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"Gheorghe Asachi" Technical University of Iasi, Romania

ADVANCED NUMERICAL MODELING USING MIKE 11 TO DETERMINE THE WATER VOLUME ACCUMULATION IN A DRAINAGE CHANNEL FOR IRRIGATION USE

Daniela Cristina Stoica Untaru[1], Teodor Eugen Man[1], Robert Florin Beilicci[1], Anisoara Aurelia Ienciu[2], Mircea Visescu[1*], Marin Ilca[1]

[1]*Politehnica University of Timisoara, Department of Hydrotechnical Engineering, Splaiul Spiru Haret 1/A, Romania*
[2]*University of Life Sciences "King Michael I" of Timişoara, Aradului Avenue no. 119, Timişoara, Romania*

Abstract

Currently, Romanian agriculture depends on the weather in most of the cultivated areas. The dependence on weather has made it difficult for Romania to overcome the phenomenon of pedological drought in 2020. In this context, it is becoming increasingly difficult to ensure food security, maintain land properties in rural settlements protected by land improvements, and protect the livelihoods and well-being of the inhabitants because, unlike air and water, the land (area) has many owners whose existence depends on the agricultural production that can be achieved. Using Mike11 software for hydraulic modelling of flows in open channels having as a case study the CPE (Main drainage channel) channel, it is predicted the variation of the water level in time depending on the hydrograph of the input flows in various hypotheses of using the channels for drainage or irrigation purposes; the evolution in time of the deposition/ erosion in the channels for different assumptions of their use; the hydraulic modelling of the water accumulation capacity in the open channel drainage them open for various exploitation hypotheses and calculation of the area possible to irrigate from the volume of water accumulated in the storage basin. The Mike 11 software module used is Mike Zero, which allows the calculation of the elements necessary to highlight the volume of precipitation water that can be used for irrigation, assuming its accumulation in a reservoir adjacent to the drainage channel, especially during the winter and spring when there is a higher water input from precipitation.

Key words: irrigation, numerical modeling, open channel drainage

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1. Introduction and general considerations

Global warming is a well-known phenomenon throughout Europe, leading to increased rainfall, increased flood risk, and alternation of hot and dry periods, resulting in hydroatmospheric and soil drought in these regions. Desertification is progressively accentuated under varying geographical conditions, and its causes and factors that determine its manifestations may vary. In any case, the result is the same: modification of terrestrial ecosystems and installation of desertification (Armaş, 2023).

The European Union has promoted legislative instruments for the protection and sustainable management of water sources. To do this, the necessary framework for sustainable water management must be provided, which includes quantitative and qualitative treatment of healthy water and ecosystems.

Currently, Romanian agriculture depends on the weather in most of the cultivated areas. The dependence on weather has made it difficult for Romania to overcome the phenomenon of pedological drought in 2020 (Retrospectiva, 2020).

* Author to whom all correspondence should be addressed: e-mail: mircea.visescu@upt.ro

Climate change is a huge environmental challenge, as soil drought can also be considered an environmental catastrophe, representing a severe lack of soil moisture, where plants cannot absorb a sufficient amount of water from the soil, even under satisfactory atmospheric conditions.

In the west of Romania (Banat), the old channel drainage facilities have become nonfunctional or have low efficiency - for the most part, the maintenance and repair works in the post-revolutionary period or greatly reduced, being sporadic, these being physically and morally worn out, at present being necessary rehabilitation / modernisation measures to ensure their operation at the initially designed capacity, to ensure the conditions imposed by the application of new technologies, agricultural machinery, new irrigation equipment in agriculture, rehabilitation and modernisation process already started (NAEP,2014).

In this context, the question arises of finding the water sources necessary to make new local irrigation facilities of some associations / agricultural organisations of the owners of agricultural land, for which new modern equipment for irrigation by sprinkler (central pivots, laterals, hose reels, etc.) or irrigation by dripping was chosen (Pelea, 2023)

For most of the new irrigation facilities in the west of the country, one of the problems was the poor water source. The main source of water is the water from the surface watercourses (Bega, Timiş, and Mureş), transported on the existing network of open channel drainage, taken off, and adapted to serve both the drainage facilities for the evacuation of excess water, as well as for transportation of water, during the vegetation period (for the application of irrigation works), from the source to the irrigation facilities. (Man et al., 2007, Man at al., 2014, Man et al., 2015a, b). The scenarios analysed so far, with significant components relevant for addressing climate change in terms of modernisation, restoration, and efficiency, seem to highlight unfavorable developments in terms of the hydrological status of all river basins, both in the sense of a tendency to increase average flows and the intensification of hydrological phenomena (Man, 2015).

The lack of water sources requires the analysis of various possible water sources for each area. In the case of the western region of Romania (Banat Plain), the absence of water sources is even more pronounced. The existence of many drainage arrangements in the area (around 80% of the agricultural land in Banat has such arrangements) allows for storage and use of water for irrigation (Man et al., 2023).

