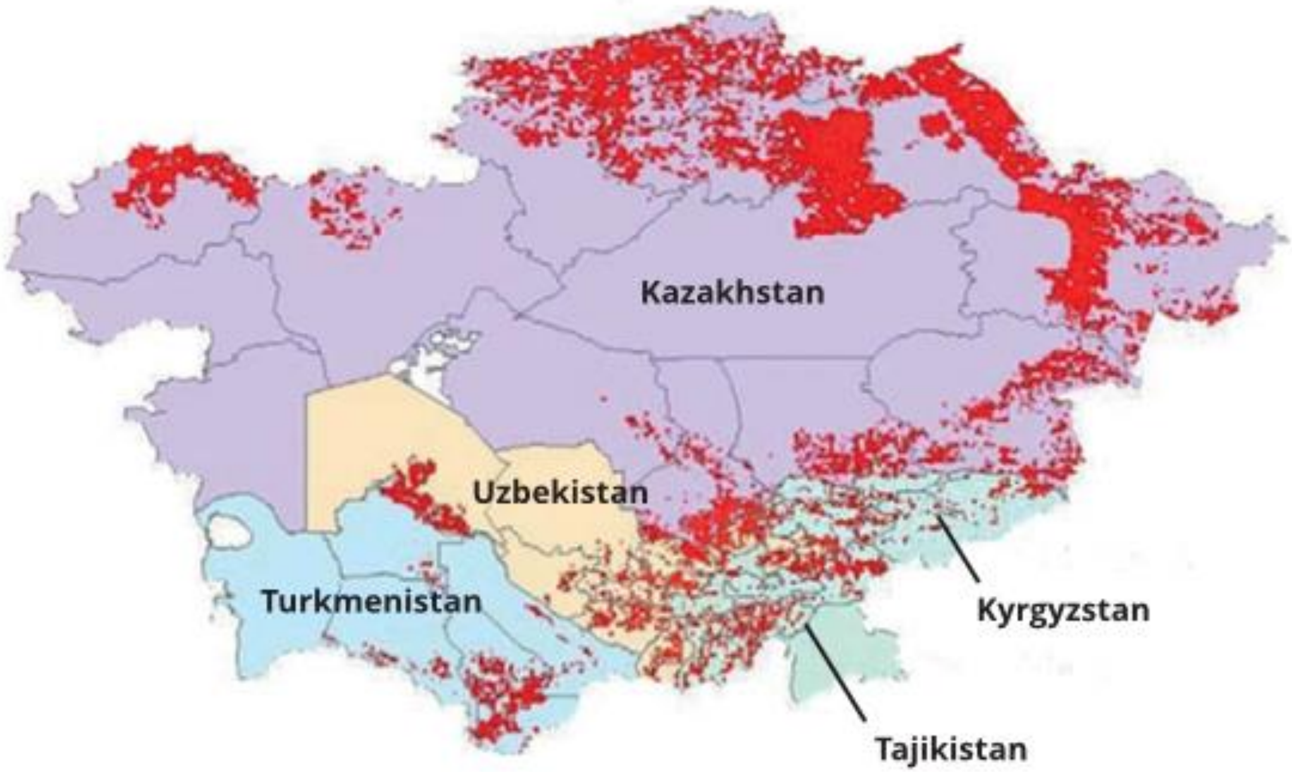


Annually glaciers of the Aral Sea basin are being covered by dust up to 20 g/m2, which being carried over by dust storms from Iran, Afghanistan, China and other deserted districts, and recently from dried territory of the Aral Sea as well.

Degraded land and its areas

States	Land degradation (mil.ha), caused by:				Total
	Salinization	Alkalinity	Swamp forming, increase of groundwater	Erosion	
KZ	21,5	107,1	38,6	7,8	175
KG	0,1	-	10,7	5,6	16,4
TJ	0,7	-	6,8	3,7	11,2
TM	7,3	1,7	3,5	0,7	13,2
UZ	6,3	4,6	3,9	1,3	16,1
	35,9	113,4	63,5	19,1	**231,9**

Sources of land degradation in Central Asia (showed in red color)



Source: Mirzabaev et al. (2016), based on the data of Le et al. (2016)

Economic and social loses from land resources degradation in Central Asia

States	Annual damage		Damage per capita, $
	$ bil.	% GDP	
KZ	3,1	3	1782
KG	0,55	10	822
TJ	0,5	11	609
TM	0,87	4	1083
UZ	0,83	3	237
	5,85		

$1.8 bil. needs to be allocated in Central Asia to combat land degradation during the next 30-years.

