# STUDIES REGARDING THE SAFETY IN OPERATION OF THE NEGRENI RESERVOIR, BOTOȘANI COUNTY, ROMANIA

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**Abstract**

The dam of Negreni reservoir, located on the Bașeu River, is an earth dam with a maximum height of 12.4 m, which provides global retention to the crest of 25.869 million $m^3$. The Negreni reservoir is a part of the hydro-technical works set, that were built to protect against the floods the localities within the river Bașeu catchment area, in Botoșani county (Săveni, Știubeni, Petricani, Chișcăreni, Bozieni). The dam is of homogeneous type, made of clayey-dusty sands and it has several installations both for external stresses and for the response to stresses. Between the years 2008 and 2012 investment works were implemented, under the project „Safety re-inforcement of Cal Alb and Negreni reservoirs, located on Bașeu River, in Botoșani county". The project was set out to build the following works: rehabilitation of dam body (repairs to the concrete tiles on the downstream slope), rehabilitation of the hydromechanical equipments, rehabilitation of the bottom outlet, rehabilitation of the evaccuation channel of the surface outlet, installation of a water management information and warning-alarm system, rehabilitation of the behaviour monitoring system. The special events recorded during the execution of the dam and during its operation have imposed the implementation of a systematic behavior monitoring of the hydro-technic constructions at the Negreni reservoir. This paper presents a brief history of the dam in its construction and exploitation phases, focusing on aspects regarding the behavior monitoring of Negreni reservoir during the years 1997 – 2020.

**Key words**: safety re-inforcement, rehabilitation of hydrotehnic constructions, reservoir, hydrostatic level, behaviour monitoring

The Negreni reservoir is located on the Bașeu River (cadastral code XIII.1.010.00.00.00.0) the right tributary of the Prut River, at the hectometer 410 from the springs and about 15 km upstream the city Săveni. The retention dam is located in the north-western part of the county Botosani, at approx. 24 km downstream of the reservoir Cal Alb.

The Negreni reservoir operated by Water Basinal Administration Prut-Bârlad, is located on the territory of Știubeni village, Botoșani county.

The reservoir commissioned in 1976 was built on the site of an old dam and has the following functions: it contributes, along with other hydrotechnical works in the area, to the protection against floods for downstream settlements in the valleys of Bașeu river, a total area of 1086 ha, in the downstream localities of Știubeni, Chișcăreni, Bozieni, Vlăsineşti and the city of Săveni; water supply for the city Săveni – 285000 $m^3$/month; irrigation; fishing; ecological flow downstream of the dam - 0.071 $m^3$/s (***, 2014) (*figure 1*).

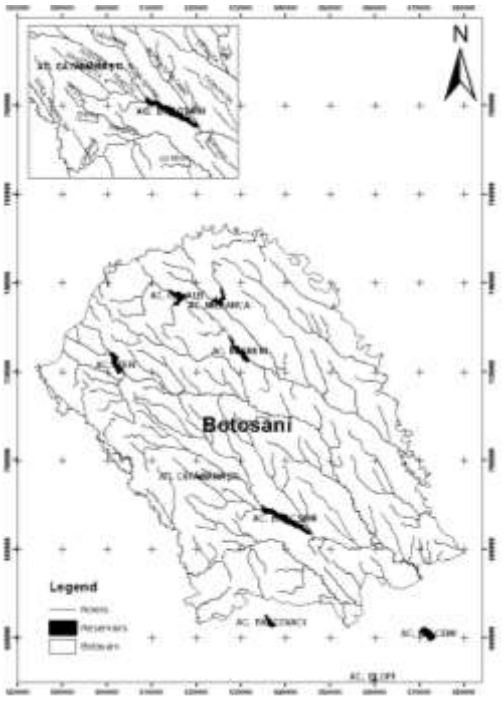


Figure 1 **Negreni reservoir positioning map**

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## MATERIAL AND METHOD

The reservoir in question falls in the III[nd] class of importance and B category of importance. According to STAS 4068/2-62, Negreni reservoir was sized using the flow with the probability of exceedance of 2% and was verified using the flow with the probability of exceedance of 0.5% with a 20% increase safety(***, 2015).

The special events recorded during the construction and during the operation of the dam have imposed the implementation of a systematic behaviour in time monitoring of the hydrotechnic constructions at Negreni reservoir.

