DRAINAGE FLOW HARVESTING AND ITS ON-FARM RE-USING IN LOCAL IRRIGATED PLOTS

L'UTILISATION REITERATIVE DE L'ECOULEMENT DE DRAINAGE POUR LES TERRAINS IRRIGUES LOCALES

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Abstract

Key words: drainage flow harvesting, re-using, purification, storage pond, sorbing materials, water balance

Social and political reforms ("perestroika") taken place in Russia in the 90s of the last century activated agrarian sector revisions. Besides large-scale agricultural enterprises many small farms with different types of landed property were established in Russia. Nowadays small farms represent about 90% of all agricultural enterprises. Large-scale irrigation projects having been built to water large fields are operated in the conditions of combined state and private landed property within the same irrigation scheme. Integrated approach in irrigation management for such irrigation units supposes high effectiveness of water use.

Such an approach providing high water productivity and big crops for arid areas is on-farm drainage flow recycling within the separate farm on the base of the common water-use for irrigation purposes. Type of drainage, filters, drain spacing and drain depth depend on requirements and special features of drainage flow-recycling structures.

An approach on drainage flow local recycling structures design providing drainage flow harvesting and conditioning is proposed in the paper. The essential constituents of the drainage flow local recycling structures are units on drainage flow desalting and purification. It enables to use treated drainage flow for irrigation in some periods of crop cultivation as well as for other purposes.

The developed approach requires construction of ponds -accumulators for drainage flow harvesting. Estimations of the required capacity of ponds –accumulators, engineering solutions on drainage flow conditioning and its reusing for local plot irrigation as well as evaporation losses reduction are considered in the paper. Estimation of the required dilution taking into consideration both drainage flow re-using and pond ephtraphication prevention is implemented in the paper. Some environmental and economics estimations are carried out.

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Résumé et conclusion

C'est connu que l'écoulement de drainage est la suite negative du fonctionnement des systèmes de drainage. D'une part il pollue des eaux de surface, d'autre part il peut être le source supplémentaire d'eau d'irrigation à la préparation correspondante. Environ 5 km^3/an des eaux de drainage d'évacuation se forme à la Russie. Pour les les petits terrains irrigués il est rationnel d'accumuler des eaux de drainage, les épurer de pollution et les utiliser réitérativement pour l'irrigation ou pour les autres buts. Cela nous donne la possibilité d'améliorer le régime d'eau du terrain, de conserver la situation écologique favorable et d'économiser des ressources en eau. En outre la particularité du régime hydrodynamique et hydrochimique exige l'approche locale à l'installation des systèmes de drainage. Sur les petits terrains de 10 à 100 ha on recommande de créer les systèmes de la rotation d'eau qui garantissent le réglage du volume et de la qualité des eaux de drainage pour l'irrigation ou pour les autres buts. Pour cela il est nécessaire d'amasser l'écoulement de drainage et de créer des bassins du réglage de saison ou des capacités en dependence de son volume et de sa minéralisation et du volume d'eau douce pour sa dilution. La relation entre le volume d'eau douce et d'eau de drainage (au mélange) se compose:

$$D=(C_{dr.}-C_{ir}):(C_{ir}-C_{pure}),$$

où $C_{dr.}$- la minéralisation d'eau de drainage, C_{ir} - la minéralisation d'eau, qu'on doit recevoir apré la dilution, C_{pure} - la minéralisation d'eau au mélange.

S'il y a de pollution aux eaux de drainage on fait le calcule suivant:

On fait le calcule du bassin du réglage de saison au base des relations entre les eaux de drainage et les eaux naturels.

Il faut prendre en consideration que le volume d'eau douce est limité à cause du déficit des resource en eau. C'est pourquoi on recommande de créer des installations technologiques pour la demineralization partielle et le nettoyage des eaux de drainage des pollutions. Cet article propose des solutions techniques assez simples et accessibles. Si la minéralisation des eaux de drainage est à 3 g/l on recommande d'utiliser des sorbents naturels ou modifiés avec beaucoup de calcium. Cela nous assure le nettoyage de l'écoulement de drainage et l'amélioration de relation entre les ions de calcium et natron dans l'eau préparé. Il faut placer les sorbents granulés dans des boîtes spésiales qu'on dispose dans le réservoir de l'écoulement de drainage. Nous avons élaboré et éprouvé des sorbents à la base des matériaux naturels (gyttja).