Expected efficiency of invested funds is $5 to each invested $1.

In case of ignoring recommendations, the losses might form almost $288 bil.

Measures of adaptation to climate change

Kokaral dam – environmental brand of the Aral Sea adjacent area

330 thousand ha of wetlands of lower Syrdarya river and the North Aral Sea are under protection of Ramsar Convention

Land reclamation at the DASB

Balneological well near Akespe village

https://kazaral.org/

Recommendations to improve water economy and environmental situation in the Aral Sea basin

- Conducting a coordinated regional water policy, which should be aimed at a balanced use of water resources and improvement of the environmental situation in the region.
- Development of new mechanisms and tools for cooperation in transboundary river basins, based primarily on deeper economic integration of the region's countries.
- Creation of international clusters in various sectors of the economy and joint promotion of export products to non-CIS markets.
- Conducting a step-by-step comprehensive reconstruction of water infrastructure with a widespread transition to water-saving technologies and reduction of wastewater volumes.

Recommendations for improving the water and environmental situation in the Aral Sea Basin

- **In agriculture,** it seems important to expand the practice of cultivation of more drought-resistant crop varieties, improve the technical level of engineering irrigation systems equipped with automation of irrigation water distribution and control over the reclamation condition of irrigated land.
- **In the industrial sector,** it is necessary to introduce low-water technologies and water recycling systems. In the public utilities sector, the technical condition of water supply and sewerage systems should be improved and water losses there should be reduced, and new technologies for wastewater treatment should be mastered.
- **Hydrometeorological services** need to further improve, accuracy and timeliness of services to sectors of the economy in order to adapt to climate change and manage disaster risks.

Cooperation on the implementation of the ASBP

Waiting for the sea!

Source: https://kazaral.org/

Thanks for your cooperation!

「中央アジア＋日本」第7回専門家会合(2022/3/16)

Japan International Cooperation Agency

Japan Sacience and Technology Agency

Ministry of Innovative Development Uzbekistan

Science and Technology Research Partnership for Sustainable Development (SATREPS)

The Project for Development of Innovative Climate Resilient Technologies for Monitoring and Controlling of Water Use Efficiency and Impact of Salinization on Crop Productivity and Livelihood in Aral Sea region

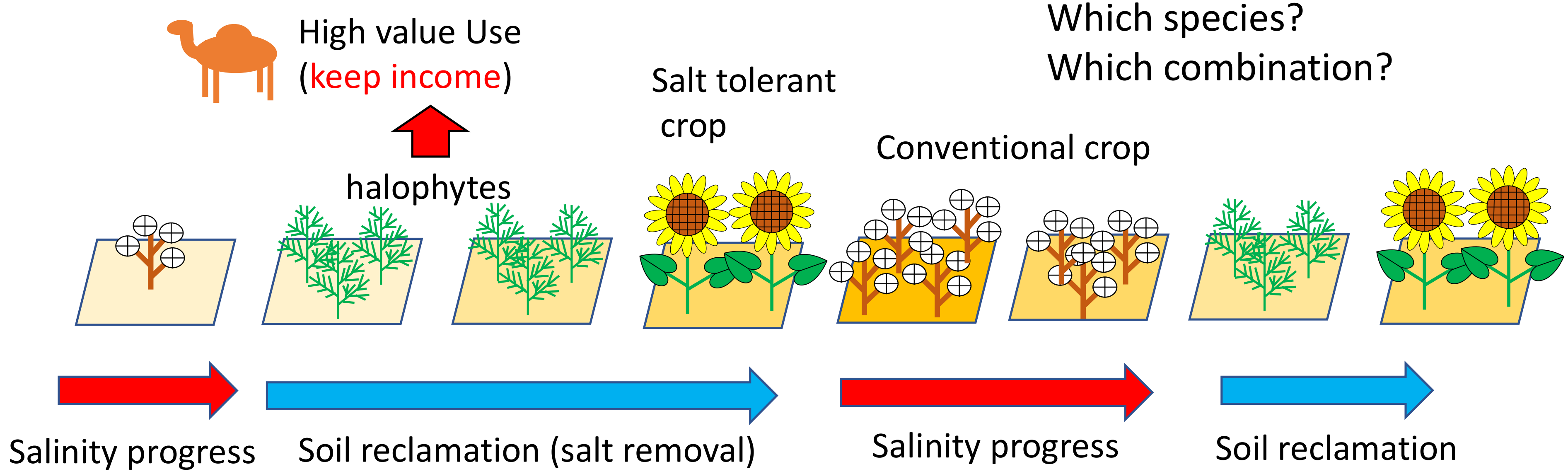
Nick Name

BLUE (Biosaline agriculture for Land Use Efficiency)