Using Mike 11 software for hydraulic modelling of open channel flows, with the CPE channel (Main drainage channel) as a case study, we will present the variation of water level over time based on the hydrograph of input discharges for various scenarios of channel use, such as drainage or irrigation purposes. We will also depict the temporal evolution of sediment deposition and erosion in the channel for different usage scenarios and perform hydraulic modelling of water storage capacity in open channels for various exploitation scenarios (Beilicci 2021).

2. Working methods using Mike 11 software

Mike 11 is a system that is used in the 1D modelling of rivers and canals, including built structures. It can be used for hydrodynamic modelling (rivers and estuaries, irrigation systems, dam breaks/dams, etc.), qualitative modelling (dissolved oxygen balance, eutrophication, heavy metals, swampy areas), modelling of advection / dispersion (salt water intrusion, temperature), or for modelling sediment transport (cohesive sediments, morphological modelling).

The MIKEv11 hydrodynamic module uses a default scheme with finite e-difference e, to calculate flow rates in rivers and estuaries. The MIKEv11 HD module solves vertically integrated equations for preserving continuity and momentum, the Saint-Venant equations. The basic forms of the equations used in MIKE 11 are presented in Eqs. (1-2).

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=q \tag{1}$$

$$\frac{\partial Q}{\partial t}+gA\frac{\partial h}{\partial x}+\frac{\partial\left(\alpha\frac{Q^2}{A}\right)}{\partial x}+\frac{g\left|Q\right|Q}{C^2AR}=0 \tag{2}$$

where: Q is the flow rate, x is the longitudinal distance of the channel, A is the cross-sectional surface, q lateral input flow, t is the time, h is the flow depth, C is the Chezy coefficient, and R is the hydraulic radius. (DHI, MIKE 11 2014)

The connection of MIKE 11 with GIS and ArcGIS can be done in order to extract cross-sections, outline watersheds, and flood maps. In order to achieve these goals, or to be used as a forecasting tool, MIKE 11 can connect to ArcGIS, Google Earth, or NASA Worldwind. MIKE 11 can be linked to other types of model, such as Simulation of integrated captures (MIKE 11 - WWTP); Mike Floods (MIKE 11 - MIKE 21); Groundwater modelling - surface water (MIKE 11 - MIKE SHE).

In numerical modelling, hydrotechnical structures can also be added, such as channels/galleries, culverts, weirs, spillways, pumps, or control and regularisation structures, or even breaks of dams and dams. Due to the effects of the accumulation, we obtain a dynamic modelling that: allows the withdrawal of water in the riverbeds as the flood attenuates; allows for a slow accumulation in the major riverbeds to mitigate and delay the peak of the flood; and takes into account the volume of accumulation available in the canals and major riverbeds.

Through the MIKE Zero programme within the MIKE 11 software package, we can access general options related to this package. Once in the actual phase of numerical modelling, a simulation programme (sim11) will be created that will be kept open at all times (valid for any type of work in MIKE 11), which is the main control centre in MIKE 11. It accesses all the files necessary to run the programme and intercommunicate them. The simulation editor also specifies the type of model to be used and the simulation mode (permanent/non-permanent). The files used in the simulation will be added, depending on the type of simulation we want to create; they will be the following:

- Network;
- Cross-sections;
- Boundary conditions;
- Precipitation and drainage parameters;
- Hydrodynamic parameters;
- Parameters for advection / dispersion;
- ECOLab parameters;
- Parameters for Time Series;
- Parameters of frost etc.

The Simulation table within the simulation editor contains the initial conditions, the time step taken into account, and the simulation details. Also, from this it is possible to calculate the maximum simulation period, based on the data entered in the system; the time step can be entered as fixed, tabular, or adaptive.

The Network editor (.nwk11) is used to define plane vision, rivers, and hydrotechnical structures. In it you can load a graphical view that shows the network with the tributaries of the model and the images in the background. One can even use saved networks as a *.jpeg format by importing them from an ASCII file, through the editor's Import interface. The editor also includes options for viewing them, as well as changing their dimensions, as needed.

The Sections editor (.xns11) is based on a binary database, several sections can be recorded, each identified by the name of the river (tributary), the related Topo identifier (Topo ID) and route (numbers increase downstream). Each section includes: information about the section and the type of radius, raw data (X, Z coordinates), information about the lateral roughness, markers defining the extension of the section. The processed data include: hydraulic radius, accumulation area and width, and flow mode. The latter are used in the simulation. The dam markers on the banks determine the actual area used in the simulation. The Margin Conditions Editor (.bnd11) contains options for including Advection/Dispersion and multilayer flow conditions, a general panel with a list of all edge conditions in the model, and a specification panel (details for advection/dispersion options). The general panel includes a box for description (open, global, structures, closed), one for the type of condition (power, levels, Q-h curves, bed level), one for identifying the user and 3 for localisation (tributary name, start (km), end (km).

