15 - DRAINAGE AND SALINITY CONTROL: REVIEW OF RELATED PROBLEMS IN CENTRAL ASIA

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Abstract: Drainage in arid and semi-arid zones that are subjected to unfavourable environmental and land processes is supposed to regulate and control water and salt balance in irrigated areas and water and salt regimes of the soil. Besides, it is used to regulate water regimes in waterlogged and humid lands as resulted from irrigated agriculture. The paper revises methods and technologies employed in Central Asia countries and analyses drainage performance observations carried out in the Azizbek experimental area, Fergana, Uzbekistan.

Keywords: Drainage, Land reclamation processes, Salinity control, Water and salt regimes, Fergana, Aral Sea basin.

Introduction

Central Asia is located in the Aral Sea basin and its unique natural conditions, involving inland nature and natural deep salinity of the soil over a vast area, besides climate aridity and water scarcity, have a great potential for the development of irrigated agriculture. As a result of irrigation, the above-mentioned factors cause secondary salinization and over-wetting (over-irrigation), the intensity of which depends on farming practices.

The total land fund of the Aral Sea basin is 155 million ha, of which about 32.6 million ha are suitable for irrigated agriculture. The area of saline land is 23.922 million ha corresponding to 73.6% of the total area, while non-saline area is 8670.5 thousand ha (26.8%). The area of heavy saline soils is 7422.5 thousand ha or 31% (Table 1). Table 1 shows that non-saline areas are mainly in Kyrgyzstan and Tajikistan. Part of this area, which is irrigated, is located in the formation zone, where natural drainability is high, i.e. in the upper watersheds of the rivers Syrdarya and Amudarya. Here, groundwater is bedded deep in the soil and does not contribute to soil-formation processes; therefore, irrigated lands are non-saline, except for some smaller irrigated schemes located in intermountain

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and interarid depressions.

Table 1. Characteristics of the land resources in Central Asian region (10^3 ha).

Republic	Total area	Agricultural area ***	Land (meliorative) resources							
			Total	Non-saline	%	Saline	%	which heavy saline	% of saline	total irrigated
Kyrgyzstan	15994	10057	3021	2267.5	75	753.5	25	63	8,0	1034.2
Tajikistan	9470	4158	1964	1595.5	81.2	368.5	18.8	73.9	19.0	689.7
Turkmenistan	32968	30325	12198	1423.2	11.7	10774.8	88.3	4253.5	39.5	1317
Southern Kazakhstan	63679	27300	4707	700	15	4000	85	1500	37.5	768
Uzbekistan	32889	26085	10710	2684.3	25	8025.7	75	1532	19.0	4164.2
Total	155000	97925	32,600	8670.5	26.8	23922.5	73.6	7422.5	31.0	7973.1

The poorer land resources s are in Turkmenistan and southern provinces of Kazakhstan where 88 and 85% of irrigable lands, respectively, are saline and located in the groundwater dispersion zone (C) and groundwater discharge zone (B) within the Amudarya and Syrdarya deltas. The drainability is low or inexistent and saline groundwater is bedded close to the soil surface (Fig. 1). There are a lesser saline land resources in Uzbekistan when compared to Kazakhstan and Turkmenistan, though in terms of total saline area, it takes the second position, after Turkmenistan. In Uzbekistan, the total irrigable area is 10710 thousand ha, of which, 8025.7 thousand ha or 75% of lands are subjected to salinization. Besides, whereas in Turkmenistan and Kazakhstan the heavy saline area is 39.5% and 37.5%, respectively, it is 19.0% in Uzbekistan due to geomorphologic and hydro geological conditions.

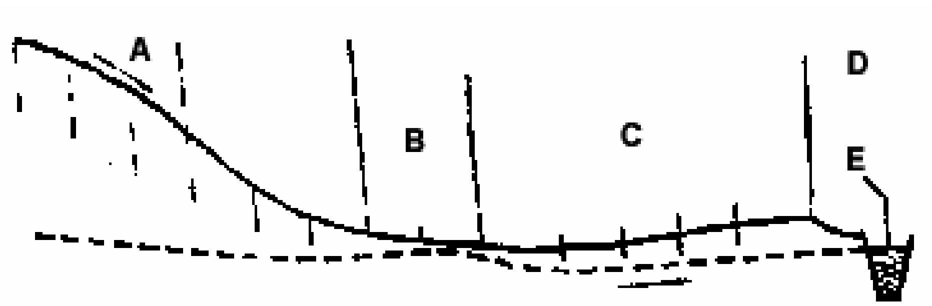


Fig. 1. Schematic representation of hydro geological irrigation zones in Central Asia: A – recharge zone; B - groundwater discharge zone; C – groundwater dispersion zone; D - flood-plain; E – channel.

Salinity: an overview on main problems

The natural soil salinity characteristics and salt accumulation patterns in Central Asia are of relevance because they indicate a perspective of the risk of secondary salinization caused by irrigation, thus when new land development is planned or when the identification of land reclamation measures is performed (such as irrigation regime and irrigation techniques, drainage types and size, leaching, etc.), as well as when the identification of reclaiming (desalinating) period is set.

SANIIRI's research, carried out in 1965-1980, following the mentioned objectives, established that geomorphologic characteristics of Central Asian irrigated areas (foothills, inter-mountain valleys, alluvial valleys, low deltas and high river terraces) together with the groundwater formation regimes, the thermal soil regimes and the surface water and groundwater balances, identify the principal distinctions of initial salt reserve and profile, both for soil layer and for lower stratum. 6 typical salt profiles were established in blanket melkozem (fine grained soil) to a depth of 20-30 m from the surface. These profiles determine the intensity of saline flow drainage under irrigation and land reclamation (Fig. 2). Moreover, the first profile type is typical for natural and intensively drained lands of submountaine valley in upper zone of talus train and for high river terraces, while II type refers to old irrigated schemes with shallow saline water table and to artesian water zones, such as Fergana Valley, Uzbekistan, Vaksh Valley, Tajikistan, and Chuy Valley, Kyrgyzstan. III, IV and V salt profiles refer to alluvial, proluvial-alluvial valleys and inter-mountain troughs prior to irrigated agriculture development, and the VI salt profile is typical for inter-conal depression and groundwater discharge zones. The above-mentioned salt profile patterns predetermine the intensive development of secondary salinization and the required amounts of desalination measures. III, IV, V, and VI salt profiles are characterized by huge salt reserves and relevant areas seem to be the main sources of drainage saline flow in the Aral Sea basin.

Simultaneously, depending on salinity content and, mainly, on chemical composition, a toxicity threshold was set for main crops, according to the soil salinity classification (Table 2).

Before extensive development of artificial drainage (1955-1960), salinity of irrigated areas in Central Asia was mainly caused by chloride-sulphate and sulphate accumulation, and, more rarely, due to chloride and sulphate-chloride. Alkaline salinity is rare and occurs in smaller areas in Turkmenistan and Kyrgyzstan.