Circular Halophytes Mixed Farming(CHMF)

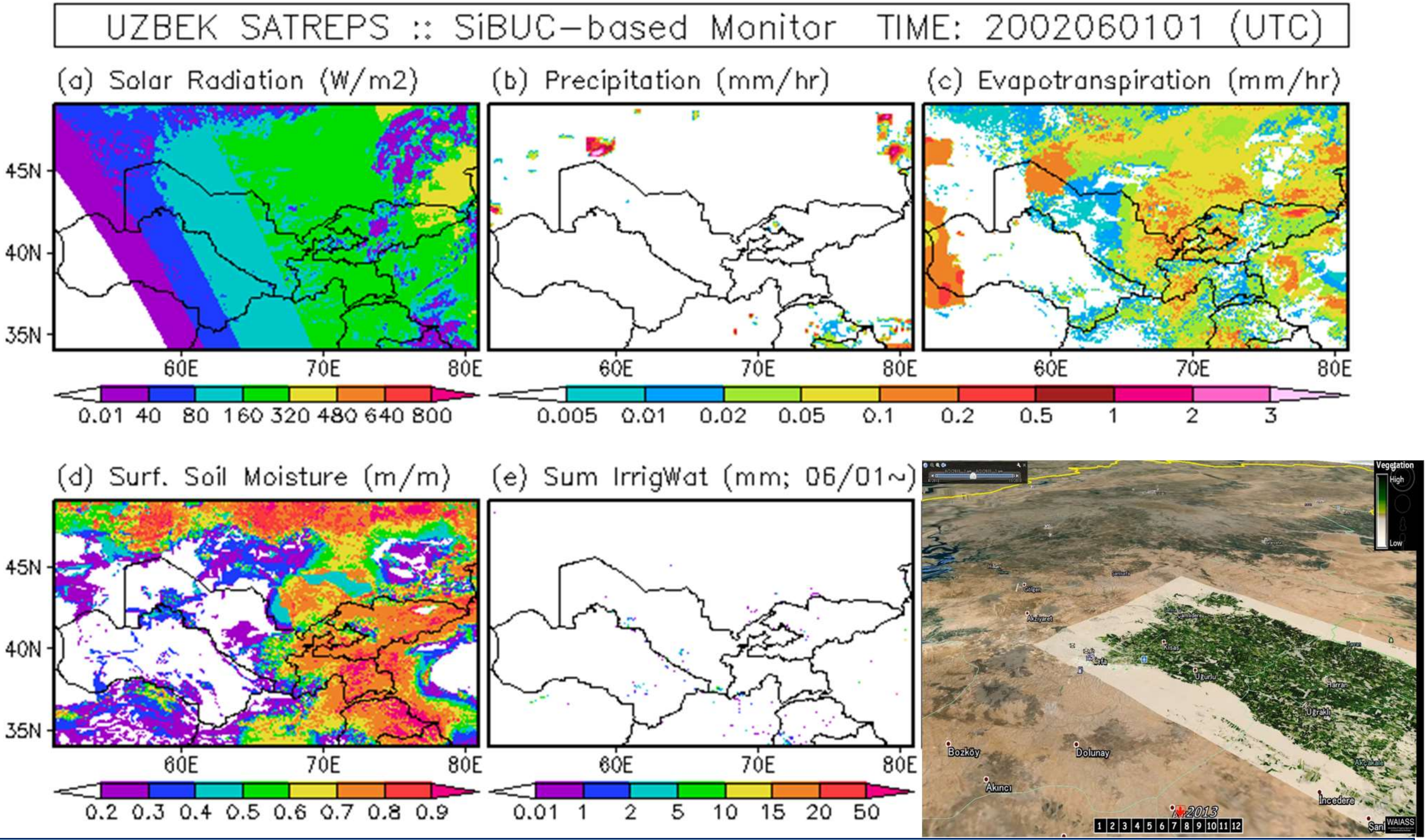
sustainable

Which species?
Which combination?



Near-Real time monitoring of land surface states

（Radiation：EXAM、 Precipitation：GSMaP、 other：JRA5



Detailed mapping of the irrigation water requirement, evapotranspiration, soil moisture, crop growth status, water stress status, etc.