The Time Files Editor (.dfs0) is a time series editor and database and communicates directly with the Margin Conditions Editor. The HD Parameters editor (.hd11) contains the initial conditions and resistance data. The picture with the initial conditions includes the local conditions superimposed on the global ones, the globally specified values, the local values (chainage) etc. The initial conditions will establish the water level in the first step of time. The resistance factor on the sectional side applies to global or local values. If the side resistance is specified as the value, then the file in question will be ignored.

Precipitation-runoff modelling follows the water cycle in nature, specifically the land phase of the cycle. It can be achieved by several methods:

UHM (Unit Hydrographic Method), NAM, SMAP, Urban, FEH, and DRiFT (Beilicci et al., 2021).

3. Case study of Checea-Jimbolia development (CPE - open channel drainage)

The need for investment is a priority to respond to climate change, prevent risks, and be resilient to adverse effects of nature.

In periods of prolonged moisture deficiency, the channel network can be used for local irrigation under the following conditions:

- temporary accumulations on canals from the water of precipitation that has fallen into the system;
- installation of sills in the existing culverts in the upstream embankment for water retention in several sections;
- the counter slope water supply of some channels by handling the diversion weirs;
- water in the channels can be sprayed by sprinkler systems or can supply the soil profile through capillarity as a result of the supply from groundwater level;
- the realisation of storage basins, which during the period of heavy rainfall collect the surplus water, which will be used to irrigate the crops in periods with moisture deficiency.

One of the most important drainage channels, from the development of Checea Jimbolia, which is also used as a water source for irrigation, is the CPE open channel drainage, a channel that represents an important component of the hydrotechnical scheme of compartment I Cenei (Guran et al., 2023).

The main exhaust channel (CPE) is a collector and discharge channel for excess water from the I Cenei Compartment on an area of 55,900 ha, gross. The main drainage channel (CPE) from the Checea-Jimbolia drainage arrangement can be used for the purpose of:

- discharge of excess water;
- irrigation in local landscaping;
- water management through the accumulation of lowland ashes, when appropriate.

The CPE will remain free, allowing for the closure or strangulation of small sections under irrigation conditions. The water needed for irrigation can be obtained in the free drainage mode on the channel through the shore outlets.

The water collected from compartment I SP Cenei is discharged gravitationally or by pumping into the CPE channel. The drainage units (U.D.): Cenei, Uihei-Cărpiniș, Clarii, and Grabați evacuate the waters gravitationally into the CPE channel.

In the exploitation of the CPE, two characteristic situations that may arise will be taken into account:

- rain-free operation in the affluence basin;
- exploitation in the rainy regime in the affluence basin;

In Fig. 1 it is shown the path of the CPE channel.

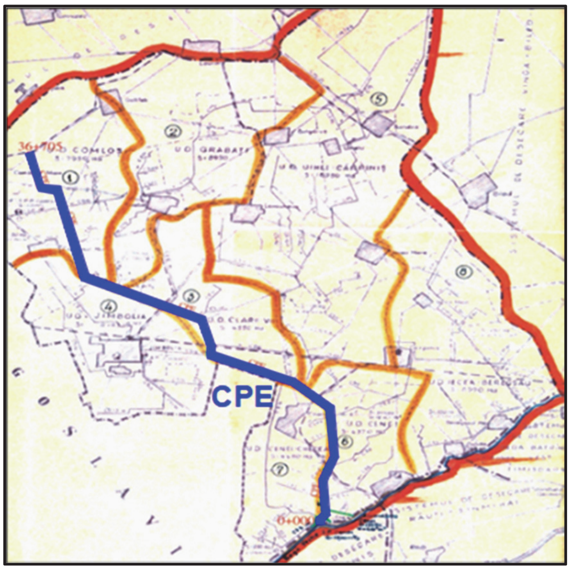

Fig. 1. CPE channel route (Guran et al., 2023)

During periods without rains in the basin, or with rains that do not give leakage, the levels on the CPE channel at the point of concentration of the waters in the absorption basin at the Cenei pumping station, will be maintained over the reading at surveying target no. 1 of 140 cm, as long as gravitational evacuation is possible.

In periods with rain that causes important leaks, corresponding to the period November-June, the level of surveying target no. 1 of 140 cm and the level of surveying target no. 2 of 80 cm, require the commissioning of the Cenei pumping station.

The CPE channel has a total length of 36,705 km, divided into 10 sections with differentiated construction characteristics, corresponding to the flow rates that carry them calculated with 5% insurance.

The CPE channel is crossed by forest roads, communal roads, county roads, national roads, and railway lines at 28 points, where culverts were built:

- Culverts on DE 17 pcs.;
- Culverts on DC and DJ 4 pcs.;
- Culverts on DN 1 pcs;
- Culverts on CFR lines 5 pcs.;
- Pedestrian walkways 1 pc.

On the canal route, a number of 3 grooms were fixed for observing the levels at:

- km 9+200;
- km 16+800;
- km 22+327.