The Bașeu River has the following features (Ministerul Mediului,1992):

- catchment area in Negreni retention section = 312 km$^2$;
- river length from spring to dam L = 41 km;
- multiannual average flow Qmm = 0.62 m$^3$/s

Characteristics of the floods are presented in *Table 1.*

Table 1

**Characteristics of the floods**

| No | Characteristics of flood waves | |
|---|---|---|
| 1 | 1.2x0.5% probability flow – m$^3$/s | 330 |
| 2 | 0.5% probability flow - m$^3$/s | 275 |
| 3 | 2% probability flow - m$^3$/s | 175 |
| 4 | Total time – hours | 60 |
| 5 | Increase time - hours | 15 |
| 6 | Form factor □ | 0.35 |
| 7 | 1.2x0.5% probabilityof exceedance volume – hm$^3$ | 24.95 |
| 8 | 0.5% probability of exceedance volume – hm$^3$ | 20.79 |
| 9 | 2% probability of exceedance volume – hm$^3$ | 13.23 |

**Geological characteristics of the site**

The site of the Negreni reservoir is a part of the Moldavian Platform, which is characterized by uniformity of deposits that compose it. The foundation is mainly made of marl with great consistency, at a depth of more than 9.0 m. The foundation is covered, in the basin, by dusty clay, clayey dust, sand and dust clayey-sandy loess (***, 2018).

The hydrostatic level of groundwater with free level in the storage area of the reservoir is cantonated at depths between 3.0 and 4.0 m from the natural ground level (*figure 2*).

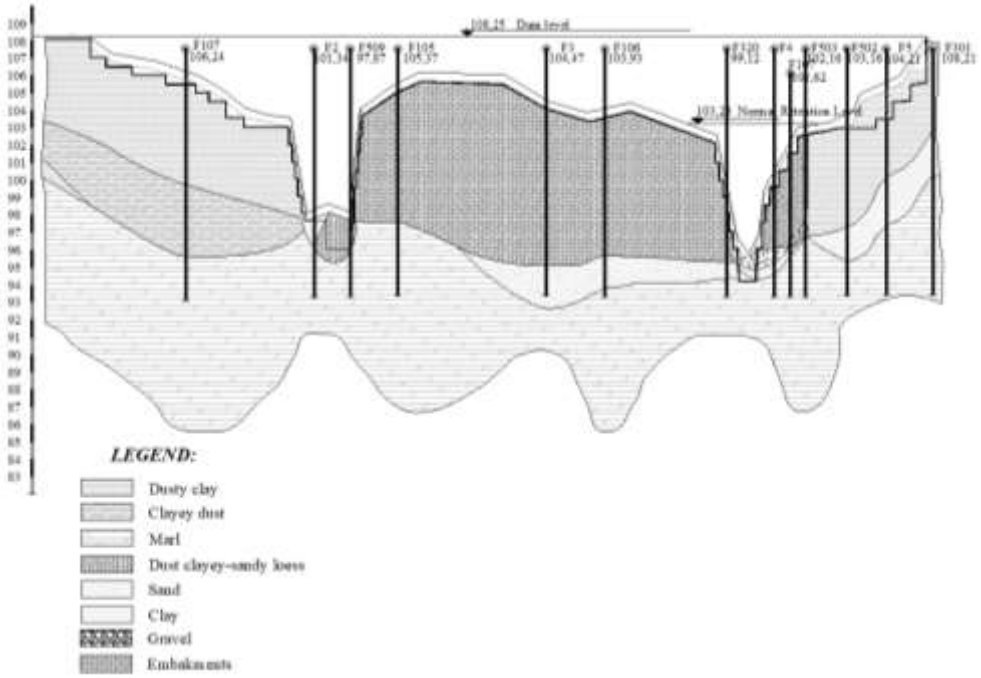


Figure 2 – **Longitudinal view of the geological stratification for the dam foundation**

**Component works of Negreni reservoir**

**a) The dam**

The retention in Negreni reservoir is made by a frontal dam made of clay and sandy dust, with a canopy length of 1008 m, a maximum height of 12.42 m, and a width of 5.0 m. The dam is provided with a drainage mattress of 1.0 m width and 16.5 m width, located in the downstream third of the

footprint base. Drainage culvert for water collection and drainage is 365 m long and consists of polyvinyl chloride pipes with the internal diameter of 300 mm, for the collection of infiltration water, which discharges into the energy dissipator of the bottom outlet, left branch and right branch.

