DRAINAGE OF IRRIGATED LAND

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Contents

Summary

Theoretical and practical questions concerning drainage of irrigated land are considered. The main causes of inundation and secondary salinization are discussed, and calculations are presented for rise of groundwater level and accumulation of toxic salts on irrigated land. Information on soil salinity types and their effect on growth and development of crops are summarized. Calculations are presented for assessment of the need for drainage on irrigated land, for both horizontal and vertical drainage, and their parameters. The final section provides information on biological drainage, including its construction and disposition schemes, as well as its efficiency.

1. Inundation and salinity of irrigated land

Land irrigation as mean of agricultural intensification was important as long ago as the third and fourth centuries B.C. At that time, there were complex and effective irrigation systems in many countries (e.g. Mesopotamia, Egypt, India, etc.).

At the same time, history knows many cases where large areas of irrigated land became worthless as a result of radical change of hydrological and geochemical conditions, and land salinity. Prevention and struggle against these phenomena, in spite of centuries-old experience, was only achieved in our time. According to the Wyoming Experimental Station and the US Bureau of Drainage Research, even in the earliest days of drainage development in the western states of USA, there were serious complications connected

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with land inundation and salinity. Also, the emphasis was put on raising the level of groundwater, even where it was relatively deep (≥ 10-20 m). This report relates to 1908-1909 but in 1944, according to the Department of Agriculture, as a result of inundation and salinization more than 100 000 ha of irrigated land was removed from agriculture. Disastrous over-inundation and salinization of irrigated land has occurred in other countries of Europe, Asia and Africa.

Inundation of irrigated lands is linked with rise of groundwater level, following soil over-moisturing and intensive evaporation. The value of the level may be determined by means of critical bedding depth (Δ_{cr})

$$\Delta_{cr} = 170 + 8t \pm 15 sm \qquad (1)$$

The evaporation from groundwaters surface with (Er) depending on bedding depth may be determined as

$$Er = E_0 \left(1 - \frac{\Delta}{\Delta_{cr}}\right)^n, mm \qquad (2)$$

where t is average annual air temperature, in ^oC; E_0 is evaporation from water surface, in mm; Δ is bedding depth of groundwaters, sm; n is exponent, n=1-2.

The main reasons for rise in groundwater level and inundation of irrigated land are filtration water losses from irrigation channels and water losses during watering (in a leaching regime).

The probability and timing of groundwater level rising to critical values and causing land inundation may be determined by means of long-time prognosis of groundwater dynamics, depending on hydrogeological conditions, methods and technology of land irrigation. The methods of groundwater dynamics calculation were based on solution of equations of unsteady water motion in grounds with different degrees of saturation.

For the easiest hydrogeological conditions, the calculation of groundwater level dynamics may be carried out by means of the following equations:

Flow scheme	**Calculation dependencies**
Unrestricted flow $x \to \pm\infty$	$\Delta = \frac{\omega t}{\mu}$ (3)
Band stratum	$\Delta_{(x)} = \frac{\omega t}{\mu} F\omega(\tau)$; with $x<\ell$ $F\omega(\tau) = [F\omega(\tau_1) + F\omega(\tau_2)]/2$ (4) with $x>\ell$ $F\omega(\tau) = [F\omega(\tau_1) - F\omega(\tau_2)]/2$

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	$? = \frac{\mathrm{HK}}{\mu_o}$; $\tau_1 = \frac{at}{(\ell + x)^2}$; $\tau_2 = \frac{at}{(\ell - x)^2}$;
Sem-irestricted stratum	$\Delta_{(x)} = \frac{\omega t}{\mu} F\omega(\lambda)$; (5) $\lambda = \frac{x}{2\sqrt{at}}$ $? = \frac{\mathrm{HK}}{\mu_o}$;

where Δ - rising of groundwaters level in a time t, m; t - time, days; ω - intensity of filtration load, m/day; $\Delta\omega = \Phi_K + \mathrm{g}$, Φ_K - filtration losses from irrigation channels.

$$\Phi_K = \frac{1-\eta}{\eta} O_p \tag{6}$$

η - coefficient of efficiency of irrigation channels system; O_p - net watering norm, mm; g - filtration water losses during watering (leaching regime), mm; μ - moisture shortage of aeration

zone grounds, in parts of volume; $F\omega(\tau)$ and $F\omega(\lambda)$ - functions whose values may be

found on Figures 1, 2 in dependence of values τ and λ ; ℓ - size of irrigated land, m; a - coefficient of stratum conductivity $\mathrm{a} = \frac{\mathrm{HK}}{\mu_O}$, sq.m/day; H - depth of water-bearing stratum, m; K - coefficient of hydraulic permeability with full saturation of water-bearing grounds, m/day; μ_O - coefficient of water-transfer, in parts of volume.

