MANAGEMENT OF THE IRRIGATION WATER IN SOUTH OF UKRAINE

Mykhailov Yu.1, Shevchenko A.2, Danylenko In.3, Liutnytskyi S.4

ABSTRACT

Ukraine has limited water resources and its spatial distribution is uneven. Considering regional displays of global climate change the questions of rational water use and integrated management of the available resources of surface and groundwater becomes more urgent.

An approach to integrated water resources management as the development and implementation of measures aimed at achieving "good" state of water for specific water bodies and improving quantitative characteristics of water use by fitting the current water balance of the area in accordance with target one is proposed in the paper. For these target values, the following are minimized: non-technologically-based water losses in irreversible water use, filtering and discharges; the volume of insufficiently treated wastewaters; total water intake to the needs of branches of the economy in the region under consideration.

Keywords: Irrigation, Water management, Water use, Agricultural crops.

1. INTRODUCTION

The main problems of water resources use in the south of Ukraine are its deficit and uncertainty of rainfall over space and time. Taking into account regional manifestations of global climate changes, particularly increase of its aridity and variability of weather, this issue become more escalate. More actual becomes the issue of water recourses rational use in agriculture, which is their main user (more than 80%). In turn, in agriculture, the biggest share of water is directed to the needs of irrigated agriculture.

The goal of sustainable water management is to achieve at particular territory the balance between water resources available for use and total water consumption for all needs, including irrigated agriculture. The environmental impact of water management and irrigation should be minimal.

Based on the fact that irrigated agriculture is a complex process of stochastic nature, the most appropriate measure is preventive management of water balance on irrigated lands, including water inflow to the system (Mesarovich & Takahara, 1978). To address this issue authors used the scenario approach, the essence of which is as follows.

1 Institute of Water Problems and Land Reclamation, Kyiv, Ukraine, Senior Specialist of investments activities, mihailov1333@gmail.com
2 Institute of Water Problems and Land Reclamation, Kyiv, Ukraine, Head of Water recourses Department, monitoring_protect@ukr.net
3 Institute of Water Problems and Land Reclamation, Kyiv, Ukraine, Head of Laboratory of Water management, julia_danilenko@ukr.net, iuliia.danylenko@gmail.com
4 Institute of Water Problems and Land Reclamation, Kyiv, Ukraine, Senior engineer of Laboratory of Water management, lutnizki@ukr.net
The retrospective analysis of long-term data on the actual water use on irrigation systems in south of Ukraine was conducted. According to the method developed by authors, for a number of years current water balance of irrigated lands within irrigation season, namely the period from the last week of March to the first week of October, was calculated. During this period the changes of water content in the root soil layer is usually minimal, which greatly simplifies the calculations. Similarly, target water balance (Table. 1), which lays in the basis for scenario management, was calculated. On the base of calculations results, empirical relationships between data that characterize from one hand the total water income on irrigated lands by rainfalls and water intake from the irrigation system for watering and from the other hand - quantities of consuming elements of water balance, including filtration, water discharge (surface runoff), evapo transportation, etc were established.

Similar relationships were set for series of data on total water income and indicators that characterize water discharge, efficiency of water use in general, efficiency of irrigation application that provides moisture for soil root layer. Our experience shows that these relationships are stable on the entire range of real fluctuations of total water income value.

Graphical visualization of the water balance of irrigated lands significantly simplifies its factor analysis. The nature of impact total water income makes on water balance and its structures formation is clearly tracked.

Generally, by using such charts, critical value of total water income, above which the structure of water balance changes significantly toward disproportionate growth of the losses of irrigation water to the filtration and runoff (discharges), can be set.