The outlets of the dam are represented by: the high waters surface spillway, the medium water spillway and the bottom outlet in the shape of a circular oriffice.

**b) The surface spillway outlet** consists of the following parts:

- the weir has a trapezoidal threshold with a circular shape in plan view and an access length of 75.85 m of the spillway.
- a connection area with the evaccuation channel
- the evaccuation channel is 18.40 m long and is made of reinforced concrete
- the fast channel has a 0.12% slope and a length of 45.50 m, and has artificial mcacrorugosities represented by longitudinal concrete ribs.
- the energy dissipator chanel is 18 m long.
- the channel that connects with Bașeu river is covered with stone, on the slopes and the bottom.
- bridge that connects the dam with the right embankment is 17.0 m long and 4 m wide *(figure 3*).

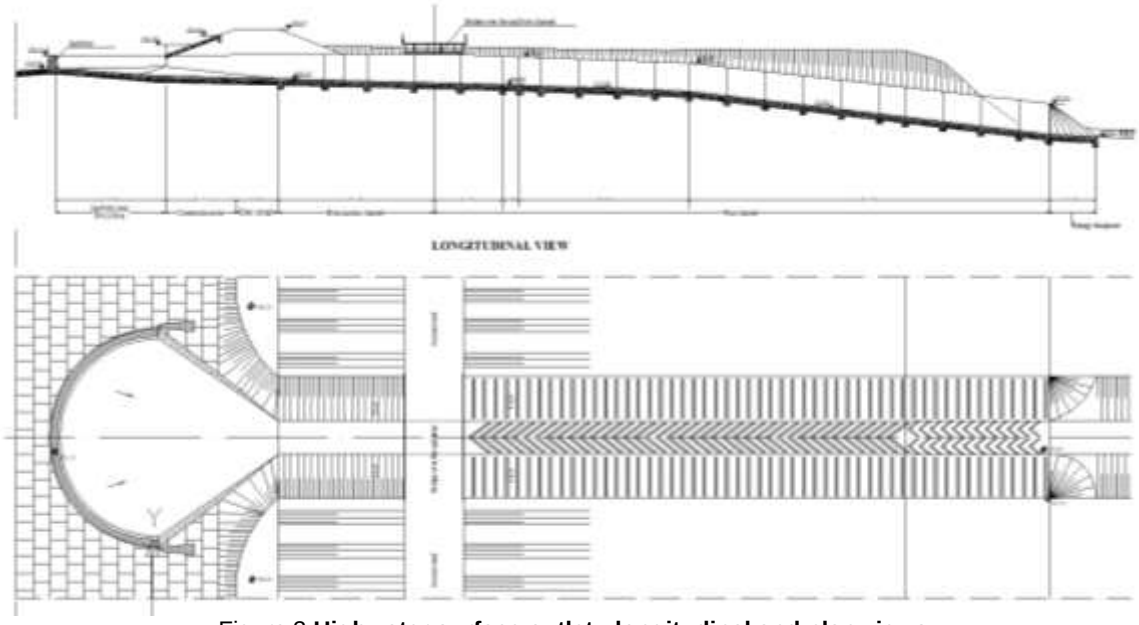


Figure 3 **Highwater surface outlet - longitudinal and plan views**

**c) The bottom outlet** is represented by a circular oriffice with the interior diameter of 1200 mm. It is pipe made of fiberglass-reinforced polyester and sand insertion, inside the initial concrete tube with interior diameter of 1400 mm, in 6 m sections for a total length of 78 m.

The hydro-mechanical equipment for the bottom outlet consists of:

- metallic grid: 2330 x 2350 mm – 3 pieces
- cofferdam 2330 x 3000 mm
- flat slide gate for draining the lake with the dimensions of 1500x1500 mm, operated electrically, with normal position **closed**.
- flat slide gate for closing the bottom outlet with the dimensions of 1500x1500 mm, operated electrically, with normal position **open**.
- flat slide gate for water intake for users, with the dimensions of 250x1000 mm, operated electrically, with normal position **closed**.

**d)** The maneuvering tower is equipped with a **medium waters outlet**, made up of from 2 overflow oriffices located in the side walls of the tower. The windows are provided with fixed metallic grates, with the dimensions BxH=1100x2140 mm *(figure 4*).