Si la minéralisation est de 3 à 10 g/l on recommande d'utiliser des installations d'électrodialyse avec la productivité 20 c/v.

On propose le methode d'échange ionique pour les conditions du grand deficit des resource en eau et de la minéralisation plus que 10 g/l. Nous avons élaboré la technologie qui permet de desaler l'écoulement de drainage sur le système en faisant l'eau laisser passer à travers les filtres d'échange ionique. Au cours de la demineralisation il n'y a pas aucuns déchets outre des ionits travaillés qu'on dirige pour la régénération. Le processus de la régénération se réalise dans le régime écologique pure sans aucuns écoulements.

Les recherches de VNIIGiM de la desalinisation de l'écoulement de drainage avaient lieu sur le système Pallasovskaya à la règion de Volgograd. L'eau de drainage avec la minéralization 17 g/l avais la minéralization moins que 0,3 g/l après la filtration à travers le cationit KU-2x8 et anionit AN-511. Pendant les 100 cycles de «dessalement – régénération» la capacitè d'échange ionique n'a pas changé pratiquement, cela témoigne de la solidité suffisante du moyen proposé. Ce que limite l'utilisation de cette technologie – c'est la necessité de créer des enterprises pour la régénération des ionits qu'on doit remplacer périodiquement.

Ainsi dans les conditions des economies avec des petits terrains et de deficit des resource en eau ou du manque de la possibilité d'évacuation des eaux de drainage sans dommage pour l'environnement on propose des systèmes d'irrigation et de drainage locales de la rotation d'eau qui possédent des réservoirs des eaux de drainage d'évacuation et des installations technologiques pour la demineralisation et de nettoyage d'écoulement de drainage. En dépendance du volume et de la qualité de l'écoulement de drainage on utilise des méthods de la préparation d'eau differentes: la dilution par l'eau naturel, le nettoyage et la desalinisation partielle en utilisant des sorbents, les installations d'électrodialyse et l'échange ionique. L'eau nettoyé et desaliné se conditione et s'utilise pour l'irrigation. En même temps on économise jusqu'à 15-20% d'eau natutel et assure l'intégrité de l'environnement.

Introduction

In the 90s last century the land reform was implemented in Russia. Socio-economic obstacles of the transition period provoked continuous economic crisis both in Russian agriculture and in land reclamation. Decentralization was being accompanied by financing reduction in agriculture and reclamation projects. Only large hydraulic structures and reclamation projects are financed from the state budget. On-farm reclamation network is in the use of regions and separate farms now which are not ready to provide its efficient operation and maintenance.

Due the above transformations in the agrarian sector of economy small farms are predominant in Russia now resulted in reduction of both cash crops productivity and water use efficiency within irrigation projects.

Large irrigation projects are being operated in the terms of combined state and private landed property within the same irrigation scheme causing difficulties in water allocation and waste water discharge being resulted in environmental issues. Therefore water saving technologies are both environmentally efficient and economically feasible for the small estate farmers in the south of Russia.

One of the water saving approaches is irrigation return water and rain water harvesting within the small farms for its subsequent on-farm using. However irrigation return waters are often mineralized and polluted with heavy metals which constrain their re-using for irrigation and other domestic purposes. Therefore technological unites on irrigation return water purification and conditioning is recommended to create in the accumulation tanks (ponds-accumulators) [1].

To prevent water evaporation and seepage it is rational to construct tanks equipped with cover and watertight bottom. Storage pond is recommended to design as a two section structure having overflow weir filled with grained sorbing material or gabions containing grained sorbets.

In the case of irrigation return water mineralization exceeds 10 mg/l ion exchange unite is requited to be installed in the storage pond.

To prevent water eutrophication in the pond the extra dilution is provided using the following relation:

$$\mathbf{V_{del\ pond} = V_{live\ storage} * K_{del}} \quad , \qquad (1)$$

где $V_{del\ pond}$ - volume of natural water required for return irrigation water dilution in the pond to prevent eutrophication; K_{del} – coefficient of required dilution; $V_{live\ storage}$ – live storage.

There are the following limitations at storage pond designing: pond depth is not less than 2 -2,5 m to prevent plant overgrowth and to minimize evaporation losses; pond should not be deeper than 3,5 m to minimize excavation, to prevent drainage network disruption and to facilitate silt removing at pond operation. Dead storage should provide appropriate sanitary state of the storage pond. Live storage capacity is determined using irrigation return water pattern.