Visualize the places to improve irrigation efficiency, as well as places where conversion to halophytes is desirable. Scenario analysis for different land use and future climate conditions

Reclamation of saline soil

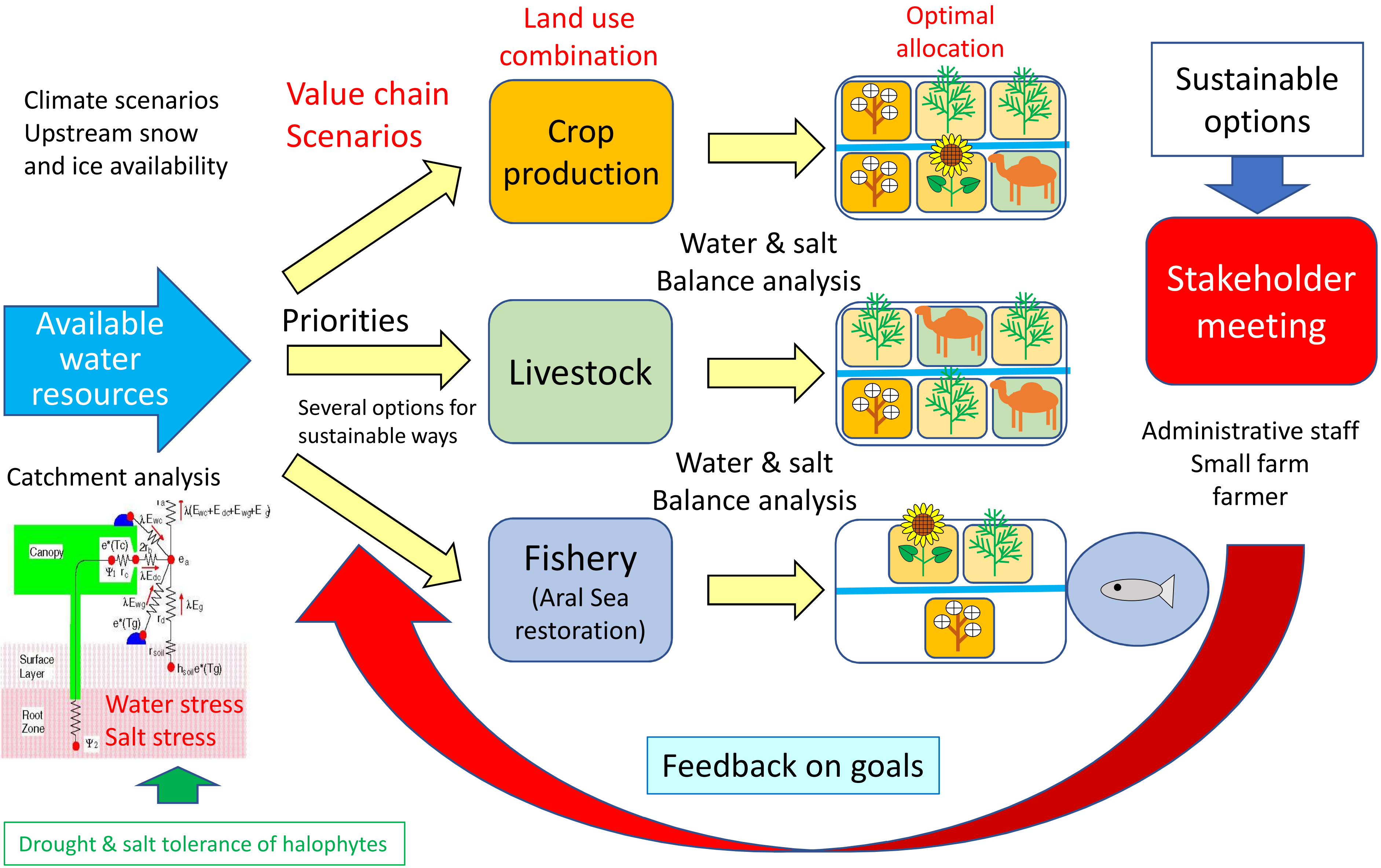
Types of soils damaged by salt	Recoverable?	**Soil restoration method**
Class I. Maximum (desertification)	impossible	Soil removal (civil engineering)
Class II. High (abandoned lands)	necessary	Restoration with halophytes (Bio-remediation, BLUE-SATREPS)
Class III. Medium (yield reduction)	possible	Growing salt-tolerant crops (legumes, sunflower), Washing by irrigation
Class IV. Non-saline	-	Normal cultivation of conventional crops