**Rehabilitation works**

During the years 2008÷2013 investment works were implemented, under the project *„Safety re-inforcement of Cal Alb and Negreni reservoirs, located on the Baseu River, in Botoșani County".*

The project was set out to build the following works: rehabilitation of dam body (repairs to the concrete tiles on the downstream slope, conslodiation of the left embankment, placement of a draining mattress downstream of the dam), rehabilitation of the hydromechanical equipments, rehabilitation of the bottom outlet, rehabilitation of the evaccuation channel of the surface outlet, installation of a water management information and warning-alarm system, rehabilitation of the behaviour monitoring system.

**Characteristic levels and volumes**

The land rates reference plan is Black Sea 1975 and they were updated by topographic measurements performed by specialized staff from the Prut-Barlad Water Basinal Administration on the lake basin, dam body and related constructions in 2014 *(table 2).*

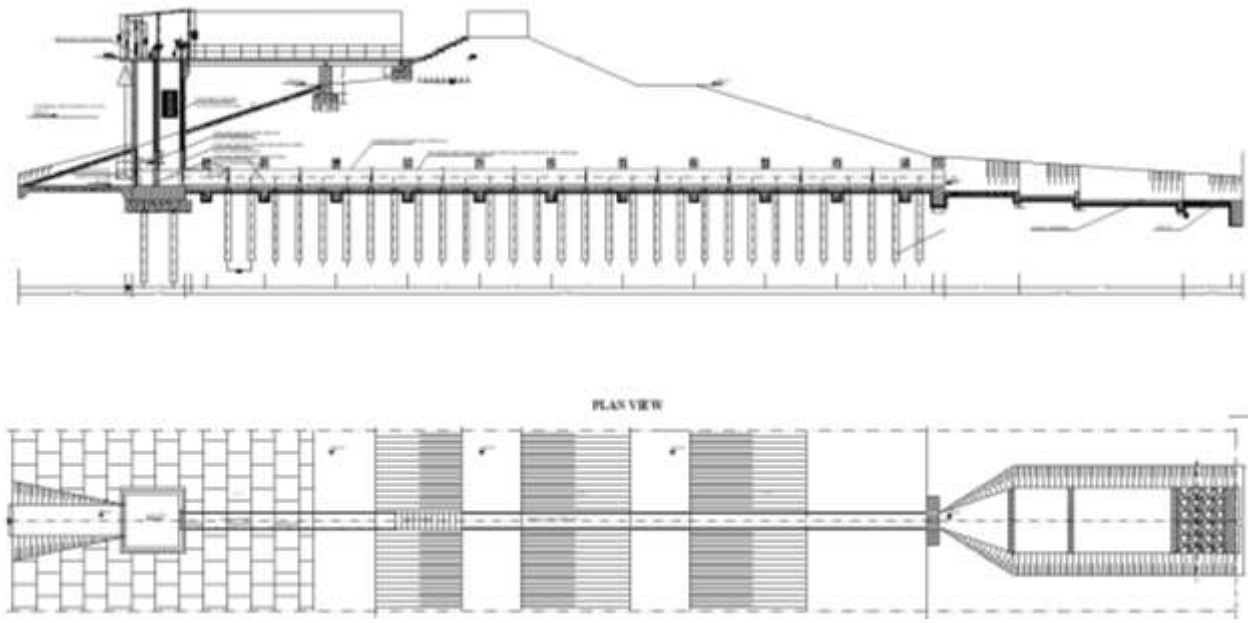


Figure 4 **Bottom outlet - longitudinal and plan views**

Table 2

**Characteristic levels and volumes**

| Parameters | Characteristic levels | Meters above Black Sea Level |
|---|---|---|
| Parameters determined by structural characteristics | - bottom outlet sill | 95.98 |
| | – intake level for irrigation water | 99.47 |
| | - medium waters spillway – operation tower | 103.23 |
| | - surface outlet - threshold weir | 105.13 |
| | - dam canopy | 108.25 |
| Parameters determined by the operating conditions | - normal retention level-N.R.L. | 103.23 |
| | - 2% probability of exceedance | 105.53 |
| | - 0.5% probability of exceedance | 106.04 |
| | ***Volumes*** | $hm^3$ |
| Parameters determined by the operating conditions | - global (at dam canopy) | 25.869 |
| | - 2% probability level | 16.209 |
| | - at surface outlet - threshold weir | 14.923 |
| | - at N.R.L. | 9.942 |
| | - total (0.5% probability level) | 18.645 |
| | - atennuation between 2% prob. level and N.R.L. | 6.267 |
| | - atennuation between 0.5% probability level and N.R.L. | 8.703 |
| | - safety (between the 0.5% probability of exceedance level and dam canopy) | 7.224 |

**Component elements of the behaviour monitoring system**

According to the current legislation (NTLH–021/2002), for the **Negreni** dam it was calculated a 0.31 risk index (established in the authorization for the safety in exploitation - number 545/2-23.12.2015), that fits the reservoir in „**B - special**”, category of importance. Monitoring behaviour is done accordingly to the „Project of special monitoring”.