The literature contains the calculation methods Δ for lands of any configuration and size.

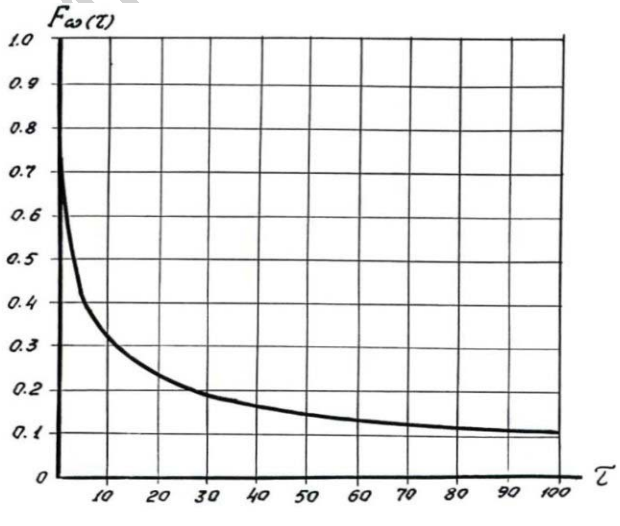

Figure1. Function $F\omega(\lambda)$

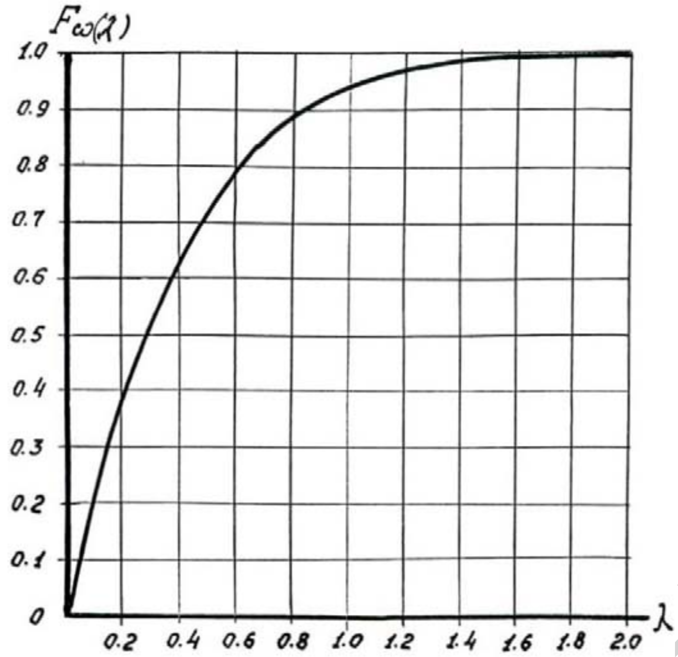

Figure 2. Function $F\omega(\tau)$

As a rule, prognoses are made for 5, 10 or 15 years. Simultaneously with prognosis of groundwater level change, prognosis can be made for mineralization and chemical composition change.

2. Reasons of secondary irrigated land salinity

Land salinity may be primary (natural) or secondary (technogenic). Naturally saline soils are those whose solid and liquid phases contain readily soluble salts in a concentration high enough to decrease soil fertility and negatively affect the growth and development of crops. Secondary saline soils are those where readily soluble salts have accumulated during irrigation. Without analyzing the existing water and salt regimes in the soil and forecasting possible changes in these regimes during irrigation, it is impossible to identify in advance land prone to secondary salinization. In general terms, lands liable to secondary salinization during irrigation are those where the soil, subsoil and groundwater contains readily soluble salts which may create toxic conditions for the crop during irrigation.

Methods for calculation of salt regime dynamics during irrigation are based on joint solution of equations of salt and water motion in soils, subsoil and groundwater, taking into account convective diffusion, salt dissolution in solid phase, and phenomena of ion exchange sorption.

Theory and practice of irrigation in different countries of the world show that secondary soil salinity depends on natural and economic factors including groundwater level and mineralization, value of watering norms, the technical condition of irrigation systems, methods and technology of crop watering, mineralization and chemical composition of irrigation water, and physical and chemical properties of soils. Accumulation of salts in

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soils with the above-mentioned factors (especially the presence of readily soluble salts in soil, subsoil and groundwater) can be expressed by the following equation:

$$\overline{O}_p = \frac{O_p}{E - O_c} = \frac{1}{1 - \overline{C}_n}\left(\frac{\overline{C}_r - 1}{\overline{\Delta}} + 1\right) \qquad (7)$$

where O_p - watering net norm, mm; E and O_c - evaporation and precipitation, mm; $\overline{C}_n = \frac{C_n}{C}$, C_n - mineralization of irrigation water, g/l; C - permissible content of salts in a soil solution (threshold of salt resistibility), g/l; $\overline{C}_r = \frac{C_r}{C}$, C_r - groundwaters mineralization, g/l;

$\overline{\Delta} = \frac{\Delta}{\lambda_0 \cdot \mathrm{m}}$, Δ - bedding depth of groundwaters level, m; λ_0 - parameter of hydrodynamic dispersion, m; m - soil porosity, in parts of volume.