Table 1. Target water balance for irrigated lands in south of Ukraine

<table>
<thead>
<tr>
<th>Year</th>
<th>Water</th>
<th>Total water</th>
<th>Including</th>
<th>Precipitation</th>
<th>Evapotranspiration</th>
<th>Filtration</th>
<th>CCWUE</th>
<th>CWU</th>
<th>CWD</th>
<th>CCWA %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>1</td>
<td>510</td>
<td>204</td>
<td>306</td>
<td>433</td>
<td>116</td>
<td>0.85</td>
<td>0.62</td>
<td>0.15</td>
<td>100</td>
</tr>
<tr>
<td>2001</td>
<td>8</td>
<td>538</td>
<td>259</td>
<td>279</td>
<td>440</td>
<td>133</td>
<td>0.82</td>
<td>0.62</td>
<td>0.18</td>
<td>100</td>
</tr>
<tr>
<td>2002</td>
<td>37</td>
<td>559</td>
<td>326</td>
<td>233</td>
<td>436</td>
<td>150</td>
<td>0.78</td>
<td>0.62</td>
<td>0.22</td>
<td>100</td>
</tr>
<tr>
<td>2003</td>
<td>39</td>
<td>561</td>
<td>332</td>
<td>230</td>
<td>436</td>
<td>152</td>
<td>0.78</td>
<td>0.62</td>
<td>0.22</td>
<td>100</td>
</tr>
<tr>
<td>2004</td>
<td>1</td>
<td>424</td>
<td>0.5</td>
<td>423</td>
<td>424</td>
<td>56</td>
<td>1.00</td>
<td>0.62</td>
<td>0.00</td>
<td>100</td>
</tr>
<tr>
<td>2005</td>
<td>40</td>
<td>566</td>
<td>338</td>
<td>229</td>
<td>438</td>
<td>154</td>
<td>0.77</td>
<td>0.62</td>
<td>0.23</td>
<td>100</td>
</tr>
<tr>
<td>2006</td>
<td>49</td>
<td>576</td>
<td>363</td>
<td>214</td>
<td>439</td>
<td>162</td>
<td>0.76</td>
<td>0.62</td>
<td>0.24</td>
<td>100</td>
</tr>
<tr>
<td>2007</td>
<td>89</td>
<td>624</td>
<td>474</td>
<td>150</td>
<td>444</td>
<td>194</td>
<td>0.71</td>
<td>0.62</td>
<td>0.29</td>
<td>100</td>
</tr>
<tr>
<td>2008</td>
<td>1</td>
<td>498</td>
<td>177</td>
<td>321</td>
<td>431</td>
<td>107</td>
<td>0.67</td>
<td>0.62</td>
<td>0.13</td>
<td>100</td>
</tr>
<tr>
<td>2009</td>
<td>63</td>
<td>594</td>
<td>402</td>
<td>191</td>
<td>441</td>
<td>173</td>
<td>0.74</td>
<td>0.62</td>
<td>0.26</td>
<td>100</td>
</tr>
<tr>
<td>2010</td>
<td>1</td>
<td>476</td>
<td>114</td>
<td>362</td>
<td>433</td>
<td>90</td>
<td>0.91</td>
<td>0.62</td>
<td>0.09</td>
<td>100</td>
</tr>
<tr>
<td>2011</td>
<td>69</td>
<td>606</td>
<td>424</td>
<td>182</td>
<td>445</td>
<td>180</td>
<td>0.73</td>
<td>0.62</td>
<td>0.27</td>
<td>100</td>
</tr>
</tbody>
</table>

The target or normalized water balance (Table. 1) is calculated by formulae (1) - (6) for each rate of net water need for crops irrigation. The rates correspond to technologically justified volume of total evapotranspiration with the water content in the soil root layer at least at the level of productivity. Then used, water consumption
and its losses for filtration and runoff are minimal. It also excludes accumulation of ground water volume, which causes the rise of their level.

Normal rate of water intake for irrigation system (the volume of water that should cover deficit of water consumption during irrigation season) is calculated by:

\[ P_0^H = \eta_m^{-1} \eta_n^{-1} (E_0^H - X_n) \], \hspace{1cm} (1)

where \( E_0^H \) - optimal total evapotranspiration in the condition of deficit absence of productive water content in soil root layer; \( X_n \) – amount of rainfalls; \( \eta_m, \eta_n \) – coefficients of irrigation system and irrigated field efficiency respectively.