In order to prevent overflow of water during flood periods, dams were provided in the depression areas, made from the systematisation of the deposits.

Table 1. Discharge calculated with 5% assurance

Section I	km 0+000-3+850	Q=16.36 m^3/s
Section II	km 3+850-10+275	Q=14.00 m^3/s
Section III	km 10+275-16+000	Q=9.50 m^3/s
Section IV	km 16+000-23+375	Q=6.32 m^3/s
Section V	km 23+375-30+100	Q=3.00 m^3/s
Section VI	km 30+100-32+200	Q=3.00 m^3/s
Section VII	km 32+200-34+630	Q=0.39 m^3/s
Section VIII	km 34+630-35+580	Q=0.39 m^3/s
Section IX	km 35+580-36+330	Q=0.19 m^3/s
Section X	km 36+330-36+705	Q=0.06 m^3/s

On the right bank, at km 16+828, an undercrossing with a flap was executed, for the evacuation of the water collected in the depression area, behind the systematised depot. On the left bank, at km 14+962, a shore outlet was executed for the irrigations from the local arrangements of the state enterprises (I.A.S. Jimbolia).

In the past, state-owned enterprises (I.A.S) owned local irrigation facilities on agricultural land. In the area of land served by the CPE open channel drainage, there were several such developments, namely:

a) The local irrigation arrangement of I.A.S Jimbolia (old, nonfunctional arrangement) with an area arranged for irrigation at I.A.S. Jimbolia is 32 ha, is part of the Checea-Jimbolia drainage system, and is located east of the city of jimbolia, being delimited as follows:

- to the north of the infiltration channel Cs 12;
- to the east channel Cn 11;
- to the south channel Cs 14;
- to the west channel Cs 13.

The source of the water was represented by a lake that was fed by groundwater, precipitation, and the ceramica Jimbolia quarry. The pumping of water was carried out with an electric floating pumping station. The discharge of water is made through a pipe with a diameter of 600 mm, in a concrete discharge basin, from where the water is directed through a channel (CPE) to the hydrotechnical node located on the CS12a (CS -secondary channel). From here, the water is directed to SP (pumping station) Jimbolia (reversible electrical) which provides the second pumping step in the Cs 12 channel, from where, by pumping through thermal aggregates, the water is distributed in the last order channels to be taken over and distributed by sprinkler to the plants. The watering scheme is with a variable number of sprinklers, depending on the distance between two neighbouring manifolds or the width of the plot.

The location of the watering wings is made perpendicular to the distributor channel, and the direction.

b) The local irrigation arrangement with Clarii Vii wastewater with an area of 512 ha (old, non-functional arrangement); during the winter period, the volume of wastewater that could be stored was in a volume of 192000m^3, the total annual volume of decanted wastewater that was distributed being 383000 cubic metres.

The Accumulation of Cenei plain is located on the right bank of the Bega Veche emissary, has an area of 193 ha, between the left dam Bega Veche and the ring embankment that follows the left bank of the CPE channel (km 0+000 - 1+000) and the CS1 channel (Fig. 2). The lake basin was provided with a network of exhaust channels, with a total length of 7.15 km, which gravitationally evacuated into the CPE channel at km 0+115.

The exploitation of the Cenei Saddle accumulation is functionally related to the exploitation of all land improvement works and water management in the Old Bega hydrographic basin, including those on Serbian territory. The common regulation of protection against floods in the Romanian-Serbian area states: "In case of breaking of dams on Romanian or Serbian territory, any pumping of water in the Bega Veche canal, on both territories, will be immediately stopped until the cause is removed" (source ANIF).

4. Results

Numerical modelling was performed with the MIKE11 calculation programme. The model was applied to the CPE with the variable cross sections projected on sections of trapezoidal shape, sections that have undergone changes over time through clogging and erosion of the banks.

The drainage arrangement situation plans, as well as the longitudinal section through the CPE (Fig. 3) and the cross sections through the channel as a result of the topographic measurements are presented in Fig. 4.

Table 2. Geometric and hydraulic elements of the CPE channel

Section	*l (m)*	*Downstream quota*	*Upstream elevation*	*b(m)*	*m*	*i‰*	*Q (m³/s)*
0+000-3+850	3850	74.00	74.96	5.0	3.0	0.25	16.36
3+850-10+275	6425	74.96	75.92	5.0	3.0	0.15	14.00
10+275-16+000	5725	75.92	76.78	5.0	3.0	0.15	9.50
16+000-23+375	7375	76.78	77.89	3.0	3.0	0.15	6.32
23+375-30+100	6725	77.89	78.03	1.5	3.0	0.20	3.00
30+100-32+200	2100	78.03	78.66	1.0	2.0	0.30	3.00
32+200-34+630	2430	78.66	79.39	0.5	2.0	0.30	0.39
34+630-35+580	950	79.95	80.90	0.5	1.5	1.00	0.39
35+580-36+330	750	80.90	82.02	0.5	1.5	1.50	0.19
36+330-36+705	375	82.02	83.15	0.5	1.5	2.10	0.06

