16 - RELATIONSHIPS BETWEEN IRRIGATION AND DRAINAGE

V. A. Dukhovny[1], Kh. I. Yakubov[1], P. D. Umarov[1]

Abstract: Irrigation is impossible without drainage, whether natural or artificial, in order to create appropriate conditions to sustain the required water-salt soil regime. In arid zones, the combination of irrigation and drainage helps to prevent salt accumulation in the root zone, to maintain adequate moisture conditions in the soil, to provide for potential minimum water use per unit production and area, as well as to produce return flow to rivers with minimal water quality impacts. However, this combination contributes to heterogeneous effects on agricultural lands and may lead to great deviations from design parameters of water use and of drainage flow. These aspects are discussed in this paper.

Keywords: Drainage, Irrigation, Land reclamation, Water and salt regimes, Soil physical characteristics, Groundwater.

Introduction

During the formation of the earth's crust, the strictly defined regimes of water-salt dynamics were developed in agreement with the geomorphological and lithological structure. Their intensity depends on natural and climatic conditions (e.g. moisture availability and evaporation) and geomorphological properties, thus forming an individual natural system, which is characterized by a certain degree of natural drainage in the terrain and by surface and groundwater runoff.

Using the existing techniques, crop irrigation naturally causes changes in water regimes in all chains of an irrigation network and in the fields that, in turn, lead to changes in natural regimes and levels of groundwater and in processes of salt accumulation in the soil. Depending on groundwater outflow and depth and on evaporation rates, those changes may (or may not) ask for certain types and depths of drainage and to other measures so that to prevent the negative effect of irrigated agriculture development.

[1] Interstate Commission for Water Coordination in the Aral Sea Basin – Scientific Information Center (SIC ICWC), B. 11, Karasu-4, Tashkent 700187, Republic of Uzbekistan. Email: dukh@icwc-aral.uz

According to natural and climatic properties, two large landscape-ecological zones are identified in Central Asia:

- Foothill plains, including:
  1. upstream river terraces (partially midstream), which are well-drained foothill plains under natural conditions;
  2. undulated submontane plains with intensive drainage;
  3. debris cones, which upper parts are well-drained, while the lower ones have no groundwater outflow.
- Desert lowland
  1. river terraces (mid- and downstream), poorly drained under natural conditions;
  2. alluvial plains, which are closed depressions without groundwater outflow;
  3. coastal deltas, drainless;
  4. deltas of dry, small and medium rivers, that have groundwater outflow.

According to hydrogeological, soil and soil-reclamation conditions, the geomorphological structures of foothill plains, excluding the last hydrogeological zone, refer to intensively drained terrains, with deep (> 5 m) slightly saline groundwater (up to 1.5 - 2.0 g/l) and non-saline soils. Most of these areas are characterized by high precipitation (more than 350 - 550 mm) and refer to the zones of groundwater formation and transit to lower geomorphological structures. In this context, water-salt balances in these massifs are favourable under both natural and irrigated agriculture conditions, i.e. they do not need artificial drainage. Human water management activities are limited to minimize water losses from fields and the irrigation systems so that soil degradation can be avoided (erosion and washout) and aquifers may receive additional recharge.

All areas in the desert zone and part of the debris cones in the foothill zone, including lower river terraces, peripheries of debris cones and large depressions in alluvial plains and river deltas, refer to poorly drained and drainless terrain where, under natural conditions, hydromorphic soils are formed, with shallow high-saline groundwater (up to 3 m). In such places, positive water and salt balances are generated. Moreover, in most zones, there is a stable high moisture in the aeration zone, excluding the top layer (up to 1 m), where abrupt moisture changes occur, particularly during dry periods of year. Development and irrigation of such lands make produce a positive and intensive water-salt balance, which requires that artificial drainage be constructed.

Desert lowland zone, with deep highly saline groundwater (lower than 3.0 - 3.5 m) and huge salt stock in soil horizons, when subjected to natural conditions show negative water-salt balance and desalinization of soil in 1.0 - 1.5 m layer. Simultaneously, and depending on soil texture and structure, variable moisture profiles are developed up to water table. Usually, the upper layer to 1.5 - 2.0 m is practically dry, while moisture ranges from 12 - 14% to 18 - 20% in lower layers. With development and irrigation, a positive water-salt balance is formed in these lands. Groundwater rise is then followed by an increase in its salinity due to leaching of salts from the soil.

In general, in Central Asia, lands with natural drainage that ensures sufficient outflow under irrigation, account for 37.5%, while the remaining area needs artificial drainage, degree of which depends on parameters of water-salt balances in irrigated terrain, aeration zone and groundwater.

Under the influence of natural moisture exchange processes in non-irrigated areas, sufficiently stable water balance is developed but depending upon to intensity of processes of natural evaporation, precipitation, outflow to the rivers, inflows from upstream areas, and percolation to underlying artesian aquifers, under which natural groundwater regimes are formed (Fig. 1). Simultaneously, the variability of water tables and groundwater salinity depends on fluctuations of rainfall, natural flows, natural salt removal and accumulation processes, as well as on waterlogging during floods or soil drying during drought periods.