Deviation of actual irrigation water supply volumes from its normal rate is calculated by:

\[ \Delta P_o = 100 \frac{P_o - P_o^n}{P_o^n} \], \hspace{1cm} (2)

where \( P_o \) – actual volume of irrigation water supply.

Coefficient of water use efficiency (CWUE) is calculated by:

\[ \eta_o = \frac{E_o}{P_o + X_n - (-\Delta W_0)} \], \hspace{1cm} (3)

where \( \Delta W_0 \) – changes in soil water content.

Normative value of this coefficient is calculated by:

\[ \eta_o^n = \frac{E_o^n}{P_o^n + X_n} \], \hspace{1cm} (4)

where \( E_o^n \) – total evapotranspiration under optimal soil water content.

Normative coefficient of irrigation water use efficiency (CIWUE) is calculated by:

\[ \eta_o^H = \frac{E_o^H - X_n}{P_o^H} \]. \hspace{1cm} (5)

Deviation between normative and actual values of coefficients calculated by formulae (3) – (5) is determined by analogy to (2).

Coefficient of crops water availability (CCWA) is calculated by:

\[ \lambda_o = \frac{\eta_m \eta_n P_o + X_n}{E_o} \times 100\% \], \hspace{1cm} (6)

where norm is 100%.

Coefficient of water discharge (CWD) is equal to 1 - CWUE.

Analysis of the results of water balance calculations shows that the wetter irrigation season is the more likely total water income exceeds the critical value, which is 450
mm for the irrigation season. The reason is the lack of real-time control of water use in irrigation systems. As a result, even in dry conditions total water income increases with decreasing rainfalls, i.e. water use management is carried out with insufficient conjunction with the current weather conditions.

Graphical visualization of the water balance of irrigated lands (Fig. 1) indicates that when the total water income ranges within 430-580 mm for a season there are no runoff and accumulation of moisture in the root zone, while filtering increases. Then the total water income is more than 580 mm for a season, runoff appears (discharge of water from canals). Its volume is up to 50 mm in the case of total water income equal to 650 mm. Values of the coefficients of water use efficiency or irrigation water efficiency indicates that total water income is better to keep in the range of 430-460 mm per season.

Upon that, it should be considered that exceed of total water income level by more than 520 mm for the season will lead to accumulation of moisture in the root layer of soil. In this case, soil water content will exceed minimal moisture-holding capacity and lands become over moistened, which negatively affects their productivity.

When water use is normalized, increase of total water income inevitably leads to a decrease in the efficiency of water use, while the efficiency of use of irrigation water remains almost unchanged (Fig. 2). This pattern changes due to the nature of surface runoff and seepage losses that cannot be eliminated entirely upon existing technologies of irrigation management and not satisfactory technical condition of irrigation systems.
Integrated water management scenario given in the Table. 1 is aimed to implement preventive measures to maintain recommended water balance structure by limiting the volume of water supply through the main waterworks of irrigation systems. Water scarcity in the range of 20-25% does not lead to negative consequences such as similar volume of excessive water income does.

For the south of Ukraine, this approach requires adherence of logically and functionally related technological operations sequence concerning

(a) implementation of the schedules of water supply into canals and its intake with a clear sequence of actions with regard to restrictions on water and energy resources;
(b) integration (balancing) the need for water and electricity on each canal reach and the system as a whole;
(c) Filtering and discharges minimization to prevent negative impact of irrigated agriculture on the environment.

Thus, the preferred scenario of integrated water management is optimized water balance structure similar to given in Table 1. Optimization in this case consists in drafting water balance with use of water consumption norms corresponding to discharge norms to insure minimum water supply on territories under planning, which excludes excess water discharges and groundwater accumulation.

Under these conditions, total water income calculated from the norm of group water need and gross water intake for irrigation that corresponds to it, will grow with the increase of water availability of irrigation season, and while rainfalls in these conditions decreases (Fig. 3).
Filtration losses on irrigated lands increase in proportion to the total water income. The intensity of this growth is much lower under normalized water use conditions. For example, when conventional rate of total water income is about 350 mm per season, filtration is missing, while in the conditions of non-compliance with norms reaches 140 mm (Fig. 1).