Fig. 2. The CPE and the accumulation of lowland Cenei (Polder dam) (Guran at al., 2023)

The input flows in the CPE channel are: the flow rate in the upstream section at Km 36+705 according to a hydrograph as well as the input flows at the confluence with various main open channel drainage at km 36+330, 35+580, 32+200, 23+375, 16+000, 10+275, 3+850 according to some hydrographs. These flows are shown in Fig. 5. The hydraulic flow model was made in two variants:

Variant 1

The choice of boundary conditions regarding the input flows according to the input hydrographs at km 36+705, 36+330, 35+580, 32+200, 23+375, 16+000, 10+275, 3+850 respectively downstream at km 0, the key capable curve of the drainage channel was introduced.

This variant involves the operation of the Cenei pumping station conditioned by flows that reach its right, so that flows are evacuated according to the key capable curve of the CPE drainage channel (Fig. 6). After running the MIKE11 programme, the longitudinal profile was obtained through the existing channel, showing the water levels along the respective channel (Fig. 7). The running of the sediment transport model results in the volume and elevations of sediment/erosion deposits (Fig. 8).

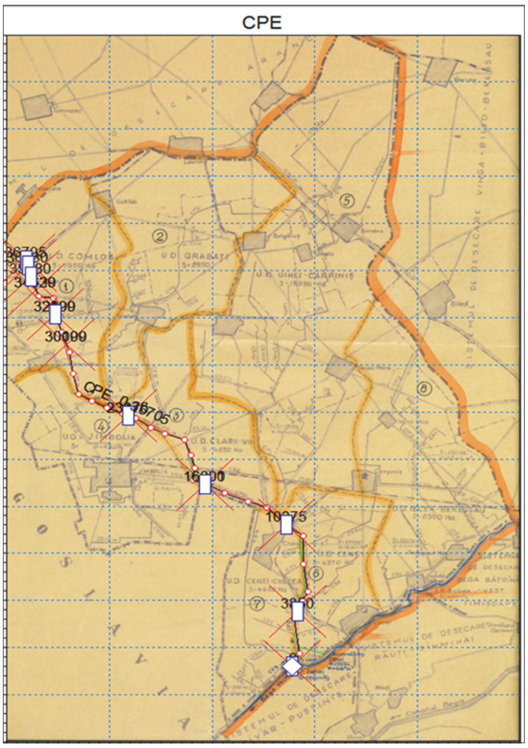

Fig. 3. Situation plan of modelled CPE from the arrangement of Checea Jimbolia (Guran et al., 2023)

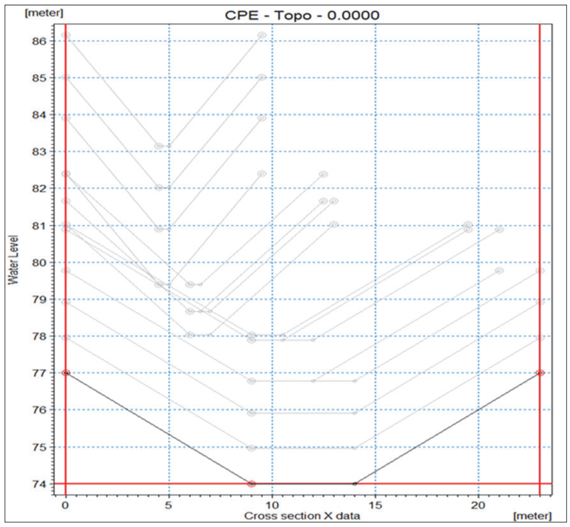

Fig. 4. Cross-sections of the CPE on different chainage according to plan view - Stereo 70 surveying elevation (Fig. 3)