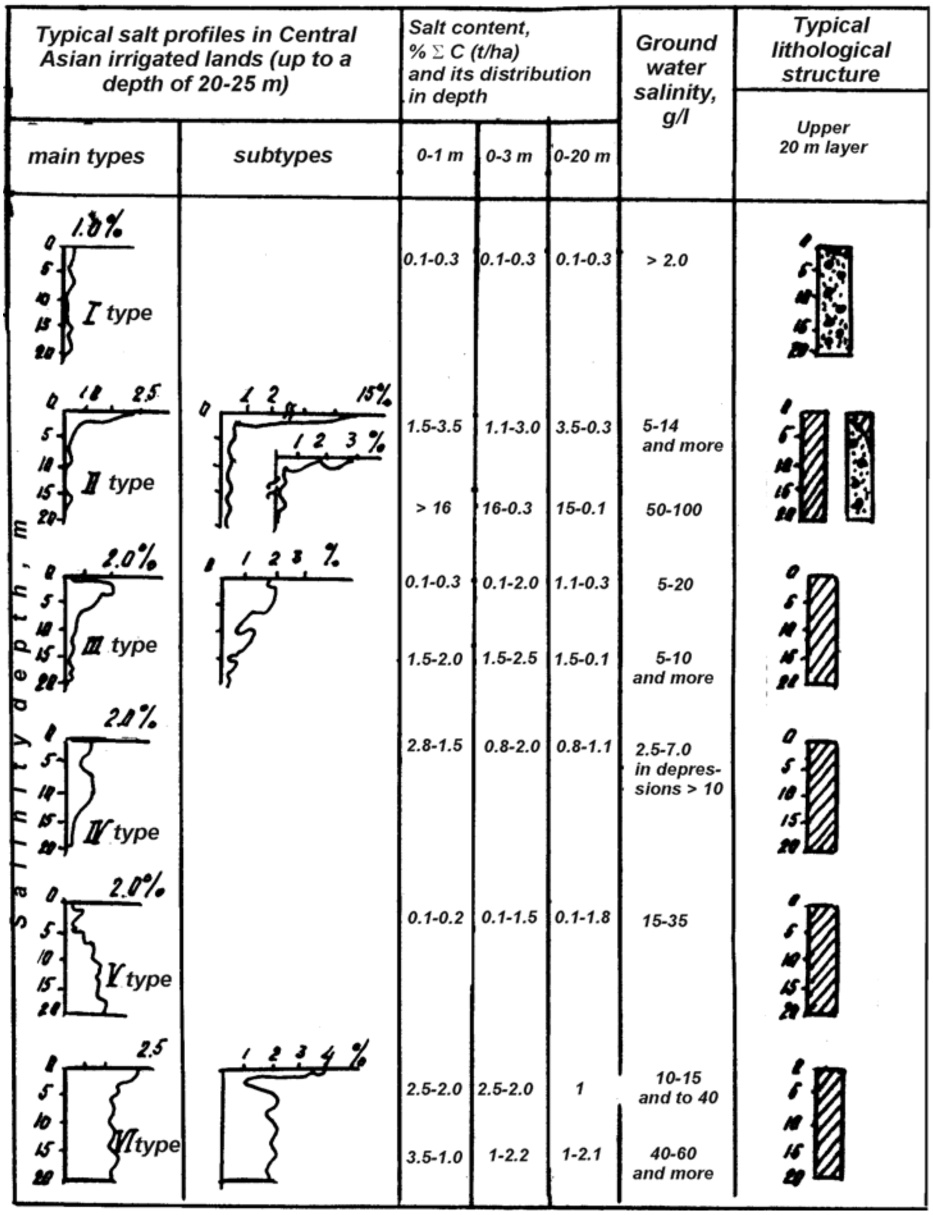


Fig. 2. Salt profile types in irrigated areas in Central Asia (Dukhovny *et al.*, 2004).

According to SANIIRI and other research institution's data, more than 5.97 million ha out of the total irrigated area need artificial drainage. The actual total area covered with collector-drainage network is 5347300 ha (Table 3).

Table 2. Soil classification by salinity degree and chemism (above the line – total salts, under the line – toxic salts) – (Pankova *et al.*, 1996).

	Salinity chemism (ion ration, mg-eqv/100 g of soil)		
	Neutral salinity (pH<8.5)		
Degree of soil salinity	chloride, sulphate-chloride $Cl:SO_4>1$	chloride - sulphate $Cl:SO_4=1-0.2$	sulphate $Cl:SO_4<0.2$
Toxicity threshold (non-saline soil)	<0.1 <0.05	<0.2 <0.1	<0.3(1.0)*** <0.15
Low	-0.2 0.05-0.12	-0.4(0.6)*** 0.1-0.25	0.3(1.0)-0.6(1.2)*** 0.15-0.3
Medium	0.2-0.4 0.12-0.35	0.4(0.6)-0.6(0.9)*** 0.25-0.5	0.6(1.2)-0.8(1.5)*** 0.3-0.6
Heavy	0,4-0,8 0,35-0,7	0.6(0.9)-1.0(1.4)*** 0.5-1.0**	0.8(1.5)-1.5(2.0)*** 0.6-1.5
Very heavy	>0.8 >0.7	>1.0(1.4)*** >1.0	>1.5(2.0)*** >1.5
	Alkaline salinity (pH>8.5)		
Degree of soil salinity	chloride - soda**** soda- chloride $Cl:SO_4>1$ $HCO_3>Ca+Mg$ $HCO_3>Cl$	sulphate -soda soda - sulphate $Cl:SO_4<1$ $HCO_3>Ca+Mg$ $HCO_3>Cl$	sulphate - chloride -carbonate $HCO_3>Cl$ HCO_3 SO_4 $HCO_3<Ca+Mg$
Toxicity threshold (non-saline soil)	<0.1 <0.1	<0.15 <0.15	<0.2 <0.15
Low	0.1-0.2 0.1-0.15	0.15-0.25 0.15-0.25	0.2-0.4 0.15-0.3
Medium	0.2-0.3 0.15-0.3	0.25-0.4 0.25-0.4	0.4-0.5 0.3-0.5
Heavy	0.3-0.5 0.3-0.5	0.4-0.6 0.4-0.6	Not found
Very heavy	>0.5 >0.5	>0.6 >0.6	Not found

* Total toxic salts are equal to sum of ions expressed in %. S_{toxic} salts = ($Cl+Na+Mg+SO_{4tox}+HCO_{3tox}$). Ions Cl, Na, Mg refer to toxic salts; HCO_{3tox} general-($Ca-HCO_3$). Total toxic ions are calculated in mg-equivalent, and then these ions are converted into % and summed up.

** Under chloride-sulphate type of salinity, indicators on total toxic salts for heavy and very heavy saline lands are approximated to 1.0-1.5% (for easy use) against 0.9-1.4 in the table shown in Soil Classification and Diagnostics (1997).

*** Figures in brackets refer to degree of salinity regarding total in gypsum-bearing soils that contain more than 1% $CaSO_4 * H_2O$; according to analysis of soil water extracts, these soils usually contain more than 10-12 mg-eqv. of Ca and SO_4 (non-toxic).

**** Degree of soda salinity is estimated using the indicators of chloride-soda salinity.

Drainage in Central Asia

Horizontal (surface and subsurface) and vertical drainage systems are the most developed in Central Asia.

The area covered with horizontal drainage is 4 750 860 ha. The regulating part of this type of drainage is represented mainly by subsurface pipe drainage and open drainage collectors.

Subsurface horizontal drainage is by perforated pipelines (made of ceramic, plastic, or asbestos-cement, 0.07-0.3 m in diameter) placed under surface for a depth of 2 to 4.0 m and surrounded with a filter, 0.15-0.18 m thick, made of sand and sand-gravel. Recently, artificial protective filter materials (synthetic fibres, needle-punched fabrics) and their combinations with natural filters have been used (Dukhovny *et al.*, 1979).