The norm of irrigation water use efficiency for the conditions of south of Ukraine can be considered to be equal to 0.62. In contrast to the coefficient of water use efficiency in the case of normalized water use, coefficient of only irrigation water use efficiency mostly does not depend on the value of total water income.

The growth of total water income to the value more than 550 mm per season will increase water losses and reduce the efficiency of water use, but it will be out of our control scenarios scope. Priority of target scenario can also be estimated from the deviation between current and target coefficients, calculated by formulae (2) - (6). Negative deviations indicate that the actual values of coefficients are lower than normalized ones.

In the wet seasons caused by natural conditions with water availability at the level of at least 10%, it is appropriate to form an artificial shortage of the total water income. With the increase of aridity, irrigation systems of south of Ukraine should operate in a range of provision for water shortage of 90-95%.

To increase the level of water use efficiency the technologies of in-time management of water distribution and lands irrigation should be used. This is confirmed by Fig. 4, according to which the coefficient of water use efficiency and the coefficient of irrigation water use separately are less deviated from their normalized values under conditions when there is no similar total rejection of total water supply. The permissible range of deviation thus is very limited.
Figure 4. Impact of deviation of actual total water income from its norm on similar deviations of other water use indicators

Figure 5. Impact of actual total water income deviation from its target value on deviation of coefficient of crops water availability from its optimal value

Note that it is better to keep moderate deviation about 10% from the critical value of total water income. However, the irrigation systems have high enough self-regulatory (damping) properties due to the presence of reserve capacities in the canals and depressions of relief.

A significant damper role on the of irrigation systems plays soil root layer. It allows you to change the total water income in the range of ± 20% of its norm without negatively affecting water use management (Fig. 5).

Optimal planning goals correspond to all measures after implementation of which the total water income will become as close as possible to the level at which you reach the maximum value of coefficient of water use efficiency with its minimum deviation between actual value and target value.

The important precondition for such management is reliable forecast of water insurance during irrigation season on base of water use shortage, which is currently the most problematic. Partly this problem can be solved, if under climatic conditions of south of Ukraine at the beginning of irrigation season (April-May) we will maintain water intake for irrigation at the level, which corresponds to the structure of the water
balance at 20-30% water availability, in June and July – at 70-80% and in August - September – at 80-95%.

At the end of each month, it is necessary to form the actual water balance of irrigated lands for adjustment of water supply for future period and forecasting water shortage for crops that are irrigated.

Short-term water use plans drafted for a few days or in the case of real-time management for one day will insure the minimization of water supply for irrigation and will minimize the imbalance between water supply and water consumption what automatically reduces the volume of water losses for filtration and discharges.

The economic effectiveness of the integrated water use management is assessed on the base of specific water flow that is needed to ensure the implementation of chosen management scenario. Target function of this assessment is based on the dependence of break-even volume of water supply for irrigation on the price for providing such services. In the conditions of south of Ukraine, it is described by a function That is, the more the price (UAH$^5$ per 1000m$^3$) for services is, the larger should be the volume of total water intake and accordingly a larger number of consumers.

Encouraging farmers to irrigation is an important task of enterprises or institutions that operate irrigation systems. It is necessary to provide them with information that the profitability of irrigated agriculture appears in the case when the share of irrigated lands is 60-70% from total area of a farm, and under the conditions of the south of Ukraine it should be about 1,5-3,0 thousands ha.

2. **CONCLUSIONS**

Stochastic nature of water resources (which essentially implies uncertainty) makes it imperative to apply preventive water use management methods. In this case, scenarios are used in the form of tables of irrigated lands water balance calculated for different level of water insurance to cover crops water consumption deficit. Calculation formulae approximate relationships between water balance elements.

**REFERENCES**


---

$^5$ UAH is the abbreviation of Ukrainian currency. 1 US dollar = 24.81 UAH.