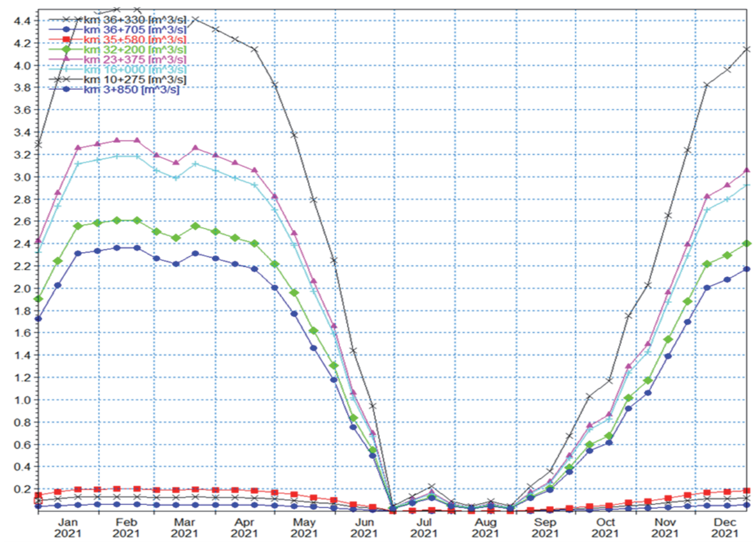

Fig. 5. Hydrograph of input flows on the CPE

Variant 2

The choice of boundary conditions regarding the input flows according to the input hydrographs at km 36+705, 36+330, 35+580, 32+200, 23+375, 16+000, 10+275, 3+850 respectively downstream at Km 0, the constant water level at the 77 m altitude was introduced. This variant involves the operation of the Cenei pumping station conditioned by the elevation of water in the CPE channel so that the channel is kept full. The validation and calibration stages of the model are performed by adjusting the roughness of the canal bottom and slope, ensuring that the discharge rates at the pumping station are correlated with real situations recorded during the pumping station's operation.

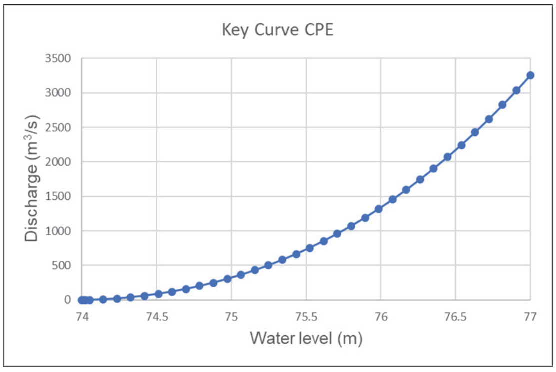

Fig. 6. Key curve of the CPE near the Cenei pumping station

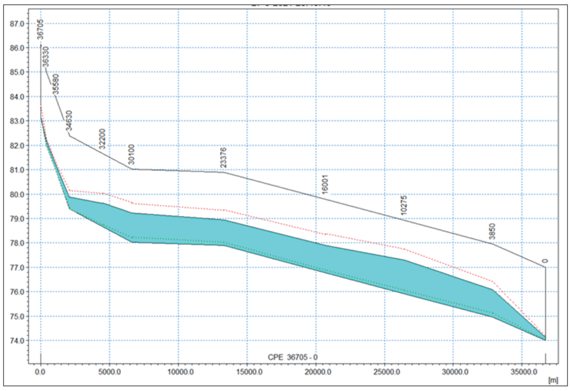

Fig. 7. Longitudinal profile through the CPE, showing the water levels along the Variant 1 channel

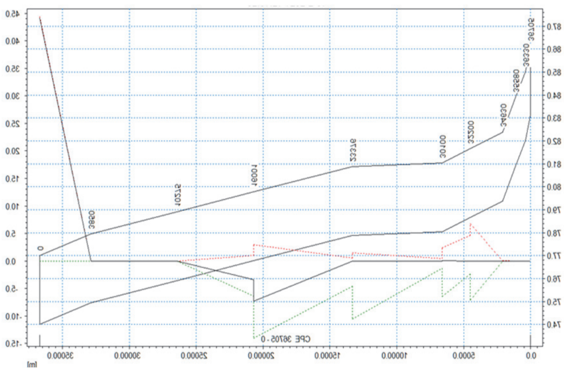

Fig. 8. Longitudinal profile through the CPE, presenting the sediment deposits elevations Variant 1

After running the MIKE 11 programme, the longitudinal profile was obtained through the existing channel, showing the water levels along the respective channel (Figs. 9-10). During the 1-year studied period, the curves of the discharged water flows in one year were drawn, respectively the volumes of water discharged in the same period, these are shown in Figs. 11-12. It is noted that strictly in relation to the periodic discharged flows without taking into account the volumes of water accumulated in the CPE channel, the variation curve of the possible watering areas relative to the flow transit period can be drawn taking into account a watering hydromodule of 0.6 and a watering efficiency of 0.9, this is represented in Fig. 13.

At the same time, calculating the total volume of water discharged from the CPE through the Cenei pumping station over the study period of one year results in a volume of 282,087.6 thousand cubic meters per year. This volume of water discharged could provide irrigation of a considerable area of agricultural land which can be calculated for a watering norm of 700 mc/ha corresponding to the study area for the maize crop. Applying the watering scenario of 6 irrigations per year results in a possible irrigated area of 60.447 hectares.

For effective watering of this theoretical area, it would be necessary to capture the water from the CPE and accumulate it in the accumulation basins of farmers in the vicinity of the CPE.

For *Variant 1* of exploitation of the Cenei pumping station conditioned by the flows that reach its right so that the flows are evacuated according to the key capable curve of the CPE open channel drainage, it is noticed that in the CPE a volume between 275.926 cubic metres and 316.915 cubic metres accumulates in the CPE. These available volumes of water could provide irrigation of an agricultural land area that can be calculated for an irrigation rate of 700 cubic metres per hectare corresponding to the study area for the maize crop applied in the watering schedule of 6 waterings per year resulting in a possible irrigation area of between 354 and 407 ha.