**Measuring installations for external stresses**

- **3 vertical hydrometric stations are used to monitor hydrometric parameters for Negreni reservoir:**

- at the Downstream Cal Alb hydrometric station for tracking the evolution of inflow to the lake;

- on the upstream dam slope, near the operation tower, for tracking the evolution of the levels/volumes in the lake;

- at the surface outlet, downstream the threshold weir, for tracking spillway flows;

- at the Downstream Negreni hydrometric station for tracking the evolution of outflow from the lake;

To follow the evolution of hydrological parameters in the reservoir and at the downstream hydrometric station a collecting/data transmission system for water management is in use a level sensor at the operation tower for real-time transmission of the data to the local dispatch and other levels of analysis: Botoșani Water Management System and Prut-Bârlad Water Basinal Administration.

- 1 rain gauge to measure rainfalls in the catchment of the reservoir (located near Negreni dam)

**Measuring installations of the dam response to stress**

- For tracking the evolution of **vertical deformations** are used:

- 37 vertical axis landmarks on the dam;
- 3 fixed landmarks (1 - in the left embankment of the dam and 2 - in the right embankment);

- For tracking the evolution of body dam seepage 9 piezometric wells, and 2 outlet conduits for the dam seepage in the left and right branch in the bottom outlet channel are used;

## RESULTS AND DISCUTIONS

### Recording and analysis of special events in the behaviour of Negreni reservoir

**External stresses recorded during the years 2000 – 2020**

The database with water levels in the reservoir, rainfalls, floods recorded between the years 2000 - 2020, provided by the Water Basinal Adminstration Prut-Barlad, was used for the interpretation of the reservoir behaviour *(table 3).*

Table 3

**External stresses between the years 2000 and 2020**

| Year | Water level (maSL) | | | Level difference (m) | Precipitation (mm) | | |
|---|---|---|---|---|---|---|---|
| | Maximum level | Minimum level | Average level | | Annual total | Maximum | |
| | | | | | | daily | monthly |
| **2000** | 103.72 | 101.65 | 102.09 | 2.07 | 501.60 | 232.10 | 133.00 |
| **2001** | 102.55 | 101.53 | 101.90 | 1.02 | 736.90 | 171.50 | 94.20 |
| **2002** | 102.70 | 101.82 | 102.24 | 0.88 | 459.00 | 126.60 | 28.60 |
| **2003** | 103.75 | 100.94 | 101.98 | 2.81 | 276.40 | 76.40 | 22.00 |
| **2004** | 102.10 | 100.71 | 101.36 | 1.39 | 318.80 | 84.30 | 27.00 |
| **2005** | 104.39 | 100.93 | 101.98 | 3.46 | 566.90 | 158.80 | 86.10 |
| **2006** | **104.99** | 101.80 | 102.43 | 3.10 | 469.20 | 104.30 | 41.00 |
| **2007** | 101.90 | 101.04 | 101.50 | 0.86 | 489.00 | 104.30 | 52.00 |
| **2008** | 102.77 | 101.31 | 102.09 | 1.46 | 588.50 | 126.40 | 52.00 |
| **2009** | 103.05 | 101.60 | 102.06 | 1.45 | 416.60 | 77.80 | 41.50 |
| **2010** | 104.29 | 101.55 | 102.11 | 2.74 | 522.70 | 226.60 | 84.50 |
| **2011** | 102.40 | 100.98 | 101.57 | 1.42 | 288.10 | 83.00 | 23.50 |
| **2012** | 102.10 | 100.76 | 101.35 | 1.34 | 385.00 | 69.90 | 35.90 |
| **2013** | 102.46 | 100.80 | 101.46 | 1.66 | 492.00 | 114.10 | 35.00 |
| **2014** | 102.60 | 101.53 | 102.01 | 1.07 | 575.20 | 222.40 | 74.40 |
| **2015** | 102.87 | 101.63 | 102.29 | 1.24 | 225.60 | 46.10 | 28.00 |
| **2016** | 101.55 | 100.58 | 101.09 | 0.97 | 470.50 | 110.30 | 37.20 |
| **2017** | 101.55 | 98.22 | 100.86 | 3.33 | 418.6 | 91.1 | 30 |
| **2018** | 99.46 | **97.77** | 98.83 | 1.69 | 433.7 | 104.3 | 25 |
| **2019** | 101.23 | 99.48 | 100.62 | 1.75 | 303.2 | 112.0 | 30 |
| **2020** | 101.16 | 100.16 | 100.66 | 1.0 | 567.6 | 120.0 | 47 |