Water flows are to be drained by gravity under the available hydraulic head formed due to difference in water table levels at mid-drain and in the perforated pipelines. To repair and operate subsurface horizontal drain, special structures, such as observation wells and outfalls are installed. Drain spacing depends on hydrogeological and economic conditions, as well as on design characteristics of drain inlets and is not less than 50 m.

Table 3. Characteristic of collector-drainage network in the Aral Sea basin, as of 2000 (Dukhovny *et al.*, 2004).

Country	Irrigated area (10^3 ha)					Vertical drainage wells		
		of which						
	total	1	2	3	4	number	of which, operable (%)	Area served by 1 well (ha)
Uzbekistan	4250.6	3360.0	2893.4	2523.9	450	4179	25-30	107.7
Kazakhstan	786.2	530.0	420.2	257.9	320	1503	00	213
Kyrgyzstan	411.8	158.04	158.04*	157.14	0,9	64	37.0	14.0
Turkmenistan	1860.6	1511.2	1511.2*	1488.69	22.5	254	87.0	88.6
Tajikistan	718.0	364.5	364.5	323.23	41.24	1962	20	21.0
Total Aral Sea basin	7896	5973.6	5347.3	4750.86	764.6	7762	36.7	107.5

Country	Network extension (km)				
	Off-farm		On-farm		
				including	
	total	specific (m/ha)	total	subsurface	specific (m/ha)
Uzbekistan	31353.6	8.1-19.0	106439.7	38300.2	10-67.0
Kazakhstan	2400.0	3.1	13700.0	experiment	28.0 Kyzyl-orda
Kyrgyzstan	42.0	0.27	869.2	137.5	5.5
Turkmenistan	8988.9	5.24	25263.4	6345.8	14.7
Tajikistan	2213.0	6.4	9279.0	3817	32.0
Total Aral Sea basin	44997.5		155551.3	48600.5	

*Irrigated area covered with collector-drainage network;

1. Area, which needs to be drained; 2. Area provided with drainage; 3. Area under horizontal drainage; 4. Area under vertical drainage

Vertical drainage covers 764600 ha and is a system (Fig. 3) comprised of drill wells provided with inlets and outlets and water-lifting equipment; of buildings for control, automation and telemetry equipment operation station; of power lines, transformer substation; and of service roads. Vertical drainage wells, usually 0.9-1.2 m in diameter, are designed to impact the upper layer of groundwater and therefore drilled for a depth of up to 50-100 m.

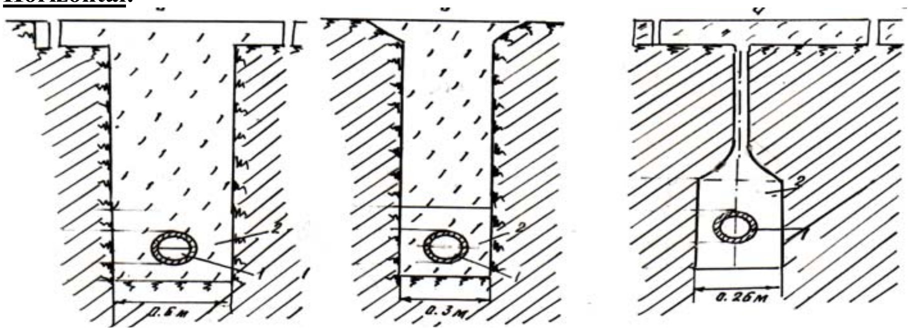
The wells inlets are located in highly permeable sandy-gravel sediments and equipped with a filter case protected by a sandy-gravel envelope. Water-lifting equipment is located in a housing pipe above the filter case. Steel casing, thin-walled welded, polymeric and asbestos-cement pipes-up to 0.4 m in diameter, were usually used as housing pipes, while, perforated pipes made of the same materials or manufactured filters were preferred as filter cases. Well's service area depends on hydrogeological and economic conditions and may extend to 100-150 ha.

The combined drainage (Fig. 3) is a system comprised of horizontal drains (collectors) placed in poor-permeable surface melkozems and of vertical blowing wells installed in well-permeable sub-layers by its inlet section. Under such systems, the head created during irrigation and accompanied by groundwater rise is transferred to the lower and well-permeable layer and creates an inflow to the vertical wells and discharge into a horizontal drainage network. Hence, blowing wells placed along the drain allow wider drain spacing by increasing the drain effect. In order to increase water collection, combined drainage wells were drilled (not deeper than 30 m) across 500 mm in diameter and cased by plastic pipes across 100 mm in diameter with perforation in lower section placed in well-permeable sub-layer (Dukhovny *et al.*, 1982). This type of drainage was developed by the authors and made ready for application at a large scale (1975-1985), has been implemented in an area of 35-40 thousand ha.

As a filter protection, the sandy-gravel mixture of special composition is filled in annular space between the lift string and the well walls. The spacing between wells, placed along the drain depends on hydrogeological conditions, and is 100-200 m.

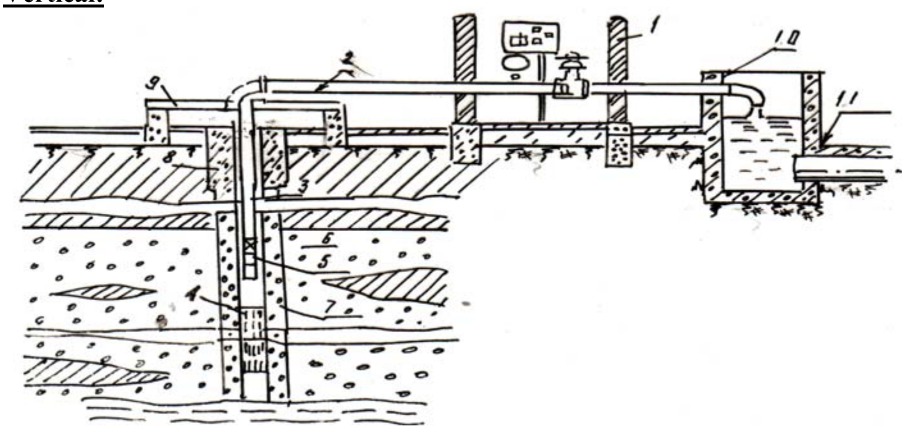
Based on analysis of hydrogeological conditions of given area, one or another of above-mentioned drainage types may be selected. Horizontal drainage is mainly suitable for homogenous soils conditions, with permeability coefficients varying from 0.01 to 1 m/day and more if under the shallow confining layer (up to 5 m). This drainage is also effective under heterogeneous soils with thin (3-4 m) surface melkozem, where it is possible to open well-permeable sub-layers (sand, gravel, etc.) and place horizontal drains.