1. Drainage flow composition and storage pond parameters for the Pallasovskaya irrigation project

Storage pond capacity was determined for the Pallasovskaya irrigation project (state farm Revput) which is located in the Volgograd region in the south of Russia. Irrigated project area is 213 hectares. Crops are cultivated in the extreme dry conditions (annual precipitations value is less than 200 mm), soils being poor too. Plenty of sun and high temperatures allow obtaining big crops of high-quality vegetables, melons and gourds in this region under irrigation.

To prevent soil salinity drainage's been constructed in the Pallasovskaya irrigation project. Drain depth is 3-3,5 m, drain space is 120m. Drainage flow has sulfate-natrium mineralization - 11…17 g/l, pH 8,5. It is polluted with fertilizers residues and pesticides (Table 1, 2). Overflow water pollution exceeds maximum permissible concentration (MPC), overflow water mineralization varies from 3 to 3,5 g/l. Overflow water is mixed with drainage flow (irrigation return water) in the main drain at the ratio 1:1, so the mean mineralization does not exceed 8,5 g/l.

Table 1. Drainage flow composition for the local irrigation plot "Revput" of the Pallasovskaya irrigation project (Volgogradsyy region) (g/l).

La table 1. La composition de l'écoulement de drainage pour le terrain locale d'irrigation « Revput » du système d'irrigation Pallasovsky (Volgogradsky région) (g/l).

Composition	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	$Na^+ + K^+$	Mineralization (g/l)
Drainage flow (irrigation return water) (mean values)	0,347	2,502	5,912	0,474	0,730	2,658	12,625

Table 2. Fertilizers residues and heavy metals content (mg/l) in drainage flow (irrigation return water) for Pallasovskaya irrigation project (VNIIGiM data).

La table 2. Le contenu du reste des engrais (mg/l) et des métaux lourds (mg /l) dans l'écoulement de drainage des terrains irrigués du système d'irrigation Pallasovsky (les données de VNIIGiM).

Sampling point	$N\text{-}NO_3$	P_2O_5	Zn	Cu	Pb	Cd	Mn	Fe
Drain	9,74	1,94	0,0016	0,0045	0.1875	0,0008	0,0163	0,0764
Main drain	10,18	2,1	0,0026	0,0045	0,0938	0,0023	0,0204	-
MPC	9,1	0,3	0,010	0,001	0,006	0,005	0,010	0,100

To provide sustainable crop yields in the water shortage circumstances it is advisable to harvest and storage irrigation return and overflow water and re-use it for vegetables, melons and gourds irrigation during dry periods. Since shallow water table (up to 2, 5 m) storage pond is recommended to construct with concrete lining using watertight films to prevent water seepage to the aquifer.

Mean drainage flow rate during the vegetation period is 0,05 l/s*hectare.

Local irrigated plot area is 213 hectares. Drainage flow is discharged to the main drain GK-2. Drainage flow coming from the irrigated plot during the first month of the irrigation period equals:

$$V_{dr} = 0{,}05*213*2{,}59 = 0{,}027 \text{ mln. } m^3$$

Dead storage preventing frost penetration and overheating of the pond is:

$$V_{d.s.} = 0{,}0027 \text{ mln. } m^3$$

Alfalfa irrigation rate in the Pallasovskaya irrigation project equals 1200-1300 m^3/hectare. To irrigate the total area where alfalfa is planted it is required 0,27 mln m^3. Part of irrigation water is taken from the storage pond:

$$V_{ir.dr}=0,027-0,\ 0027=0,0243 \text{ mln. } m^3,$$

which consists 9% of the total water supply for irrigation.
To prevent pond's eutrophication the required dilution is calculated taking into account the limiting pollution index ($K_{l.p.}$):

$$W_{dil.} = W_{dr.flow} \cdot K_{l.p.},\ mln.m^3 \qquad (2)$$

where: $K_{l.p.}$ – index taking into account the maximum required dilution factor depending on pollutants concentration in the drainage flow.

The limiting pollution index is determined using the following equation:

$$К_{пз} = \frac{1}{n}\sum_{j=1}^{n}\frac{C_j}{ПДК_j} - 1 \qquad (3)$$

where: C_j – pollutant concentration in the drainage flow (irrigation return waters), mg/l; MPC_j – maximum permissible concentration of the number j pollutant mg/l; n – amount of pollutants taking into account at water pollution estimation.