Human activities, particularly water management and irrigation, significantly corrects the natural hydrogeological processes. This is reflected through the rise or drop of groundwater, and increase in waterlogging. Also buildings, roads, and other constructions have different effects on groundwater regimes and on its relationship with the river. Irrigation sharply changes natural regimes and create dynamic conditions for re-formation of common cycles, which then gets stabilized under the new rates of water cycle and the intensity of moisture exchange between the surface layer and the deeper soil layers in the aeration zone, between the aeration zone and the groundwater, and finally, between the groundwater and tail-water ditches as well as the rivers, lakes, and closed depressions (Fig. 2).

The characteristics of water balance components in the aeration zone and groundwater depends on irrigation system performances; irrigation techniques; soil salinity and leaching requirements; infiltration properties; and conditions of irrigated scheme's groundwater interrelation with adjacent aquifers. Moreover, system performances, irrigation techniques, and leaching norms are primarily manageable factors; their interrelation with groundwater is a result of changes in the scheme's water table, which, can be regulated by drainage.

Differences in hydrogeological and land reclamation processes are defined, mainly, by differences in geomorphological landscape structure, degree of natural drainage, and amount of groundwater inflow from adjacent areas. This inflow often creates primary artesian waters that are complemented with secondary artesian waters that occur during the filling of systems and through large main canals that have good hydraulic link with groundwater.

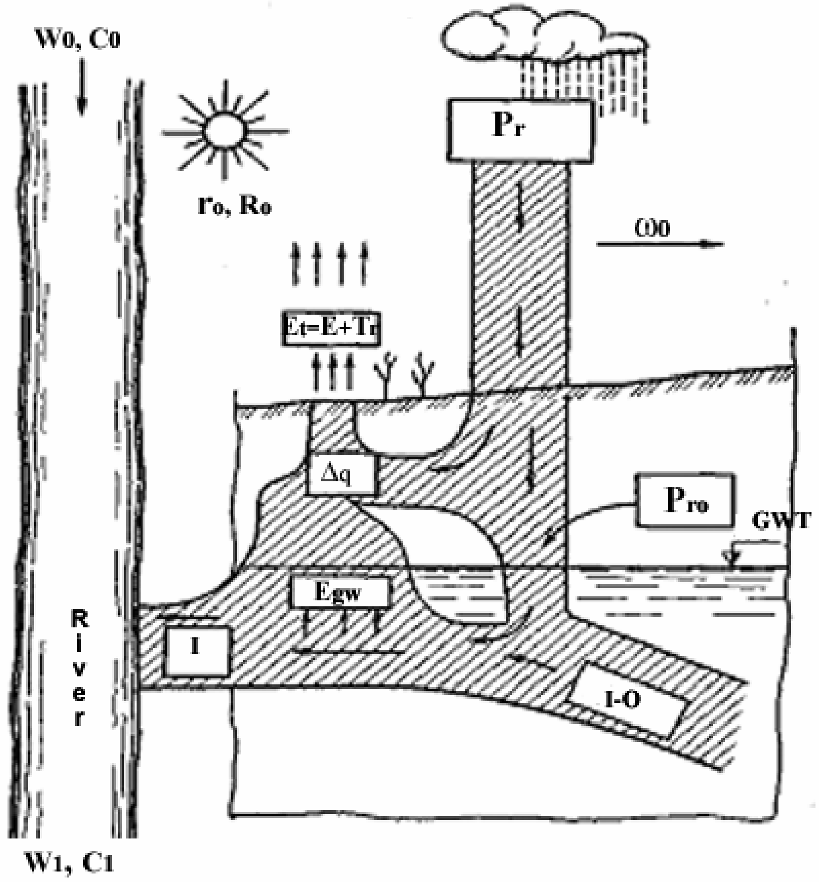

Fig. 1. Natural water interaction (dynamics) without irrigation.

(P_r: precipitation; $E_t = E + T_r$: evapotranspiration; ω_0, r_0, R_0: wind speed, mean monthly relative humidity and radiation balance, respectively; Δq: vertical water exchange; $P_{r\alpha}$: percolation of precipitation; E_{gw}: evaporation from groundwater; GWT: groundwater table; I: groundwater inflow to river; I – O: groundwater inflow and outflow)

In light of drainage requirements, there are zones referring to risk group, where natural groundwater outflow is lower than total infiltration, and percolation to groundwater or where groundwater is artesian, therefore forming additional recharges to the aeration zone. From this point of view, the evaluation of groundwater "inflow – outflow" (I – O), and especially of artesian water inflow, is of big importance for estimating the required depth of artificial drainage - D_o. Table 1 gives values of groundwater inflow-outflow over planning zones in the Syrdarya and Amudarya basins.