Horizontal:



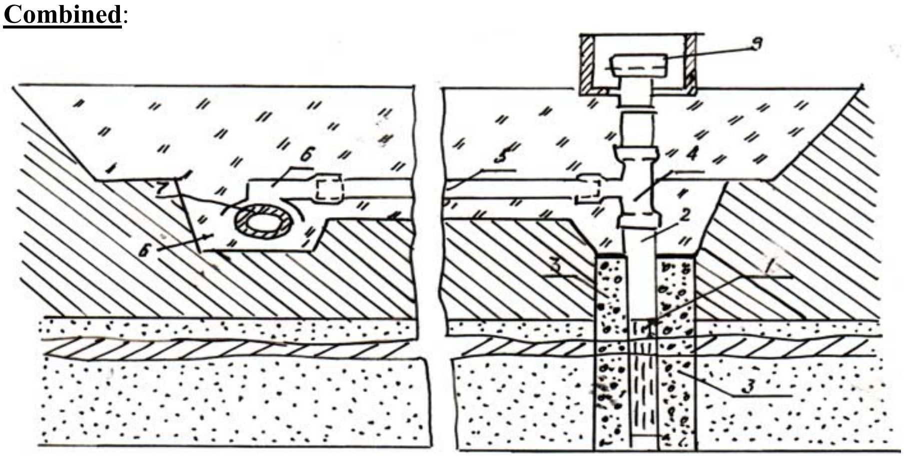
a: ditch; b: narrow ditch; c: without ditch. 1: perforated pipe 2: sandy-gravel filter 3: backfilling

Vertical:



1: control building; 2: head conduit; 3: operational string; 4: filter string; 5: pump; 6: electric engine; 7: gravel filling; 8: conductor string; 9: supporting frame; 10: intake well; 11: outlet

Combined:



1: filter string; 2: water-lifting string; 3: filter filling of well; 4: T-shaped pipe; 5: diverting pipe; 6: shroud with outlet; 7: drain pipe; 8: filter filling of drain; 9: well head

Fig. 3. Main drainage types in Central Asia. (Dukhovny *et al.*, 1979, 1982 and Reshetkina *et al.*, 1978).

Vertical drainage is promising for heterogeneous soils with thick (15-45 m) surface melkozem and underlying and well-permeable sandy-gravel layers, with more than 5 m thick, with transmissivity of more than 100 m^2/day. This type of drainage may be efficient under poor permeability conditions (less than 0.1 m/day) of surface melkozem or groundwater pressure in underlying layers. Surface melkozem thickness limits are caused when thickness is less than 15 m under vertical drainage, where spatial non-uniformity occurs in terms of groundwater bedding, drop and soil desalination rates. When thickness exceeds 45 m, the resistance of surface melkozems sharply increases and weakens the hydraulic links between the shallow groundwater in surface melkozems and the under-layers's deep groundwater (Reshetkina *et al.*, 1978).

The combined drainage is suitable for heterogeneous soils comprised of poor permeable (0.01-0.5 m/day) surface melkozem, 5-15 m thick, and of well-permeable artesian or free-flow under-layers having transmissivity of more than 10 m^2/day. Combined drainage is not applicable in cases of thin surface melkozem since placement of its horizontal component (for a depth of 3-4 m) directly in well-permeable under-layers makes installation of its vertical components (i.e. wells) useless. When melkozem is more than 15 m, its resistance increases and the coefficient of overflow (ratio between water volume coming from top melkozem and total water volume taken out by combined drainage) decreases. Under poor permeable surface melkozem conditions (less than 0.1 m/day), when draining ability of horizontal network may be neglected, the latter can be replaced by non-perforated blind conduits, which only transports the drainage flow coming from blowing wells.

Due to such advantages as low capital investment, simplicity, and cheap operation, the combined drainage will be particularly promising in the nearest future under implementation of drainage reconstruction and rehabilitation program.

It should be noted that widespread construction of drainage systems in Central Asian was started in 1960-1990 when new lands were intensively developed and irrigation and drainage networks in old irrigated lands were reconstructed in all the republics. Thus, by the early 90's, 200550 km of collector-drainage network were constructed, including 45000 km of off-farm and main collectors and 155500 km of on-farm networks (of which: 48600 km of subsurface drains; 7762–vertical drainage wells).

At the same time, the largest drainage coverage is in Uzbekistan, where inter- and on-farm collector-drainage network extends to 137793.3 km, of which 31353.6 km are off-farm ones. Besides, and to a larger degree, this Republic constructed some of the best drainage types, such as subsurface horizontal drains and vertical drainage wells that cover 550000 ha and 450000 ha, respectively. However, by 2000, the irrigated areas covered with vertical drainage have decreased to 380400 ha because of closing down of a share of operational wells. Similar picture is observed in subsurface drainage systems due to intensive failure of primary drains. In Uzbekistan and Tajikistan, inoperable subsurface drains amount to 34 to 40% of their total extension.

Vertical drainage was also developed in Kazakhstan and Tajikistan and covers 320 and 41240 ha, respectively, with high-flow-rate wells totalling 1503 and 1962, respectively.

An area served by one well depends on hydrogeological and reclamation conditions and ranges from 107.7 ha and 213 ha (Uzbekistan, Kazakhstan) to 21 ha (Tajikistan). Other republics have developed mostly the surface collector-drainage network, while vertical and subsurface drainage systems were constructed in experimental (pilot) fields.

When reclaiming the soil, the main indicator of drainage coverage in irrigated lands is the drainage extension per hectare, which in Uzbekistan, Kazakhstan, and Tajikistan is 67 m/ha, 28 m/ha and 32 m/ha, respectively, at on-farm level and 8.1-19 m/ha, 3.1 m/ha and 6.4 m/ha at off-farm level. According to this indicator, reclaimed lands in those republics may be referred to as areas provided with artificial drainage, taking into account vertical systems. Such conditions are not observed in Turkmenistan, where specific drainage extension averages 14.7 m/ha. However, one should take into account, that lands in this country are more complex in terms of hydrogeological, soil, and reclamation conditions.

Until 1991, main and off-farm collectors, vertical drainage and partially subsurface drainage had been subsidized by national governments (Ministries of land reclamation and water resources); on-farm surface collector-drainage network (CDN) and most subsurface drains had been under responsibility of farms. Therefore, off-farm CDN, vertical drainage and a part of subsurface drainage were operated by Province hydrogeological, land reclamation, and other special agencies at expense of national budgets. On-farm CDN was operated at expense of farms. Such operational system has been kept in Uzbekistan till present.

Drainage and salinity problems in Fergana province

Fergana province, as a research site, is characterized by more complex and unfavourable hydrogeological and soil conditions contributing to the development of adverse environmental and soil processes under irrigation and land development (intensification of water table head, rise of water table, increase of groundwater salinity and particularly accelerated rate of salinity restoration).

In geomorphological terms, the territory of Fergana province is represented by closed hollow intermountains, with Quaternary alluvial sediments of the Syrdarya river in the upper layer and alluvial-proluvial sediments in marginal parts. The thickness of quaternary sediments is up to 400-500 m in the central area and 25-50 m in the marginal parts. As to lithology, the quaternary sediments are comprised of interstratified sandy-gravel-pebble soils dividing surface melkozem in form of lenses. The upper 10-20 m layer is comprised of interstratified melkozems: sandy loam, loam, and clay. The relief of the plain zone is smooth, with a slope ranging from 0002 to 00005, while submountain zones are characterized by larger slopes >0002–0.05. The Syrdarya river crosses the territory from the south-east to north-west and serves as an intake conduit for collectors and drainage waters (Dukhovny *et al.*, 2004; Reshetkina, 1960).