The limiting pollution index calculation for the drainage water coming from the irrigated local plot "Revput" is shown in the table 3.

Table 3. Limiting pollution index values.
La table 3. Les dimensions des indices de la pollution des eaux maximum.

Pollutants	$C_{вв}$, mg/l	ПДК, mg/l	$K_{l.p.i}$
P_2O_5	2,1	0,3	2,5
$N\text{-}NO_3$	10,18	9,1	-0,44

As it is shown in the table it is necessary to provide drainage flow dilution due to high phosphate concentration, whereas we shouldn't take into account nitrate pollution since $K_{l.p.i}(N\text{-}NO_3)$ is negative (-0,44).

Taking into account the required dilution the storage pond capacity is:

$$V_{live\ storage} = V_{live\ storage} * K_{l.p.} = 0,027*2,5=0,068 \text{ mln. } m^3$$

In that way, having been diluted water mineralization in the pond will be reduced up to 5,2 g/l. In order to use water for irrigation of forage crops (in particular alfalfa) it's required to dilute the storage drainage flow up to 4-6 g/l. Research investigation and irrigation practice have proved the environmental safety and economic advisability of alfalfa irrigation using mineralized water in the semi-desert soils. Using the mentioned recommendations to provide storage water mineralization up to 5 g/l it is required to supply 0,004 mln. m^3 of natural water having mineralization up to 1 g/l to the pond.

Natural water required for storage water dilution is:

$$V_{dilution} = V_{live\ storage}*D= 0,068*0,076=0,005 \text{ mln. } m^3$$

$$D= (Cdr.f-Cir): (Cir-Cnatural),$$

$$D = \frac{5,2 - 4,9}{4,9 - 1} = 0,076$$

Storage pond capacity taking into account the required mineralized water dilution with natural water is determined as:

$$V_{live\ storage}= V_{live\ storage}+ V_{dilution}=0,068+0,005=0,073 \text{ mln. } m^3$$

Pond capacity:

$$V_{pond}= V_{live\ storage}+V_{dead\ storage}= 0,073+0,0027=0,0757 \text{ mln. } m^3$$

Storage water having been prepared for irrigation has mineralization 4,9 g/l which allows its using for irrigation purposes in the dry periods.

2. Materials and techniques for drainage flow purification and conditioning

To remove heavy metals and to provide storage water conditioning it is recommended to use grained sorbing materials having been developed in VNIIGiM on the base of natural carbonate sapropel: SORBEX, SAPROPEL-active, SAPRILEN. Sorbing properties of these sorbents are given in the table 4.

Table 4. Sorbing properties of sapropel and sapropel-based sorbing materials (SEC*, mg/g – numerator; AR% - denominator). [2]
La table 4. Les caractéristiques de sorption de gyttja et des sorbents sur sa base.

Pollutant	Grained sapropel	SORBEX	SAPROLEN	SAPROPEL -active
ПАВ	0,44/88	0,47/95	0,29/58	0,49/98
Zn	2,25/85	2,58/98	-/91	1,25/97
Cu	0,87/95	0,85/92	-/87	0,43/95
Pb	0,70/89	0,74/94	-/87	0,35/97

Comment * SEC– static exchange capacity,**AR- absorption ratio
Sorbent amount which is required to absorb heavy metals containing in drainage flow is determined as:

$$G_{sorb}. = \sum \left(C_{dri} - ПДК_i \right) \cdot V \cdot 10^3, кг \quad (4)$$

where:
C_{dri} – concentration of pollutant i in drainage flow, mg/l; MPC_i – maximum permissible concentration of pollutant i (fishery water use category), mg/l; V – drainage flow volume, m^3.