It is significant that foothill and intermountain valleys, where the research site is located, are characterized by great difference of inflow-outflow (for Fergana province, near 5000 m^3/ha), most of which refers to the autumn-winter period. Annual artesian recharge is 2500 m^3/ha for the site. This is also confirmed by using the RZQWM model (Stulina *et al.*, 2005), which produced the value 248 mm/year. This explains the fact that drainage flow (as the total of anthropogenic and natural inflow-outflow) often exceeds the amount of water applied.

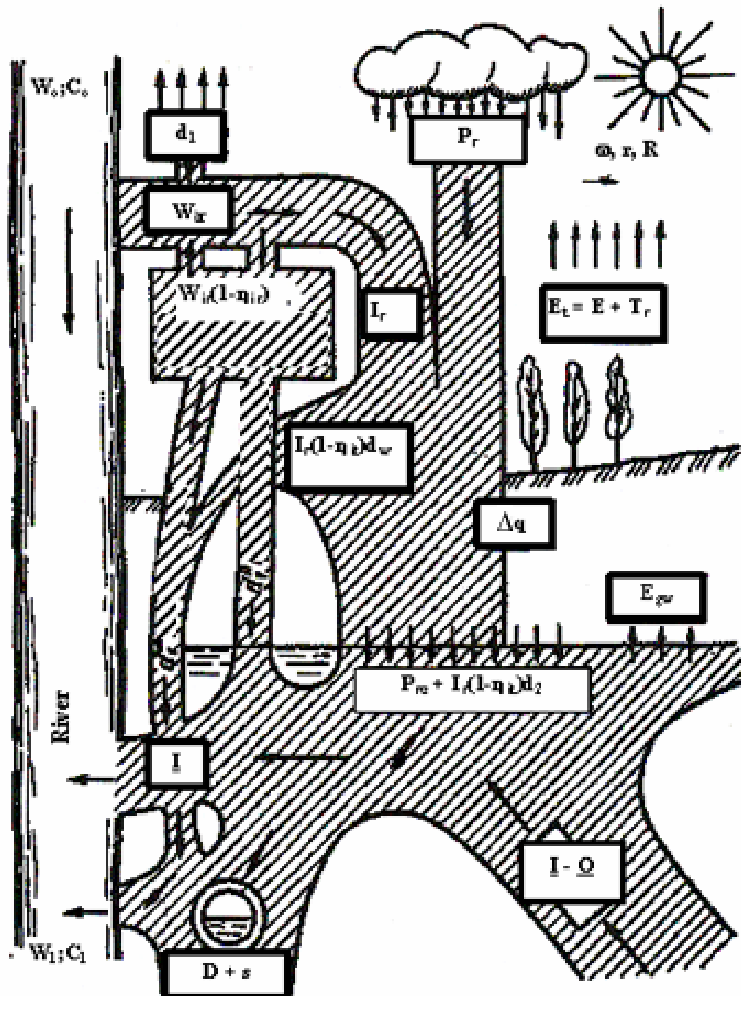

Fig. 2. Irrigation and drainage interactions in irrigation systems.

(P_r: precipitation; W_{ir}: water intake from river; W_{ir} $(1-\eta_{ir})$: losses in the system, of which: d_1- losses through evaporation from irrigation network; d_1 – losses through seepage; d_1 – losses through transit bypass; I_r: irrigation water; $I_r(1-\eta_{it})d_w$: losses in the field, $E_t = E + T_r$ evapotranspiration; E_{gw}: evaporation from groundwater; ω_0, r, R: wind speed, mean monthly relative humidity, and radiation balance, respectively; Δq: vertical water exchange; $P_{r\alpha} + I_r(1-\eta_{it})d_2$: percolation in irrigated field; $\underline{I}$: groundwater inflow to the river; $\underline{I} – \underline{O}$: groundwater inflow - outflow; D + s: drainage and waste water)

Table 1. Water balance equations.

Conditions	Balance	Equations	Number
Natural conditions (no irrigation)	General	$\Delta W=(\bar{I}-\bar{O})+(\underline{I}-\underline{O})+(P_r-I_f)-E_w-(E+T_r)\pm p$	1
	Aeration zone	$\Delta W_a=(\bar{I}-\bar{O})+(P_r-I_f)-E_w-(E+T_r)\pm q$	2
	Groundwater	$\Delta W=(\underline{I}-\underline{O})\pm q\pm p$	3
Irrigation (no drainage)	General	$\Delta W=(\bar{I}-\bar{O})+(\underline{I}-\underline{O})+(P_r-I_f)+(V_i-w_w)-E_w-(E+T_r)\pm p$	4
	Aeration zone	$\Delta W_a=(\bar{I}-\bar{O})+(P_r-I_f)-E_w-(E+T_r)+(V_i-w_w)+(1-a)F_c\pm q$	5
	Groundwater	$\Delta W_{gw}=(\underline{I}-\underline{O})+F_c\pm q\pm p$	6
Irrigation and drainage	General	$\Delta W=(\bar{I}-\bar{O})+(\underline{I}-\underline{O})+(P_r-I_f)+(V_i-w_w)-(E+T_r)-E_w-D\pm p$	7
	Aeration zone	$\Delta W_a=(\bar{I}-\bar{O})+(P_r-I_f)-E_w-(E+T_r)+(V_i-w_w)+(1-a)F_c\pm q$	5 bis
	Groundwater	$\Delta W_{gw}=(\underline{I}-\underline{O})+aF_c\pm q\pm p$	8