The geomorphology caused the unique character of hydrogeological conditions in Central Fergana, i.e. formation of artesian deep groundwater flown from mountains, as well as close beddings of shallow saline groundwater. Here, before drainage development, groundwater was bedded at 2.0 m and its salinity varied from 3-5 g/l to 10 g/l and more. The hydraulic head mid-drains are set at 0.2-0.95 m more than the water table. Water in deepest layers (>20-50 m) are less saline, with maximums reaching 3 g/l. At the same time, deep ground waters at depths of 180-200 m and more are self-discharged and their salinity does no exceed 0.5-1.0 g/l. Groundwater recharge due to overflow from underlying artesian aquifers is approximately 2-3 to 8-10 thousand m^3/ha, thus creating conditions for shallow water tables and formation of huge drainage flow, i.e. increase of drainage capacity (Yakubov, 1990).

Soil characteristics are closely related with geomorphological and hydrogeological factors. The plain submountain zone is comprised of thin light textured soil (sandy loam, light loam, etc.) and of underlying coarse detritus sediments. Here, groundwater does not contribute to soil-formation processes. The lowland zone is comprised of meadow-sierozem and meadow soils formed under the influence of groundwater. The lands are characterized by stratified soils of various textures. The inland zone consists of meadow and meadow-swampy soils formed under major influence of groundwater.

Due to shallow water table and increased head of deep groundwater, surface salinization is observed in all the zones, excluding the intensively drained one, and salts are distributed in the upper 1.0-1.5 m layer, while lower layers are practically desalinated due to an upward flux from the underlying aquifers. Thus, Fergana province is a very difficult region with intensive adverse environmental and soil processes, therefore a set of complex capital-intensive is required to control them.

Here, until the XX the century, more than 150 thousand ha of lands had been irrigated; moreover, irrigation system had been constructed without engineering designs and particularly without drainage. The areas that did not require artificial drainage were mainly irrigated. By mid-XX, the irrigation area had been expanded by 240-250 thousand ha. Irrigation was expanded to zones of moderate and poor drainage by constructing off- and on-farm collectors (the later rare) without primary regulating drains that led to secondary salinization under the shallow water tables.

By 1970, the irrigated area was 286700 ha, while by 1990 it increased to 350000 ha, mainly including lands in the Central part of Fergana Province, between the Big Fergana canal and the Syrdarya river, located within the boundaries of a natural drained area. Next development of adyry soil made groundwater contributions to downstream schemes more intensive, thus deteriorating such lands. At the present moment, in the Fergana province, about 90-100 thousand ha out of the total irrigated area don't need artificial drainage. The drainage-covered area was 188000 ha (65.7% of total irrigated area) in 1970 and reached 261000 ha (73.2%) in 2000.

By 1995, in this area 13837 km of collector-drainage network (including, 1332 km of subsurface horizontal drainage) and 1303 vertical drainage wells had been constructed and operated. However, by 2000, the number of operable wells decreased to 1288, while the extension of subsurface horizontal drainage (SHD) was shortened by 248.1 km (Table 4). The specific extension, indicating a degree of artificial drainage provision, was relatively high even in 1970-1975 and equalled 44.7-52.8 m/ha, i.e. it has not practically changed since 1975. Slight increase in specific extension is accounted for by the construction of subsurface drainage. Moreover, vertical drainage was intensively developed in this area (100 wells in 1970 and 1003 wells in 1995).

Such powerful systems, comprising horizontal and vertical drainage provided huge water and salt outflow. In 1970-1975, the total drainage flow amounted to 2554 Mm^3, at a water diversion equalling 5078 Mm^3. Since 1980, drainage flow has more or less stabilized at a level of 2729-3051 Mm^3/year at a total water diversion of 5000 Mm^3/year. In 2000, both water diversion and the total drainage flow decreased. The share of total drainage flow in water diversion in the Fergana province varied from 40.7% (1970) to 50.4% (2000).

According to total water diversion and its salinity, which changed from 0.4 to 0.7 g/l, salt intake increased from 2285500 t/year (1970) to 3600200 t/year (1985), and its specific rate equalling 17.7 t/ha and 15.8 t/ha per year. By 2000, specific salt intake dropped to 11.4 t/ha per year. Simultaneously, total and specific salt outflow from irrigated areas are slightly more than salt inflow: specific salt inflow with irrigation water varies within 8-10 t/ha/year, while specific salt outflow with drainage flow is 15-21.1 t/ha/year. Water and salt balances of surface water are formed depending of type of salinity control, with salt outflow reaching 5.2-11.3 t/ha/year from irrigated area. Salt outflow from aeration zone varies from 21.0 t/ha/year (1970) to 8.6 t/ha/year (1990) (Table 4).

Since 1990, the aeration zone balance has been formed, through salt inflow from the lower layers depending on type of salt accumulation above water table. In this period, a positive water balance was developed between the aeration zone and the groundwater, with the upwards flow ranging from 528 m^3/ha to 865 m^3/ha per year and the salt intake varying within 7.28 t/ha to 12 t/ha per year. Moreover, the growth trends of saline areas and particularly of medium saline ones also indicate an intensification of adverse environmental and soil processes and ultimately, to the deterioration of drainage systems. The adverse environmental and soil processes are caused by a sharp decline in operability of on-farm drain-collectors and of vertical drainage, where the pumping volumes have decreased by 2.0 – 2.5 times during the last decade.

Table 4. Changes in the state of irrigation-drainage systems in Fergana province (Dukhovny *et al.*, 2004).

Indicators of the state of irrigation-drainage systems	Year						
	1970	1975	1980	1985	1990	1995	2000
Irrigated area (10^3 ha)	286.70	306.40	318.40	335.94	349.70	357.20	356.81
Area covered with drainage (10^3 ha)	188.0	213.9	235.2	255.2	255.8	258.6	261.0
Total drainage area (km)	8398.9	11298	12414.4	12940.2	12479.9	13818.5	13837
of which, subsurface horizontal drainage (km)	14.3	30.7	48.2	83.1	1185.9	1332.4	1084.3
Specific drainage extension (m/ha)	44.7	52.8	52.8	50.7	48.8	53.4	53.0
Number of vertical drainage wells	100	255	509	768	1044	1303	1288
Pumping volume (Mm^3)	87	219.5	336.57	477.82	638.1	462.1	428.2
Diversion for irrigation (Mm^3)	5078.8	5074.6	5034	5294.4	4983.4	4960.8	4049.9
Irrigation water salinity (g/l)	0.45	0.59	0.63	0.68	0.61	0.70	0.70
Salt inflow (10^3 t)	2285.5	2994.0	3171.4	3600.2	3039.9	3472.6	2834.9
Specific water supply ($10^3 m^3$/ha)	17.7	16.6	15.8	15.8	14.3	13.9	11.4
Specific salt inflow (t/ha)	8.0	9.8	10.0	10.7	8.7	9.7	7.9
Total drainage flow (Mm^3)	2554	1598	3023	2191	3051	2871	2729
Drainage modulus (in drained area) (l/s/ha)	0.43	0.24	0.41	0.27	0.38	0.35	0.33
Net drainage flow (Mm^3)	2043	1277	2418	1753	2441	2297	2183
Net drainage modulus (l/s/ha)	0.34	0.19	0.33	0.22	0.30	0.28	0.27
Net drainage flow of water diversion (for irrigated area) (%)	7126	4168	7594	5218	6980	6430	6118
Share of drainage flow of water diversion (for irrigated area) (%)	40	25	48	33	49	46	54
Specific water disposal ($10^3 m^3$/ha)	13.6	7.5	12.9	8.5	11.9	11.1	10.4
Drainage flow salinity (g/l)	1.8	2.85	2.12	2.39	2.21	2.28	2.28
Total salt outflow (10^3t)	4598	4553	6409	5237	6742	6546	6222
Specific salt outflow (from irrigated area) (t/ha)	16.0	14.9	20.1	15.6	19.3	18.3	17.4
Share of drainage flow of water diversion (for drained area) (%)	50.3	31.5	60.1	41.4	61.2	57.9	67.4
Efficiency of irrigation systems	0.53	0.56	0.58	0.61	0.63	0.59	0.55