Equation (7) permits detection of the main causes of secondary salinity and its causative factors.

If the irrigation system uses fresh water ($C_n = 0$) and there are no readily soluble salts in the subsoil and groundwater ($C_r = 0$), secondary salinization of irrigated land is excluded. These conditions may be observed in Mongolia where irrigation systems are used with relatively fresh water and subsoils are not saline. If irrigation water contains salts ($C_n > 0$) and mineralized groundwater ($C_r > 0$) lies at a good depth ($\Delta > \Delta_{cr}$), the main cause of secondary salinity may be accumulation of salts from irrigation water. With $C_n > 0$, $C_r > 0$ and $\Delta \leq \Delta_{cr}$, that is with a high level of mineralized groundwater, the main causes of secondary salinity are salt accumulation from irrigation and groundwater.

3. Soil salinity types

Saline soils are found mainly in arid regions. The general area of saline soils, as a percentage of the arid land, is as follows: in Europe and Asia 20%, Africa 6%, North America 3%, South America 35%, and Australia 57%.

Among saline soils there are those containing salts in the upper layer (0-100 cm); badly salined areas where salts are present in in the 100-200 cm layer, and potentially saline areas where salts may be found in underlying strata (within the aerated zone) or in groundwater.

Besides the depth of the salt horizon, salined soils can be categorized by salinity degree,

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salt composition and their distribution in salt profile.

Salt composition may be estimated by ion correlation, salinity degree (as total or toxic salts), or content of particular ions. For categorizing soils by salinity degree, data from water extraction analysis $S_{BB}(1:5)$, as a percentage per 100 g of soil, mg.eqv for 100 g of soil, or data from electroconductivity of past extraction EC_{ℓ}, in msm/sm, are applied.

The conversion of conductivity from pastes data (EC_{ℓ}, msm/sm) into water extraction data (S_{BB},%), with soil moisture equal to minimum water capacity, will be done by means of the dependence

$$S_{BB} = \frac{2K \cdot EC_{\ell} \cdot MWC}{10 \cdot \gamma} \tag{8}$$

where S_{BB} - salt containing in soils, %; K - conversion coefficient, msm/sm to g/l (with $EC_{\ell} \leq 5$msm/sm K=0.64, with $EC_{\ell}>5$ msm/sm K=0.80); MWC – minimum water capacity, in parts of volume; γ - soil density, g/sm^3.

Soil salinity degree	Salinity chemism (ion correlation, mg.eqv./100 g of soil)					
	Neutral salinity (pH<8.5)			Alkaline salinity (pH>8.5)		
	Chloride, sulphate-chloride $Cl:SO_4>1$	Chloride-sulphate $Cl:SO_4=1-0.2$	Sulphate $Cl:SO_4<0.2$	Chloride-sodium and sodium-chloride $Cl:SO_4>1$, $HCO_3>(Ca+Mg)$, $HCO_3>Cl$	Sulphate-sodium and sodium-sulphate $Cl:SO_4<1$, $HCO_3>(Ca+Mg)$, $HCO_3>Cl$	Sulphate-chloride-carbonate $HCO_3>Cl$, $HCO_3>SO_4$, $HCO_3<(Ca+Mg)$
Soil toxicity threshold (non-salined soils)	$\frac{0.05^{*)}}{<1}$	$\frac{<0.1}{<2}$	$\frac{<0.15}{<3}$	$\frac{<0.1}{<2}$	$\frac{<0.15}{<3}$	$\frac{<0.15}{<3}$
Small	$\frac{0.05\text{ to }0.12}{1\text{ to }4}$	$\frac{0.1\text{ to }0.25}{2\text{ to }6}$	$\frac{0.15\text{ to }0.3}{3\text{ to }7}$	$\frac{0.1\text{ to }0.15}{2\text{ to }6}$	$\frac{0.15\text{ to }0.25}{3\text{ to }6}$	$\frac{0.15\text{ to }0.3}{3\text{ to }7}$
Medium	$\frac{0.12\text{ to }0.35}{4\text{ to }8}$	$\frac{0.25\text{ to }0.5}{6\text{ to }10}$	$\frac{0.3\text{ to }0.6}{7\text{ to }13}$	$\frac{0.15\text{ to }0.3}{6\text{ to }7}$	$\frac{0.25\text{ to }0.4}{6\text{ to }9}$	$\frac{0.3\text{ to }0.5}{7\text{ to }10}$
Strong	$\frac{0.35\text{ to }0.7}{8\text{ to }16}$	$\frac{0.5\text{ to }1.0}{10\text{ to }20}$	$\frac{0.6\text{ to }1.5}{13\text{ to }30}$	$\frac{0.3\text{ to }0.5}{7\text{ to }10}$	$\frac{0.4\text{ to }0.6}{9\text{ to }13}$	Not occur
Very strong	$\frac{>0.7}{>16}$	$\frac{>1.0}{>20}$	$\frac{>1.5}{>30}$	$\frac{>0.5}{>10}$	$\frac{>0.6}{>13}$	-