ΔW: total change in water stock within the boundaries of balance site over the estimated period; $\bar{I}$: surface water inflow; $\overline{O}$: surface water outflow outside the balance site; $\underline{I}$: groundwater inflow; $\underline{O}$: groundwater outflow; P_r: precipitation; I_f: surface run-off; E_w: surface water evaporation; $(E+T_r)$: evaporation and transpiration from the soil; $\pm p$: vertical water exchange between balance layer and deep groundwater («+»: upward artesian flux, «-»: downward groundwater flux); ΔW_a: change in water stock in aeration zone within the boundaries of balance site over the estimated period; $\pm q$: vertical water exchange between soil and ground waters; ΔW_{gw}: change in groundwater stock within the boundaries of balance site over the estimated period; V_i: irrigation water supply; w_w: tail-water outflow; F_c: seepage losses from canals; a: coefficient expressing a share of seepage that recharges groundwater; (1-a): coefficient expressing a share of seepage that recharges the aeration zone; D: drainage flow.

Water and salt balances for an irrigated soil, the aeration zone, and the groundwater

In order to characterize interaction between irrigation and drainage, it is important to perform water-salt balances for aeration zone and groundwater, besides general water-salt balance for irrigated area. Depth and parameters of artificial drainage are determined from the analysis of current water-salt balances and the forecast of their changes in the future.

Water-salt balances reflect the difference between total inflow and use of water and salts, which is equal to changes in their stock within the balance site over a specified period of time. Depending on the tasks to be solved, the balances for irrigated schemes, farms or plots are considered. In every specific case, the spatial boundaries of the balance site, the estimated period of time, and the sources of water inflow are to be determined. The balance estimations help to determine the direction of changes in environmental and reclamation processes under the development of irrigated agriculture (changes in moisture and salt stocks), the intensity of water recharge-transport from the aeration zone to groundwater, the rate of groundwater rise and salinity dynamics, and the required management measures.

The relationship between soil, surface, and ground waters is explained through the balance equations listed in Tables 1 and 2.

Table 2. Salt balance equations.

Conditions	Balance	Equations	Number
Natural conditions (no irrigation)	General	$\Delta S = (S_{\bar{I}} - S_{\bar{O}}) + (S_{\underline{I}} - S_{\underline{O}}) + S_\Delta \pm S_p$	9
	Aeration zone	$\Delta S_a = (S_{\bar{I}} - S_{\bar{O}}) + S_\Delta \pm S_q$	10
	Groundwater	$S_{gw} = (S_{\bar{I}} - S_{\bar{O}}) + S_p \pm S_q$	11
Irrigation (no drainage)	General	$\Delta S = (S_I - S_O) + (S_I - S_O) + S_a + S_i - S_f \pm S_p$	12
	Aeration zone	$\Delta S_a = (S_{\bar{I}} - S_{\bar{O}}) + S_a + S_i + S_f \pm S_q$	13
	Groundwater	$\Delta S_{гр} = (S_{\underline{I}} - S_{\underline{O}}) + S_f \pm S_q + S_p$	14
Irrigation and drainage	General	$\Delta S = (S_I - S_O) + (S_{\underline{I}} - S_{\underline{O}}) + S_a + S_f - S_w -$ $S_d \pm S_p$	15
	Aeration zone	$\Delta S_a = (S_{\bar{I}} - S_{\bar{O}}) + S_a + S_i + S_f \pm S_q$	13 bis
	Groundwater	$\Delta S_{gw} = (S_{\underline{I}} - S_{\underline{O}}) + S_f \pm S_d \pm S_q \pm S_p$	16

ΔS: total change in salt stock within the boundaries of balance site over the estimated period; S_I: salt inflow with surface water; S_o: salt outflow with surface water outside the balance site; $S_{\underline{I}}$: salt inflow with groundwater; $S_{\underline{o}}$: salt outflow with groundwater; S_a: salt inflow with precipitation; $\pm S_p$: salt inflow or outflow under vertical water exchange with deep groundwater horizons; ΔS_a: change in salt stock in aeration zone; $\pm S_q$: salt inflow or outflow under vertical water exchange between soil and ground waters; ΔS_{gw}: change in salt stock in groundwater horizon; S_i: salt inflow with irrigation water; S_f: salt inflow with seepage water from canals; S_d: salt outflow with drainage flow.