Results of drainage research and salinity control in the «Azizbek» pilot plot

It should be noted that the development of drainage systems and their adequate operation over the period 1965-1990 created conditions in irrigated lands that contributed to formation of favourable environmental and soil processes and to improvement of land and water productivities. This trend is demonstrated in detail through the results of research implemented in an experimental plot, with an area of 150 ha, in the Akhunbabayev district, in Fergana province (Fig. 4). The plot is surrounded by open collectors, such as Otsechniy in the south-east and Srednekyzyltyuba in the south-west. The regulating network is comprised of deep subsurface drains D-1A, D-1, D-2 and D-3 made of asbestos-cement tubes with sand-gravel filters.

The mentioned drains were installed in 1959-1960 and carry water to Srednekyzyltyuba collector, with a laying depth of 3.5-3.7 m. However, the collector is subjected to siltation and overgrowing and mainly serves for released irrigation water disposal. Frontier, interceptive and open drain-collectors in the northeast diverts wastewater all year round and are permanently filled.

As to hydrology, the drainage plot is located in an area of groundwater discharge. According to SANIIRI's data, groundwater inflow from the exterior is 3.0-4.0 thousand m^3/ha, and therefore the hydraulic head of groundwater in deeper aquifers (100 m deep all year round) is 20-70 cm higher than water table.

Besides the above-mentioned drains, plastic drains B-1, B-2 and B-3 were placed for a depth of 2.4 m in irrigated plots 1, 2, 3 and 4 covering about 40 ha.

As to lithology, the field is comprised of stratified sediments. The upper layer of the surface melkozem has heterogeneous silty structure and, at a depth of 0.7-1.2 m, is represented by poor-permeable gypsum layers preventing water movement, with permeability coefficient varying from 0.2 to 2.0 m/day.

Before the construction of subsurface drainage, the water table level was 1.2-1.6 m (with salinity totalling 7-9 g/l) in irrigated lands and 2.5-2.8 m (with salinity equal to 20-22 g/l) in non-irrigated lands. This made salt accumulation more intensive, in the aeration zone. Initial salt percentage in 1 m layer was 2.5-3.0% of dry soil weight and reached 5% in some spots, including 0.03-0.08% of chlorine. The type of soil and groundwater salinity is sulphate.

The subsurface drainage system was put into operation since mid 1960. In 1961-1975, the mean annual water inflow to irrigated lands varied within 13-15 thousand m^3/ha, while drainage modulus was 0.22-0.36 l/s/ha against 0.17 l/s/ha as foreseen by the time of its design. In this period, drainage lines were operated under forced flow along the whole length. The head above drainage pipe along the drains ranged from 0.5 to 1.4 m, reaching its maximum at drain outlets.

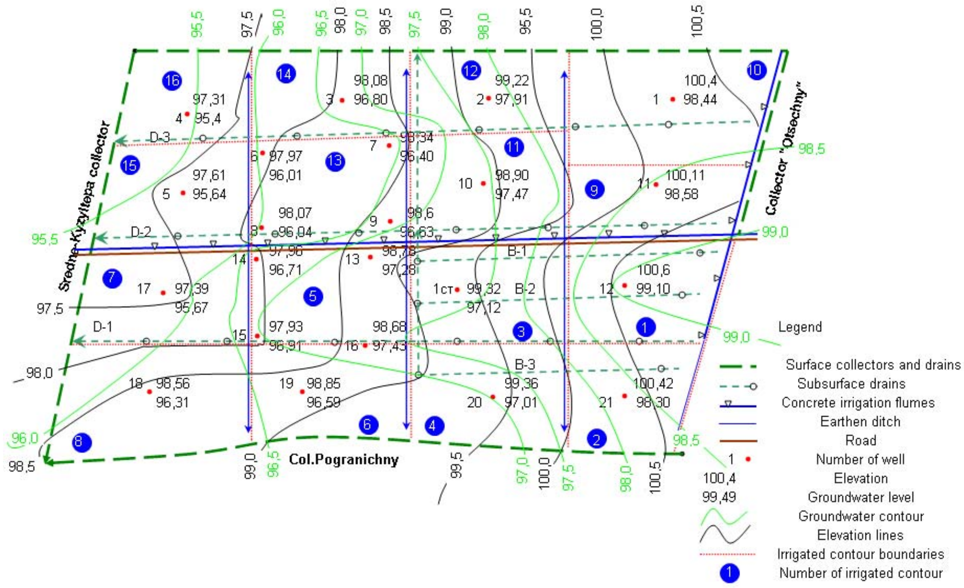


Fig. 4. Layout and groundwater contour of farm "Azizbek", Akhunbabayev district, as of 07.08.04.

By 1964-1965, as a result of high operability of constructed drains and maintenance of leaching requirements, water and salt regime has been improved in the pilot site:

- in terms of salt total, the soil was desalinated to 1.2-1.4% of dry weight;
- groundwater salinity decreased to 3.5-5 g/l against the initial 5.5-10 g/l;
- cotton yields increased to 2.5-2.7 t/ha against initial 1.2-1.8 t/ha.

In the late seventies, water-salt regimes have practically stabilized with certain size of changes within a year, depending on water inflow.

The project research has began at the point of practically "full" stabilization of water and salt processes under the background of subsurface drainage, i.e. under stable inflow and drainage flow, by sustained regimes of groundwater and its salinity and fixed variation of desalination rates within a year.

The total area of pilot site is 160 ha, including 16 irrigated plots covering 8 ha to 10 ha each. At the same time, six plots (1 and 10-14), with area totalling 60 ha, were seeded with cotton, while the rest of plots, i.e. 10 plots (2-9, 15 and 16), with total area of 100 ha, were under winter wheat.

Cotton fields were irrigated by furrows, while wheat fields were irrigated by borders. In plot 1, water was applied 6 times, for cotton, during the growing season, while other fields were irrigated 5 times. Water application depths varied from 1140 m^3/ha (minimum) to 1410 m^3/ha (maximum), and irrigation norms ranged from 5906 m^3/ha to 7283 m^3/ha (net). In 2001, water was applied to winter wheat once or twice with a depth of 522 m^3/ha (plot 7) to 1216 m^3/ha (plots 6 and 8). The irrigation norm varied from 522-1260 to 2510 m^3/ha.

After the wheat harvesting, maize was sown as double crop, but only in plots 3, 5 and 9, while the rest of plots served as evaporators. Recharge irrigation was performed in two plots (3 and 5), with water application depths of 824 and 965 m^3/ha. Water depths applied for maize ranged from 1036 m^3/ha to 1550 m^3/ha, while irrigation norms varied within 2306–2657 m^3/ha.