We can observe that the maximum water level in the reservoir (104.99 maBS) was inferior with 0,14 m to the surface outlet - threshold weir (105.13 maBS in the year 2006, before the recent measurements). The surface spillway that was deteriorated during the evacuation of flows was later repaired, during the works implemented under the project *„Safety re-inforcement of Negreni reservoir, located on the Baseu River, in Botoșani county”*.

Figure 5 shows a comparison of the monthly registered precipitations at the Negreni reservoir with the average multi annual values for Botoșani county, in a 20 years period (*figure 5*). We can noticed that the precipitations recorded at the rain gauge usualy follow the multiannual trend, but the years 2000, 2010 and 2014 had a very rainy summer, as precipitations registered in June surpassed the value of 220 l/m$^2$.

The catchment of Baseu River is characterized by an average of maximum daily precipitations of 10,0 mm, thet occur mostly in the summer. The historical maximum precipitation of 111,0 mm was registered in the 11$^{th}$ of July 2000.

**Visual observations**

**a) Integrity of the structure, including the foundation and the embankments**

The visual observations made by the operation personnel didn’t reveal any significant structural changes of the dam’s body and foundation, or of the embankments.

Following the rehabilitation works, the left embankment consolidation that was made with geotextile large bags was in affected by the water level fluctuations in the reservoir. In the years 2015-2016 remediation works were carried out by the exploitation personnel.

**b) Reservoir and embankments**

No changes in embankments or lake borderline geometry were reported and no ravines, landslides or leakings were revealed.

**c) Outlets**The outlets of the Negreni dam have a good tehnical status. The technical status of the upstream and downstream channels is also very good.

**e) Hydro-mechanical equipments**

The hydro-mechanical equipments were rehabilitated in the year 2012 and they still function very well.