The general water and salt balances in Tables 1 and 2 establish quantitative and spatial changes in water and salt stocks and dynamics in irrigated land, whereas the equations for the aeration zone and groundwater determine the value of water and salt exchange between soil groundwater layers. Based on such quantitative values, the intensity of water-salt processes in irrigated fields may be assessed and optimal irrigation and leaching norms, that ensure irreversible desalination in aeration zone and in the upper layer of groundwater, may be set. It is then necessary to determine optimal soil-reclamation regimes that contribute to development of minimum water exchange between the rooting zone, the aeration zone, and the groundwater.

Reclamation regime and its relationship with water use and drainage

The Soviet soil-reclamation science (Reshetkina, 1965) considered the reclamation regime as a combination of artificial and natural drainage, water supply and agronomic operations that determine the interaction between irrigation and ground waters and impacts the total evaporation from irrigation fields, and hence the water supply.

The reclamation regimes are set through the selection and maintenance of groundwater levels based on groundwater salinity and respective irrigation norms and implemented through a set of hydrotechnical and agronomic operations. Classification of these regimes is given by Dukhovny (1983) and Yakubov and Ikramov (1983). The basic criterion is the recharge of the groundwater and the aeration zone.

The reclamation regimes (Table 3) should also agree with the natural conditions of the areas where irrigated agriculture is developed. Basically, all four types of reclamation regimes may be established in irrigated schemes. However, they require different water and economic parameters.

To justify a need for any reclamation regime, it is necessary to make multi-optional forecasts and technical and economic assessments regarding the optimal groundwater depths, as well as about the content and parameters of soil-reclamation measures that ensure favourable conditions for achieving high crop yields.

For the regulation of a reclamation regime and its selection, it is necessary to identify the cause-and-effect relations between environment (water, air, salt and nutrient in the rooting zone), control factors (water supply, drainage, agronomic operation, etc.) and indicators of interaction between the former two factors (crop growth and development). Simultaneously, there exist specific water-salt regimes in the rooting zone that correspond to biological requirements of a given crop (reference). Therefore, the main problem is to regulate inflow of water and salt from different sources so that the water-salt regime in the rooting zone is maintained by optimal ways (irrigation, drainage, etc.). Analyzing formation and use of water-salt balance's components may solve this problem. The balance method for justification of reclamation regimes takes into account the technical status of irrigation and drainage systems and the land use patterns, as well as the water-salt components regimes in irrigated fields.

Table 3. Key characteristics of the reclamation regimes.

Reclamation regime	Interaction with groundwater	Contribution from groundwater and reclamation share, 1000 m^3/ha	Evaporation from groundwater, 1000 m^3/ha
Automorphic	Groundwater does not contribute to irrigation, infiltration is free downwards	$-P<0.05\text{-}0.1(E+T_r-P_r)$; M=0	0
Semi-automorphic	Groundwater backups infiltration of irrigation water but makes minor contribution to plant water use	$+P<0.1\text{-}0.2(E+T_r-P_r)$; M=0.5-1.0	0-1.5
Semi-hydromorphic	Groundwater makes active contribution to plant water use, which is more than irrigation water share	$+P>0.3(E+T_r-P_r)$; M≥2.0	1.5-3
Hydromorphic	Plants uptake mainly from groundwater	$+P>(E+T_r-P_r)$; M≥5.0	3-7

P: total infiltration; $E+T_r$: evapotranspiration; M: leaching share; P_r: precipitation.

As an optimization criterion for selecting parameters of reclamation regimes, the recommendations (Dukhovny, 1983) are taken so that an option is selected, which provides reduced costs under the total minimum water inputs (irrigation+drainage) per unit of crop production. The results of a general estimation of the regime's optimal parameters for average conditions of Central Asia are shown in Fig. 3.

It takes into account the capital investments for creation of these parameters and are subjected to groundwater salinity and a parameter representing the ratio of water table $h_{гв}$ to capillary rise ($h_к$) (Dukhovny, 1983). The figure shows that the most beneficial regime is the hydromorphic one, where the ratio between the groundwater level and the height of capillary rise is 0.6 that corresponds, in the Fergana Valley, to a groundwater depth of 1.0 - 2.0 m and groundwater salinity of 1…2 g/l or to the depth of 2.2 m and salinity of 5 g/l. Moreover, if the groundwater salinity increases to 10…15 g/l, it is necessary to adopt a semi-automorphic regime with this ratio more than 0.8 and the water table reaching 2.5 m. Simultaneously, when developing new lands with deep water tables of more than 3.5 - 4.0 m and non-saline topsoil under natural conditions, the most beneficial regime is the automorphic one, which is established by preventing groundwater rise and secondary salinization and by constructing vertical drainage, if natural and hydrogeological conditions are appropriate.