During irrigation of all crops, outflow from the irrigated plots amounted to 125–267 m^3/ha (10-12% of irrigation norm).

Since April 2001 till April 2002, the total water balance for that area was as follows:

- Sum of inflows is 16052 m^3/ha, of which water supply is 8417 m^3/ha, including 6700 m^3/ha in the growing season and 1947 m^3/ha (77.5%) in the non-growing season. Ground water inflow reaches 4359 m^3/ha and precipitation is 2186 m^3/ha;
- Sum of outflows is 16217 m^3/ha. Balance discrepancy (difference between inflow and outflow) is 165 m^3/ha. Total evaporation (evapotranspiration) reaches 8529 m^3/ha (56.4%), of which 7797 m^3/ha during the growing season. Evapotranspiration has been calculated based on Fergana weather station's data through crop coefficient. Drainage outflow was 3417 m^3/ha (1436 m^3/ha during the growing season), while groundwater outflow was 2344 m^3/ha. The difference between inflow and outflow is 2005 m^3/ha (Table 5).

Simultaneously, inflow from groundwater to aeration zone is recorded during the growing season. The inflow averages about 2075 m^3/ha for that area. In the non-growing season, outflow (percolation) from the aeration zone to groundwater amounts to 1942 m^3/ha. In the year profile, a positive water balance, with inflow of unsaturated zone reaching 133 m^3/ha, was attained.

Slightly different water balance was formed in the cotton field, where water inflow was 30% larger than that in other fields. Here, the water balance was negative in yearly profile, being positive only in May and August– 1023 and 1130 m^3/ha, respectively (Table 6).

The salt balance of the farm area as a whole and of cotton plot 13 is formed depending on water balances developed in these areas. The salt balance in the yearly profile was negative with inconsiderable salt outflow of 4.4 t/ha, while in the growing season, accumulation of salts up to 15.4 t/ha was observed in aeration zone. The soil in aeration zone is desalinated in the winter and spring through leaching, percolation and precipitation. As a result, salt outflow comes to 20.3 t/ha.

Table 5. General water-salt balance of irrigated area in experimental plot, farm Azizbek for IV, 2002-III, 2003.

Inflow

Months	V		P_r		E+Tr		(I-O)		W		Salt intake
	m^3/ha	t/ha	m^3/ha	t/ha	m^3/ha	t/ha	m^3/ha	t/ha	m^3/ha	t/ha	t/ha
IV	1166	0.58	135	0.04	473	-	0		17	0.01	0.63
V	665	0.33	348	0.11	770	-	0		352	0.12	0.57
VI	578	0.29	153	0.05	1526	-	711	0.25	274	0.10	0.68
VII	1596	0.80	14	0.00	1781	-	803	0.28	0	0.00	1.08
VIII	1326	0.66	7	0.00	1683	-	1402	0.49	0	0.00	1.16
IX	232	0.12	208	0.07	1080	-	1004	0.35	0	0.00	0.53
X	807	0.40	155	0.05	591	-	0	0.00	85	0.03	0.48
XI	0	0.00	81	0.03	177	-	276	0.10	102	0.04	0.16
XII	0	0.00	504	0.16	76	-	0	0.00	188	0.07	0.23
I	449	0.22	37	0.01	64	-	0	0.00	0	0.00	0.24
II	592	0.30	272	0.09	112	-	162	0.06	0	0.00	0.44
III	1006	0.50	272	0.09	196	-	0	0.00	72	0.03	0.62
Total	8417	4.21	2186	0.70	8529	-	4359	1.53	1090	0.38	6.82

Outflow

Months	-(I-O)		D		-W		Salt outflow	Salt regime in the plot
	m^3/ha	t/ha	m^3/ha	t/ha	m^3/ha	t/ha	t/ha	t/ha
IV	517	1.91	328	0.91	0	0.00	2.82	-2.19
V	244	0.90	351	0.97	0	0.00	1.88	-1.31
VI	0	0.00	190	0.53	0	0.00	0.53	0.16
VII	0	0.00	215	0.60	172	0.48	1.07	0.01
VIII	0	0.00	347	0.96	505	1.40	2.36	-1.20
IX	0	0.00	296	0.82	68	0.19	1.01	-0.47
X	174	0.64	282	0.78	0	0.00	1.42	-0.94
XI	0	0.00	282	0.78	0	0.00	0.78	-0.62
XII	460	1.70	156	0.43	0	0.00	2.13	-1.91
I	163	0.60	214	0.59	46	0.13	1.32	-1.09
II	0	0.00	388	1.07	526	1.46	2.53	-2.09
III	786	2.91	368	1.02	0	0.00	3.93	-3.31
Total	2344	8.67	3417	9.47	1317	3.65	21.79	-14.97

Note: V: water supply; P_r: precipitation; E+T_r: evapotranspiration; ± (I-O): groundwater inflow and outflow; ±W: general changes in moisture stock in given area; D: drainage

A similar situation is observed in cotton field K-83. Here, the rate of outflow both in the profiled year and in the non-growing season is slightly higher and amounts to 8.31 t/ha and 24.31 t/ha, respectively, and in summer months salts accumulate up to 15-16 t/ha. Slightly intensive salt outflow is accounted for due to huge water supply to the field as compared to the rest of area, particularly in the non-growing season. Salt balance in the cotton field indicates a water supply reduction possibility during non-growing season without causing an adverse effect on desalination of 40-50%. Percolation can be limited to 1000-1200 m^3/ha if the leaching norm is 2.0-2.5 thousand m^3/ha. Generally, the general and partial water and salt balances of drained lands trend depends on water inflow. In this context, water and salt balances of the field and in the aeration zone of plots under wheat are formed in a similar fashion to those of the cotton field. Simultaneously, water and salt balances of wheat fields, after harvesting, have not been seeded with maize, are slightly different. Thus, water and salt balances in the irrigated plot K-5, where wheat and maize are grown, were negative, with water outflow of approximately 911 m^3/ha and salt outflow reaching 10.17 t/ha per year. The balance in K-2, where only wheat is grown, is positive, with salt accumulation equalling 11.66 t/ha per year. Meanwhile, the above-mentioned rate of salt accumulation in aeration zone was observed when irrigation water and groundwater salinities vary within 0.35-0.4 g/l and 2.8-3.6 g/l, respectively.

Table 6. Soil water balance for demonstration plot 13, Niyazov farm, Akhunbabayev district, Fergana province (2001-2002).

Month	P_r	V	-Wn	inflow	$E+T_r$	Wn	outflow	±q
IV	100	0	880	980	531	0	531	-449
V	34	0	176	210	1233	0	1233	1023
VI	150	2838	0	2988	1844	880	2724	-264
VII	103	2439	132	2674	2052	0	2052	-622
VII	100	1122	0	1222	1296	1056	2352	1130
IX	70	0	836	906	841	0	841	-65
X	160	1625	0	1785	614	1144	1758	-27
XI	83	0	946	1029	176	0	176	-853
XII	457	0	880	1337	70	0	70	-1267
I	365	0	528	893	59	0	59	-834
II	262	1187	0	1449	102	1056	1158	-291
III	103	1299	0	1402	187	506	506	-896
Total	1987	10510	4378	16875	8818	4642	13460	-3415

Note: P_r: precipitation; V: water supply; ±Wn: change in soil water stock; $E+T_r$: evapotranspiration; ±q: vertical exchange between soil water and groundwater.