SORBEX amount required for lead and copper absorbing from drainage flow is calculated (as heavy metal being accumulated in the crops):

$$G_{Sorbex} = ((0{,}1875 - 0{,}006) + (0{,}0045 - 0{,}001)) \cdot (21000 - 2100) \cdot 10^{-3}$$
$$= (0{,}1815 + 0{,}0035) \cdot 18900 = 3{,}5кг$$

Absorption capacity of the grained sorbing material Sorbex: S=256 mg- equivalent/100g; its bulk density is 0,7–0,8 t/m^3.
The results of sorbing materials investigations allow to characterize their efficiency at copper absorbing: SEC of sapropel – 0,87 mg/g, SEC of «SORBEX» – 0,85 mg/g; absorption ratio is 95% and 92% correspondently. Taking into account the inaccuracy of measurements, it can be stated that sorbing materials have the similar efficiency at absorption of copper. Lead adsorption occurs at the rate of 0,7 mg/g in sapropel and at the rate of 0,74 mg/g in SORBEX. Absorption ratio is 89% and 94% correspondently.
The required SORBEX amount in the filtering weir of the storage pond is:

$$G_S = \frac{G}{S} = \frac{3{,}5 \cdot 10^5}{256} = 1367kg = 1{,}4t \qquad (5)$$

It is required 28 bags (weight 50kg apiece) of sorbing material SORBEX. The replacement period is 1 year. The scheme of the storage pond provided with the local technological unites for drainage flow purification is shown on the figure 1.

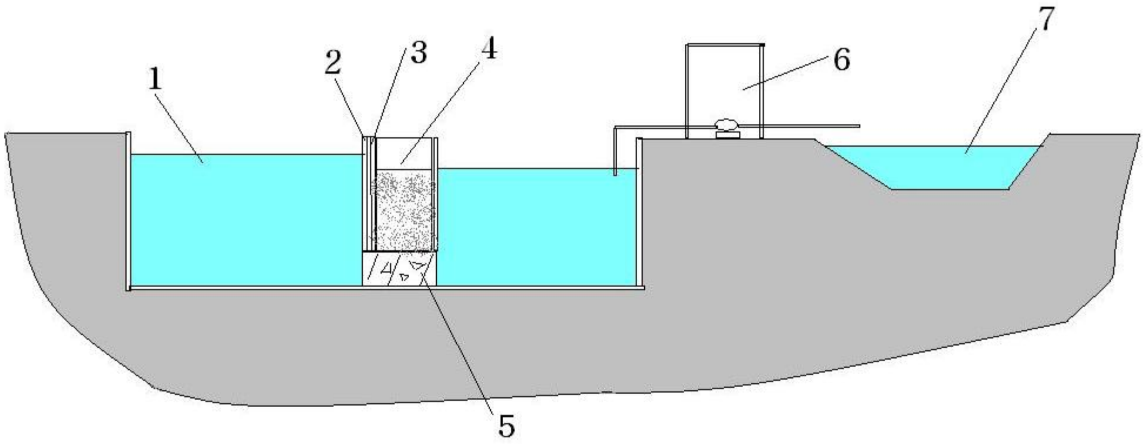

Figure 1. The scheme of the storage pond provided with the local technological unite for drainage flow purification from heavy metals.
Le dessin 1. Le schéma d’étang d’accumulation des eaux de drainage avec le système technologique pour le nettoyage des eaux.
1- section of the pond, containing polluted drainage flow (irrigation return water); 2- cage of filtering-absorbing unite; 3- coarse filter; 4- grained sorbing material; 5 – watertight partition; 6 – pumping station ; 7 – irrigation canal.

Filtering through natural carbonate sapropel provides drainage flow purification from heavy metals, pesticides and other pollutants as well as calcium ion application during irrigation which prevents soil alkalinization.

Under water shortage conditions when it is insufficient natural water requiring for drainage flow dilution it is recommended to use water demineralization techniques. Research was carried out in VNIIGiM together with Moscow State University by the name of Lomonosov in Pallasovskaya irrigation project concerning cation(-exchange) KU-2x8 and anion(-exchange)AN-511 application for irrigation return water demineralization. During irrigation return water filtration though ion-exchange filters its mineralization was reduced from 17 g/l to 0,3 g/l. Thus the additional demineralization units filled with cations and anions can be installed into the storage pond.

Conclusions

Specific character of the self-contained local systems determines parameters of drainage network and design of drains. Design of drains should provide high reliability of the drainage network which can be achieved by using plastics pipes with geotextile covering. It is essential to provide irrigation project with flow-regulating valves, water quality detectors, storage tank for drainage flow which is ready for re-using, pumping stations.

Hence in the local irrigation plots it is advisable to store drainage flow (irrigation return water), purify it from pollutants, dilute it with natural pure water, to provide its demineralization and reuse it for irrigation and other purposes. It will give us an opportunity to improve water balance of the area to safeguard beneficial environmental conditions and to save water resources of the territory.

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