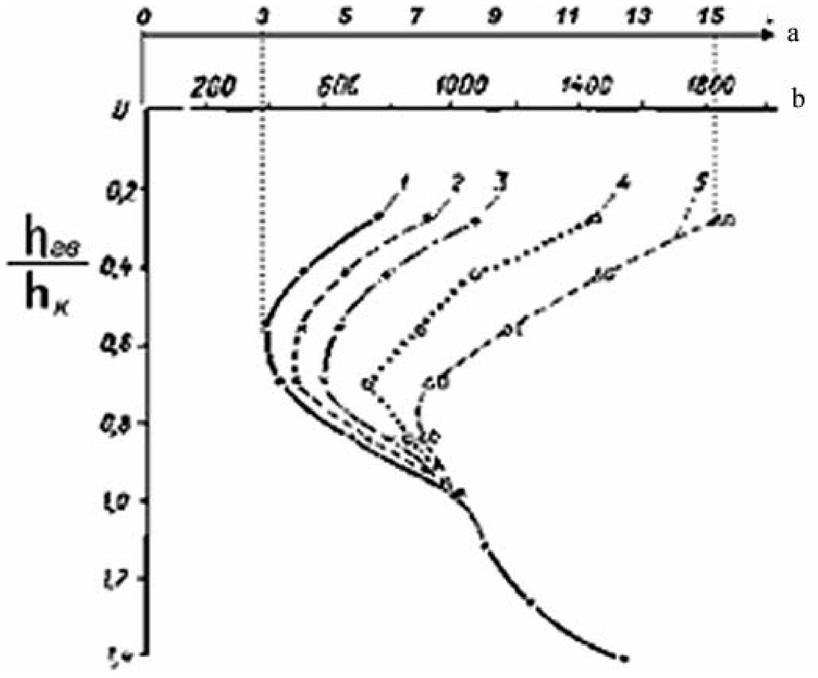

Fig. 3. Optimization of reclamation regime according to the sum of reduced costs with regard to water and crop yields:1 – C= 1 g/l; 2 – C=2 g/l; 3 – 3 g/l; 5 – 15 g/l.
(a: water supply, 10^3 m^3/ha; C: total groundwater salinity, g/l; h_{gw}: groundwater level, m; h_k: height of capillary rise, m; 1, 2, ..., 5: capital investment curves depending on h_{gw}/ h_k and groundwater salinity (C. g/l); b: net capital investments, $/ha)

For the Azizbek site, the current drainage capacity, with a net drainage flow reaching 3400 - 3700 m^3/ha per year, provides a quite rapid lowering of groundwater at the average rate of 5 - 7 cm/day. This ensures that the water table is kept at 1.7 - 2.2 m during the growing season and at 2.2 - 2.57 m in the mean annual profile. However, the spatial maintenance of water tables is a complex problem that takes into account the heterogeneous character of drainage performance in combination with the water supply/irrigation to each field in the farm.

Relating drainage intensity and irrigation

Horizontal drainage causes inequality in groundwater levels in drain spacing. This inequality is determined by the depression curve position between drains in one measurement and between collectors (or collectors and drains) in another measurement. Moreover, a groundwater curve is formed and by mid-drains reaches more than 1.0 m above the drains level. Naturally, this indicates a need of irrigation increasing norms and depths near the drains and collectors, and for their reduction when approaching the mid-drain water table curve. Surface irrigation due to irregular infiltration at the head of furrow makes this inequality more visible by causing excessive wetting at the head and under-wetting at the tail end of furrows (Horst *et al.*, 2005). This phenomenon was studied and described (Dukhovny, 1984) and may be considered when locating furrows, relatively to drain spacing.

Within the framework of the project, in farm Azizbek (160 ha), Fergana province, Uzbekistan, an attempt was made to assess influence of another factor of heterogeneity. Periodical irrigation in 15 - 20 days creates uneven load for drainage and causes dispersion of groundwater mound (a mound-shaped addition to the groundwater body built up by influent seepage) to non-irrigated area.

The site's groundwater level and regime was stabilized within a specific range, depending on the irrigation and drainage systems operation. The groundwater level is deeper in the winter and spring (December, January and February – h = 2.25 - 2.50 m in 2001 and h = 1.75 - 2.0 m in 2002) when the irrigated system is not operating or when only winter wheat is irrigated. Starting in February, the groundwater slowly rises due to leaching and percolation due to irrigation of cotton and other crops. During the growing season (April-September), the average monthly groundwater level varied from 2.04 to 1.56 m in 2001 and reached 1.65 - 1.75 m in 2002.

Minimum and maximum groundwater levels in cotton and wheat plots depend on their location relatively to the drains and the Srednetepa collector: the level is 0.25 - 0.4 m lower in the plots located close to drains than those in between drains.