It should be noted that water and salt balance in aeration zone of the irrigated plots K-5 and K-2 was formed in similar way as negative water balance was formed in plot K-5, where percolation to groundwater “q” amounted to 2088 m^3/ha per year. In plot K-2, the balance was positive, with inflow to the aeration zone from groundwater, reaching 3175 m^3/ha (Fig. 5). The balance relative to the infiltration analysis showed that water and salt balances in some irrigation plots are different despite similar degree of drainage, even under small farm areas of only 160 ha. In farm Azizbek, more than half of irrigated areas under wheat, without double crops, showed positive salt regime though, as a whole, the area is high drained and subsurface drainage has been operated here for more than 40 years. On the other hand, the collected data indicate that even in well-drained areas with continued drainage operation, leaching requirements should be met in saline lands so that to avoid salinity restoration.

The mean annual drainage modulus in 2001 was 0.1 l/s/ha and varied from 0.075 to 0.13 l/s/ha. The maximum is attributed to the growing season and spring percolation. Currently, the drainage modulus is 2-2.5 times less compared to that for 1962-1964, that is caused by water supply regulation (mainly due to reduction of leaching norm and shift to percolations instead of leaching).

Drain discharge varies within a wide range, both in year profile and in month profile. The maximum discharge is observed in closed drain UD-2 (UD – large drain at the border between plots or sections) where it varies within 3.1-5.2 l/s to 8.5-12.5 l/s. The maximum is found during the growing season and the minimum falls to autumn-winter period. The minimum discharge is formed in drains B-1 which are made of corrugated plastic pipes, placed for a depth of 2.4 m, and in У-1a, 800 m long (asbestos-cement pipes) and 3.2 m deep. These drains discharge vary within 0.8-1.5 l/s (autumn-winter) to 3.0-6.5 l/s. In autumn, inflow to drain B-1 is stopped due to deep water table ($h \leq 2.3$-2.4 m). Despite intensive operation of drainage during the irrigation period, ground water flow is directed to the Srednekyzyltepa collector (Table 7).

Changes in groundwater level in the plot are caused by total evaporation, irrigation and drainage and there is fixed ground inflow. Ground water level and regime stabilization depends on irrigation-drainage systems operation and water supply to the area. Deep ground water is observed in winter (h=2.25-2.50 m) when irrigation is not applied or only winter wheat is irrigated. Since February, groundwater slowly rises due to leaching and recharge irrigations for cotton and other crops. In the growing season (April-June), the average monthly groundwater level ranges from 2.04 to 2.24 m.

Maximum and minimum groundwater levels in cotton and wheat fields are explained by their location relative to drains and the collector: near drains it is 0.25-0.40 m lower compared to drain spacing.

Groundwater salinity stabilized at 3.0-3.8 g/l regarding toxic salts and at 0.06-0.1 g/l regarding chlorine, against the initial 5.8-10 g/l. As to chemical composition, groundwater is sulphate. The total salinity changes insignificantly in year profile: +0.2-0.5 g/l.

Irrigation water salinity varies from 0.37 to 0.47 g/l. Due to very low irrigation and ground water salinity under leaching, salt restoration processes are not observed: in the root zone (0-1.5 m), salt percentage varies within 0.9-1.1% of dry soil weight regarding total salts, whereas initially it exceeded 3.0-3.5% and reached 4.5-5.0% in some spots (Fig. 5).

Table 7. Drainage flow dynamics in farm Azizbek, 160 ha (1.04.02 – 31.03.03).

Months	Name of drains							K-2 10 ha	
	UD-1 (m^3)	UD-1A (m^3)	B-1 (m^3)	UD-2 (m^3)	UD-3 (m^3)	Total (m^3)	Drainage flow (m^3/ha)	UD-1 (m^3)	Drainage flow (m^3/ha)
IV	11095	5320	5779	18454	11872	52520	328	11095	277
V	10880	4832	5095	22574	12716	56097	351	10880	272
VI	8108	3903	1821	11666	4831	30329	190	8108	203
VII	7890	4680	3324	14482	4061	34437	215	7890	197
VIII	12176	8129	7026	23295	4902	55528	347	12176	304
IX	11108	5295	4164	21522	5216	47305	296	11108	278
X	10477	4602	4479	20131	5404	45093	282	10477	262
XI	10035	5867	3179	18956	7104	45141	282	10035	251
XII	6206	3161	0	12734	2900	25001	156	6206	155
I	4436	2476	5800	12734	8820	34266	214	4436	111
II	10375	16386	4289	20931	10103	62084	388	10375	259
III	11631	6750	5800	26515	8120	58816	368	11631	291
Annual	114417	71401	50756	223994	86049	546617	3416	114417	2860

Months	K-13 10 ha				K-5 10 ha			
	UD-2 (m^3)	UD-3 (m^3)	Total (m^3)	Drainage flow (m^3/ha)	UD-1 (m^3)	UD-2 (m^3)	Total (m^3)	Drainage flow (m^3/ha)
IV	18454	11872	30326	379	11095	18454	29549	369
V	22574	12716	35290	441	10880	22574	33454	418
VI	11666	4831	16497	206	8108	11666	19774	247
VII	14482	4061	18543	232	7890	14482	22372	280
VIII	23295	4902	28197	352	12176	23295	35471	443
IX	21522	5216	26738	334	11108	21522	32630	408
X	20131	5404	25535	319	10477	20131	30608	383
XI	18956	7104	26060	326	10035	18956	28991	362
XII	12734	2900	15634	195	6206	12734	18940	237
I	12734	8820	21554	269	4436	12734	17170	215
II	20931	10103	31034	388	10375	20931	31306	391
III	26515	8120	34635	433	11631	26515	38146	477
Annual	223994	86049	310043	3876	114417	223994	338411	4230

Thus, the research results within this project show the possibility of shifting to stricter water supply during the non-growing season if the area is provided with adequately operated drainage, with average annual modulus achieving 0.1 l/s/ha. At the same time, cereals should be combined with other crops in order to avoid salt restoration under shallow groundwater (less than 2.5 m).

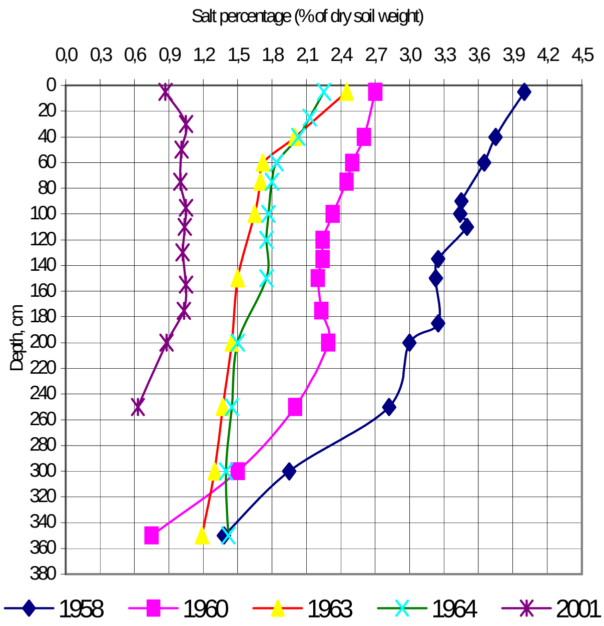


Fig. 5. Changes in salt percentage in the soil.

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