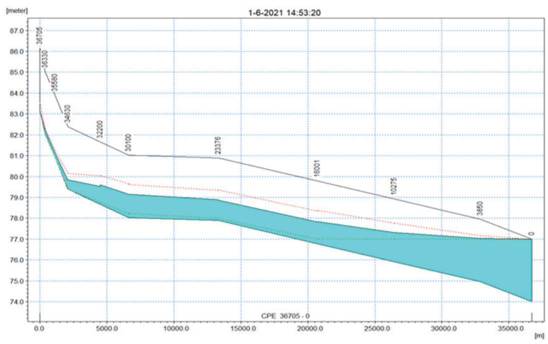

Fig. 9. Longitudinal profile through the CPE, showing the water levels along the *Variant 2* channel

For *Variant 2* of the exploitation of the Cenei pumping station conditioned by the elevation of the water of the CPE so that the channel is kept full, it is observed that in the CPE a volume between 322,678 cubic metres and 363,667 cubic metres accumulate in the CPE.

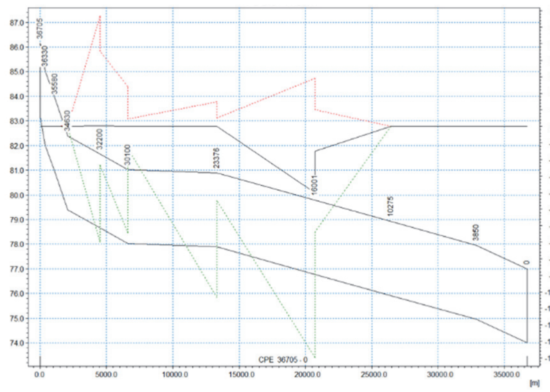

Fig. 10. Longitudinal profile through the CPE, presenting the sediment deposit elevations Variant 2

These volumes of available water could provide irrigation of an agricultural land area that can be calculated for a watering norm of 700 m^3/ha corresponding to the study area's corn cultivation using a watering schedule of 6 irrigations per year, resulting in a possible irrigating area of between 415 ha and 468 ha. In Fig. 14, the minimum and maximum possible irrigated areas from the CPE are presented, considering the transit flow rates and water volumes available in the CPE for *Variant 1.* In Fig. 15, the minimum and maximum possible irrigated areas of the CPE are presented, taking into account the transit flow rates and water volumes available in the CPE for *Variant 2.*

5. Conclusions

The rehabilitation of existing systems, but also the use of new technologies, is imperative for the transition of socialist agriculture to capitalist agriculture, compensating for the water scarcity in the soil, irrigating precisely, making as many storage basins as possible in order to store water during the excess of humidity, which will then be used for irrigation, thus ensuring a supply to maintain the moisture of the soil necessary for the development of agricultural crops. Modernizing pumping stations to remove excess water from the soil and carry out drainage has direct implications on agriculture.

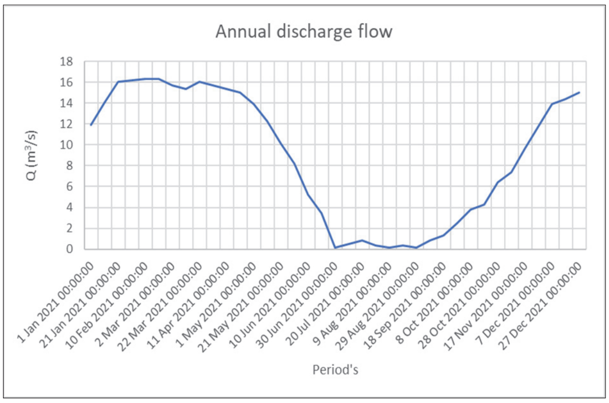

Fig. 11. The discharged flows from the CPE channel through the Cenei pumping station during the studied period

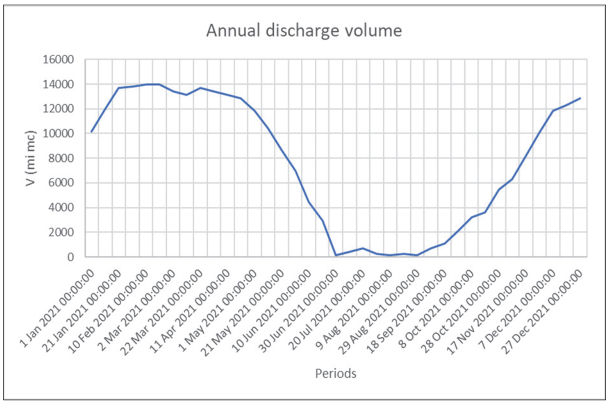

Fig. 12. Volumes of water discharged from the CPE channel through the Cenei pumping station during the studied period