Furrow irrigation has strong effect on the groundwater regime: the level increases the day after irrigation or sometime during the irrigation day. Moreover, groundwater rise after irrigation ranges from 0.79 to 0.89 m depending on irrigation depth.

In the Nr. 13 cotton field, located close to drain YD-2, the groundwater rise duration is 2 to 5 days, while it takes 5 to 11 days for the groundwater to drop down to the initial level, i.e. the rate of drop is half of that of rise. In the fields located in drains' mid-spacing, the lagging of level lowering is higher, i.e. this process is slower. The degree of inequality and its smoothing depends on irrigation depth and frequency, as well as fields location relative to drains. In the plots located close to the drain, the inequality is higher than in between drains as reflected in plots K-5 and K-13 that are under the influence of the YD-3 drain.

Effects of unevenness of groundwater level and moisture storage after irrigation are more visible in cotton fields rather than in grain ones due to different depths and dates of irrigation. The irrigation depths are generally 15-20% higher for cotton than those for grains and vary within 1100 - 1470 m^3/ha (in 2002, more than 2000 m^3/ha). Out of 9 grain fields in 2002, only fields № 1 and № 11 were sown with a double crop such as maize for silage. As a whole, quite complex interaction among the infiltrated irrigation water, the groundwater and drainage is observed in drain spacing. The Figures 4 and 5 show, this behaviour depends on the degree of coverage of the whole drain spacing with irrigation and on water application time.

Fluctuation of “groundwater mound” and groundwater level reaches maximum in July-August, when the irrigation amount continuously increases and fraction of surface, between drains, covered with irrigation rises IAC[2] from 0.25 to 0.45 in average, reaching a maximum of 0.8 in early August and then dropping to 0.4 in October, even though its duration being more than half-month in the latter case. Since the major cause of abrupt groundwater rise is infiltration occurred during irrigation, the measures undertaken to reduce inequalities in moisture stock should be dealt with deep percolation control through an appropriate selection of irrigation technique components and, mainly, by controlling in irrigation depths.

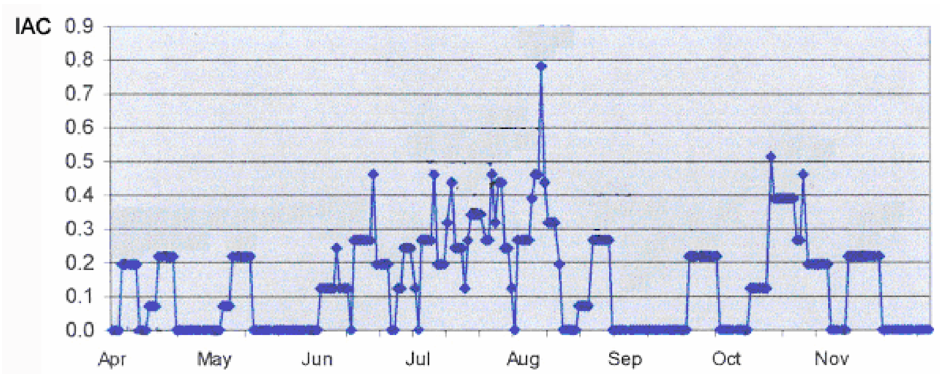

Fig. 4. Daily dynamics of the irrigated area coefficient (IAC) for the UD-3 drained area (2001).

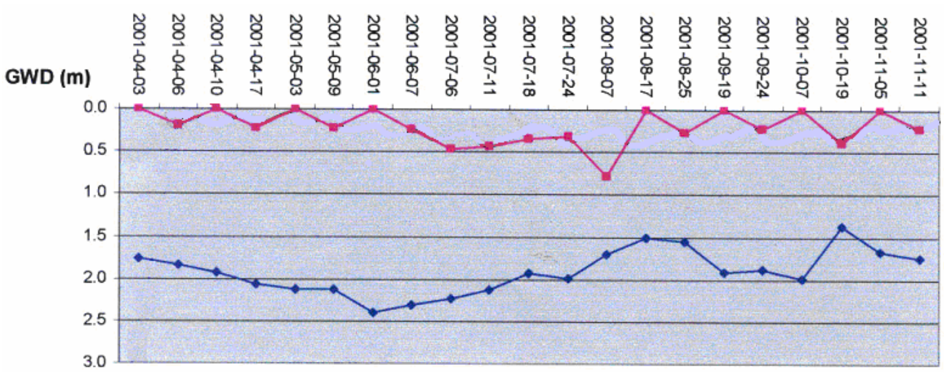

Fig. 5. Dynamics of the groundwater depth (GWD) and irrigated area coefficient (IAC) for the UD-3 drained area (2001).

[2] IAC is daily rate of irrigation area covered with each day irrigation.

However, given the irrigation methods and techniques practiced in Central Asia, it is practically impossible to achieve such optimal control. The groundwater mound is formed during application of water in growing season. This slow rise of groundwater depends on a share of infiltration recharge which was not drained. The larger is the surface covered with irrigation, higher increases the groundwater level due to the non-drainage share of infiltration.