Recovery stages

Class. II → Halophytes farming → Class. III → Salt tolerant crop production → Class. IV

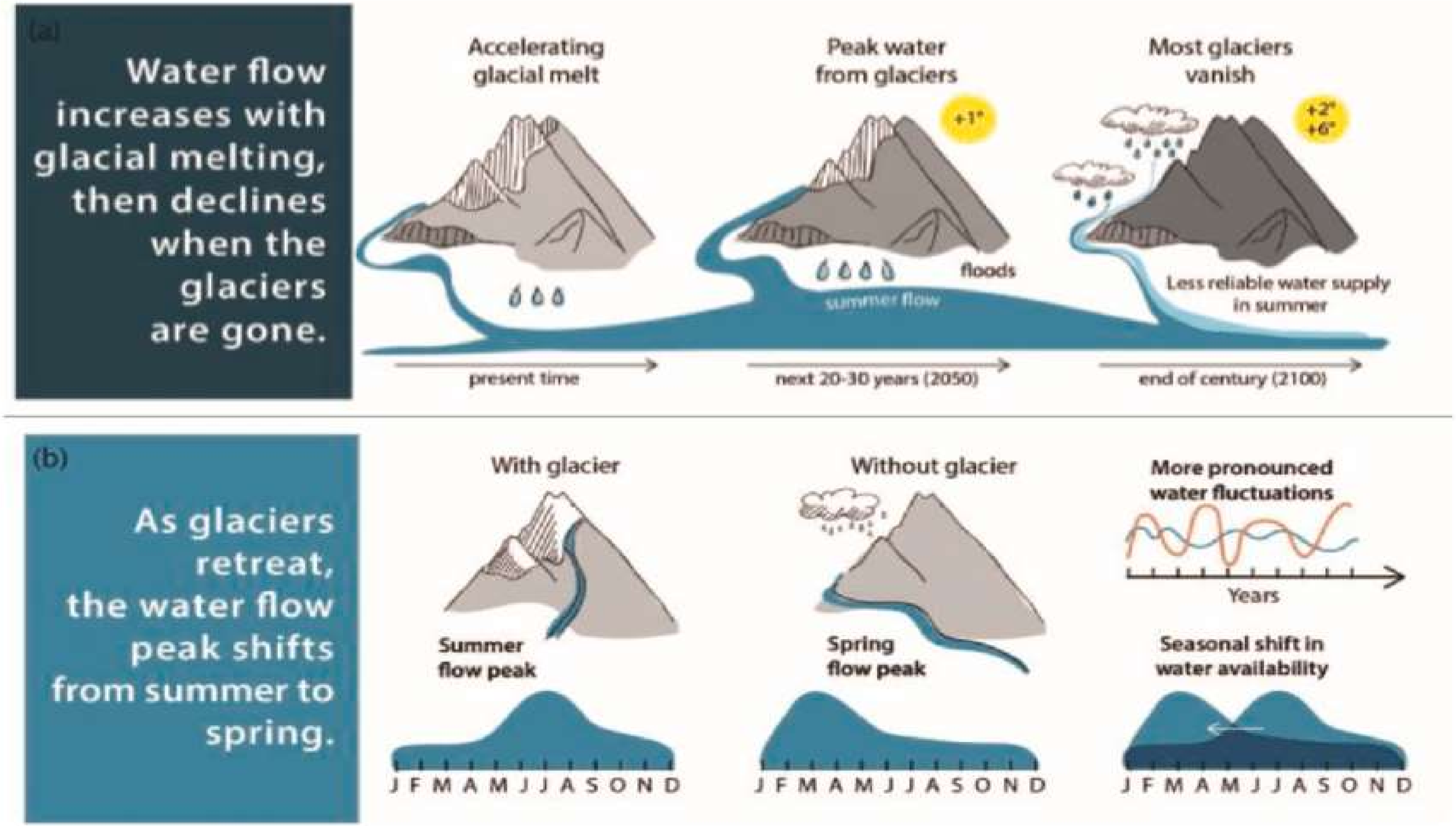
Class. I → (Soil cleaning) → Class. IV

Integration of hydrology/meteorology and biosaline agriculture



We should be prepared for the situation after "Peak Water"

Water rich environment in next 20-30 years is a good chance for trial & error.
If we can save this additional water, much water can be delivered to Aral Sea.
Water saving society is also a good preparation for drought years to come.



From Saks et al. (2020) : The state and future of the cryosphere in Central Asia