*) Numerator is a sum of toxic salts in soil (S_{BB}), in %; denominator is electroconductivity of pastes extraction ($EC\ell$), msm/sm.

Table 1.Soil classification by degree and type of salinity

The criteria of soil characterization by salinity degree and salt composition, obtained by means of analysis of water extraction (1:5) and extraction from pastes, are listed in

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Table 1.

The soil salinity type may be determined in dependence on ion correlation in water extraction (S_{BB}), (see Table 1).

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Bibliography

Agricultural Salinity Assessment and Management, 1990, 130 p. [In this article the limits of water and salt regimes control on irrigated land are presented].

Aidarov I.P., Golovanov A.I., Nickolsky Y.N. (1990). Optimization of irrigated and drained agricultural lands ameliorative regimes. Moscow.Agropromizdat, 58 p.(In Russian). [Criteria, models and technigue of water, salt and nutricut regimes optimisation on irrigated and drained soils].

Averjanov S.F. (1978). Struggle against irrigated lands salinity. Moscow. Colos, 265 p.(In Russian). [Theoretical basis for water and salt regimes control on irrigated lands].

Backstrom T.E. and L.J.Reid (Ed.) (1990). Controlling Toxic Substances in Agriculture Drainage: Emerging Technologies and Research Needs. Publ. Us. Comm. On Irrig. and Drain., 149 p.[Toxic substances supervision in farm lands: needed technologies and investigations].

Bresler A., Maklin B.L., Carter D.L. Salined soil. (1968). Experience of soil salinization classification soil science, № 11.[Saline and sodic soils diagnostics and their properties, theory and simulation of salt movement in soil saline and sodic soils reclamation].

Salvatore Ciriacono (Ed.) (1999). Land Drainage and Irrigation (Studies in History of Civil Engineering, v.3).[Drainage and irrigation of land].

De Leon M.F.B., Fuentes C.R. et al. (1998). Manual de Diseno e Instalacion de Drenaje Parcelario en Zonas Aridas y Semiaridas bajo Riego. Ed. CNAIMTA, 72 p. (In spanish).[Guide on drainage in arid and semiarid zones].

Drainage Design and Management: Proceedings (1988). Publ. Am.Soc.Agric.Engin., 440 p.[Guide on drainage planning].

Dregne H.E. (1976). Soil of Arid regions, Amsterdam, 70 p.[Soil characteristic of arid regions is given].

Luthin J. (1957). Drainage of agricultural lands, California, 670 p.[Theory and practice of agricultural land drainage are examined].

G.Le Maigue. (1992). Developing and Improving of Irrigation and Drainage Systems: Selected Papers from World Bank Seminars (World Bank Technical Paper, No. 178).[Program of irrigation and drainage systems development and improvement is given].

Pankova E.I., Basilevich N.I. (1968). Experience of soil salinization slassification soil science, № 11. (In Russion). [Soil classification on salinity type and degree].

Ritzema H.P., et al. (1996). Drainage of Irrigated Lands: A Manual (Irrigation Water Management. Training Manual, No 9). [Practical guide on irrigation and dainage].

Shestakov V.M. (1965). Theoretical essentials of head, water level decreasing and drainage estimation., M. MSUEE, 220 p. (In Russian). [Theoretical basis and calculation procedures for undergraund water filtration, hydrological design of inlet and drainage structures].

Singh N.T., Tomar O.S. (1993). Agroforestry in salt affected soil bulletin 17, Central soil salinity research institute. Karnal - 132001. India, 59 p.[Agroforestry recomendations].

Szabolcs I. Salts-affected soil. (1989). Pr. In the US by Press Inc., 274 p.[Saline soils characteristic is shown].

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