Dispersion of the groundwater mound takes place due to interrelation among intensity of irrigation, capacity of drainage and outflow outside the boundaries of daily irrigated plots. In addition, the «reduction» of a share of the mound creates an additional drainage load since drainage capacity is based on diversion of the average annual infiltration recharge. In this context, in order to control infiltration in light of "mound" occurred after each irrigation event, it is necessary to estimate the irrigation depth contribution to total evaporation, capillary flow to groundwater, drainage and outflow towards non-irrigated plots (dispersion).

Such division of irrigation depths into the above-mentioned elements, of aeration zone water balance (Table 4), shows that:

- total evaporation is 34 to 39% of the irrigation depth;
- contribution to moisture stock in the rooting zone is 36 to 46%;
- capillary flow to groundwater and groundwater mound dispersion is 9 to 25%;
- 2-4 to 12% is drained by drainage as additional load, i.e. in addition to drainage capacity.

Based on observations, the relationship between the drainage modulus and the degree of simultaneous irrigation in between drains was obtained (Fig. 4 and 5). Simultaneous irrigation on more than 50% of drain spacing briefly increases drainage modulus twice as much during a short-term, while when water is simultaneously applied to less than 20% of this space, the drainage modulus decreases by 30…40% of the designed one. This analysis shows that formation of groundwater mound has small effect, in terms of volume, on drainage flow but it can be increased twofold regarding short-term increase in drainage modulus. This is particularly visible during leaching and should be considered while designing drainage and selecting optimal irrigation regimes.

Table 4. Estimation of distribution of water applied to the field.

Irrigation number		GW level, m			Estimation parameters			W_r	W_{kk}	Water yield, μ	GW rise $h=\frac{W_{kk}}{\mu.10^3}$
		before irrigation	after irrigation	Dif.	ET+ΔET	Q+Δq	H_{fsd}				
1.	1	2.55	1.82	0.73	492	52	1.15	518	349	0.048	
2-7.06	2	2.48	1.8	0.68	(35%)	(4%)	1.08	(36%)	(25%)	0.05	
m=1411	3	2.54	1.7	0.89			1.19				
(100%)				0.77			1.14			0.05	0.70
2.	1	2.59	1.89	0.7	430	28	1.19	658	311	0.044	
23-30.06	2	2.,5	1.78	0.73	(30%)	(2%)	1.10	(46%)	(22%)	0.043	
m=1427	3	2.48	2.07	0.41			1.08			0.076	
(100%)				0.61			1.12			0.054	0.60
4.	1	2.17	1.95	0.22	455.4	132.6	0.77	470	106	0.048	
25-29.07	2	2.15	1.94	0.21	(39%)	(12%)	0.75	(40%)	(9%)	0.050	
m=1164	3	2.11	1.88	0.23			0.71			0.046	
(100%)				0.22						0.048	0.22
5.	1	2.16	1.84	0.32	376	106	0.76	430	210	0.06	
7-11.08	2	2.12	1.81	0.32	(34%)	(9%)	0.72	(38%)	(19%)	0.068	
m=1122	3	2.11	1.65	0.46			0.71			0.046	
(100%)				0.36						0.06	0.35

Note: Estimations for 3rd irrigation are not given.

1., 2., 4., 5.: number of irrigation events; next line after number of irrigation event: date of irrigation (DD/MM); m: irrigation depth, m^3/ha; 100%: % of irrigation depth; ET: mean 10-day cumulative evaporation, mm; ΔET: excess of cumulative evaporation in period of irrigation over its mean 10-day value, m^3/ha; Q: mean 10-day drainage discharge modulus minus upward flux, m^3/ha; Δq: increase in drainage discharge modulus through capillary upward flow, m^3/ha; H_{fsd}: free space depth, i.e. distance between GWT and the soil surface, m; W_r: soil moisture recharge in aeration zone up to FC; W_{kk}: groundwater capillary flow ; μ: unit fraction

Conclusions

When estimating the interactions between irrigation and drainage, which are subjected to the selected reclamation regime and its parameters, one should consider that both the irrigation modulus and its infiltration share; particularly, the relationship between the capillary rise and drainage depth determines total water inputs for irrigation and drainage. Hence, the optimal reclamation regime should agree with all these parameters and water-salt balance components, particularly with the ground and irrigation water salinity ones.

The second, very important feature of surface irrigation and drainage combination is the inequality of spatial infiltration, which is subjected to both irrigation technique parameters (Horst *et al.*, 2005) and intensity of simultaneous water application to drain spacing – the infiltration recharge coefficient in spatial dimension, and to groundwater mound formation under the depression curves influence.

Nevertheless, even though formation of such groundwater mounds increases the required design drainage modulus, they create a certain reserve in terms of drainage outflow intensity through up to 25% dispersion of groundwater mound.

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