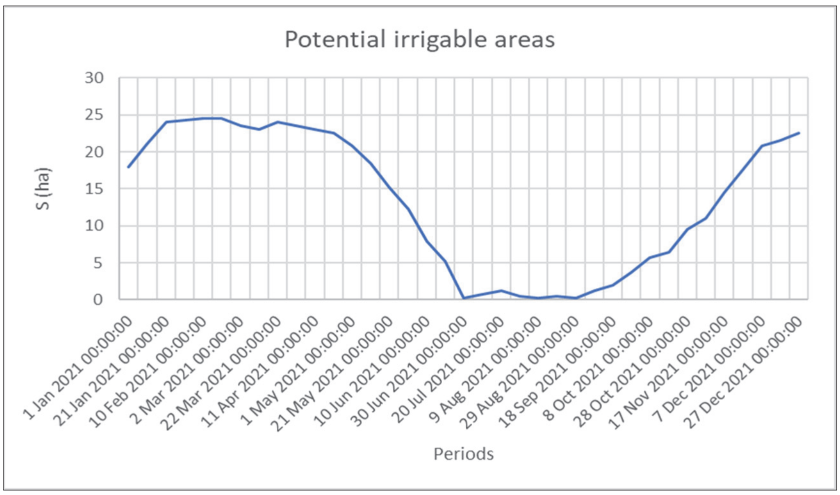

Fig. 13. Possible irrigating areas relative to transit flows in the CPE channel

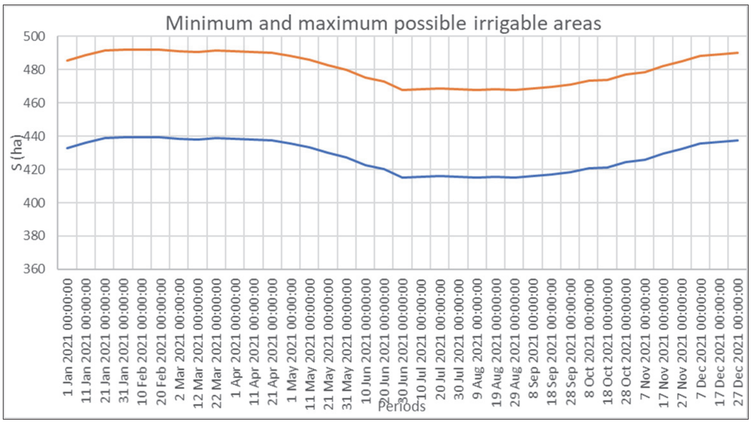

Fig.14. Possible irrigation areas in relation to the available water volumes in the CPE for *Variant 1*

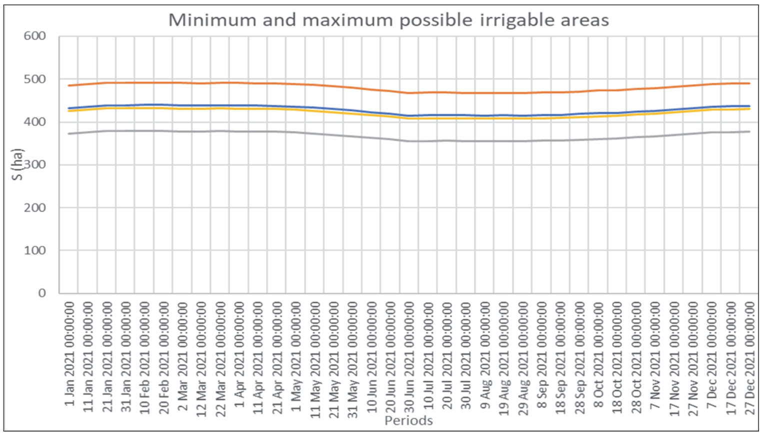

Fig.15. Possible areas to irrigate in relation to the available water volumes in the CPE for Variant 2

The numerical modelling achieved, on the two variants of exploitation of the Cenei pumping station, shows that the available water volumes (between 275.926 cubic metres and 316.915 cubic metres for variant 1 and between 322.678 cubic metres and 363.667 cubic metres for variant 2) could ensure the irrigation of an agricultural land area between 354 ha and 468 ha.

By calculating the total volume of water discharged from the CPE canal over the study period of one year through the Cenei pump station, a volume of 282.087.6 thousand cubic metres per year is obtained. This volume of discharged water could potentially support the irrigation of a large agricultural area. For an irrigation rate of 700 cubic metres per hectare, which is appropriate for the study area's corn cultivation, applying a watering schedule of 6 irrigations per year results in a possible irrigated area of 60,447 hectares.

The scenarios simulate the possibilities of exploitation to obtain the largest possible water volumes, thus increasing the irrigated surface. Through this numerical modelling, the significant volume of drainage water that can accumulate in storage reservoirs over the course of a calendar year has been highlighted. Analyzing the available water source from drainage using this numerical modeling allows the implementation of irrigation projects on larger areas in water-deficient zones.

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