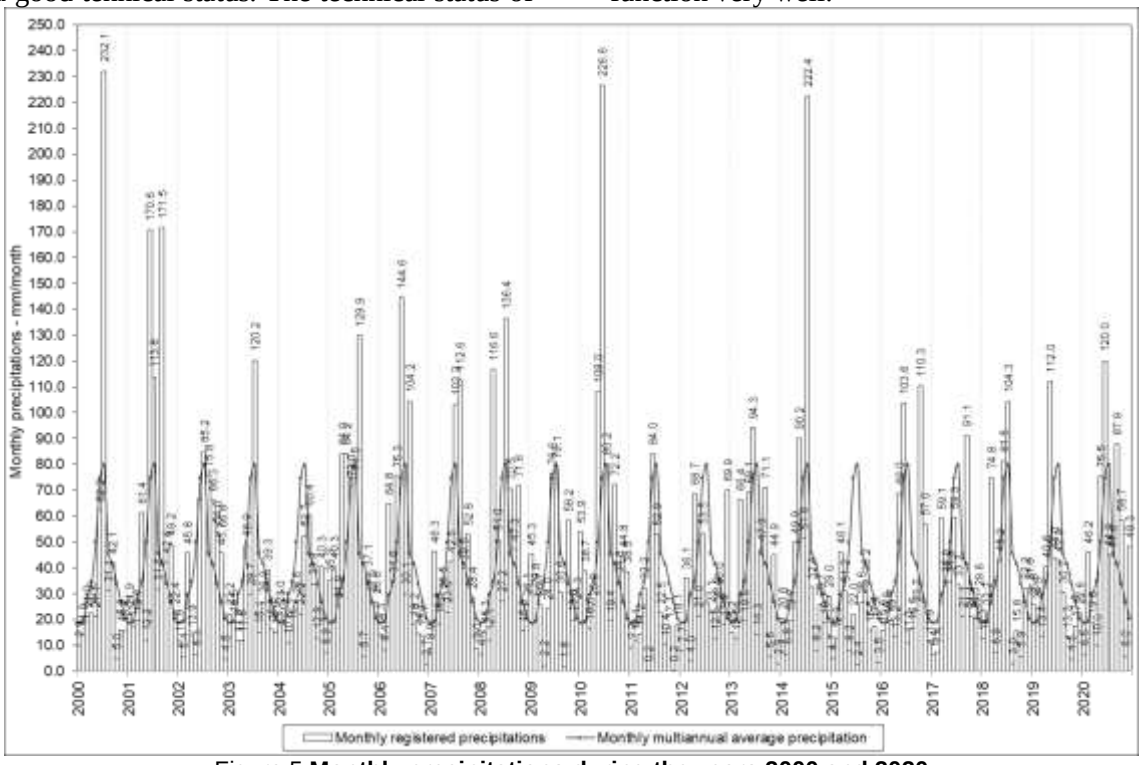


Figure 5 **Monthly precipitations during the years 2000 and 2020**

**Evolution of monitored parameters**

Analysis of the behaviour in time of the reservoir was done studying the evolution of the response parameters (hydrostatic level in the piezometric wells, infiltrations, vertical deformations) to the external stresses.

Data interpretation was completed by direct visual observations made during the entire existence period of the Negreni reservoir.

**a) Infiltrations**

The variation of the hydrostatic levels in the piezometric wells was the first response of dam body to the external stresses: reservoir water level variations, rainfalls and temperatures. Suggestive graphics were drawn with the hydrostatic levels in the piezometers, the precipitations in the dam area and the water level in the reservoir during the analyzed period of time 2000 – 2020. The graphics have shown a good correlation between the water level in the reservoir and the hydrostatic level in the piezometric wells.

Depression curves drawn for the five control sections occupy small areas of the dam body, as the seepage waters are collected by the filter drain and then routed through collection - evacuation culverts to the evacuation channel of the bottom outlet channel. The depressions curves follow the initial prognosis and the design behaviour models, as they are below the designed depression curves.

The drainage system of dam consists mainly of the draining mattress and the draining wells and the collection - evacuation culverts, that are monitored in the 2 outlet conduits for the dam seepage in the left and right branch in the bottom outlet channel.

The measuring points of seepage through the dam are positioned at a lower elevation, in the bottom outlet channel. The extreme values of the flows in the analyzed period of time were 0.0005 l/s in the right branch and 0.037-0.058 l/s in the left branch.

Some seepage problems can be evaluated through the use of graphs and charts available from published literature. These simplified methods depend on saturated flow theory and highly idealized conditions may be appropriate for preliminary evaluations of seepage issues (Ibtesam R.K. et al, 2013).

The seepage through an earth dam or a rock-fill dam generally correlates with the reservoir water level of the dam. Abnormal seepage problems, such as piping in the core zone of the dam, can be detected by carefully analyzing the relationship between the reservoir water level and

the seepage rate. The seepage rate through a dam should be measured and used as a basis of a seepage stability evaluation (Jong-Wook L. *et al*., 2018).

**Hydro isohypses**

Hydraulic head is the elevation to which water will naturally rise in a piezometer (a.k.a. "static level). Hydro isohypses represent the lines joining points with the same value of the absolute quota of the hydrostatic level in the dam body.

For further study of the infiltration regime in the dam, we used SURFER program to draw the hydro isohypses for the Negreni dam using the maximum hydrostatic levels in the piezometers measured in the year 2020.

A project was built to create the digital map of the dam composed of several layers: polygons for the component parts of the dam, contour lines, hydro isohypses contour.

We have provided SURFER with the locations of the piezometers (the X-Y coordinates) and the depth to the hydraulic head (the Z value) in the form of an XYZ data file. We used 9 points for the piezometers, 2 points for the downstream draining pipe, and 10 points for the water retention level (101.16 maSL) in the reservoir, along the upstream of dam.

In the plot window, we clicked the **Map| New|Contour Map** command. We selected the data file created in the previous step and clicked *Open* to create a contour map displaying the data locations with Z value labels.

The distribution of the hydro isohypses across the dam is strongly influenced by the location of the piezometers and the other points of measuring the hydraulic head.

**b) Compactions**

During Mai 1991 – May 2020, 31 cycles of observation were carried out.

Using the overlay maps capability of the **Surfer program** we added a new map in the Object Manager, by using the **Map|Add** command (*figure 6*).

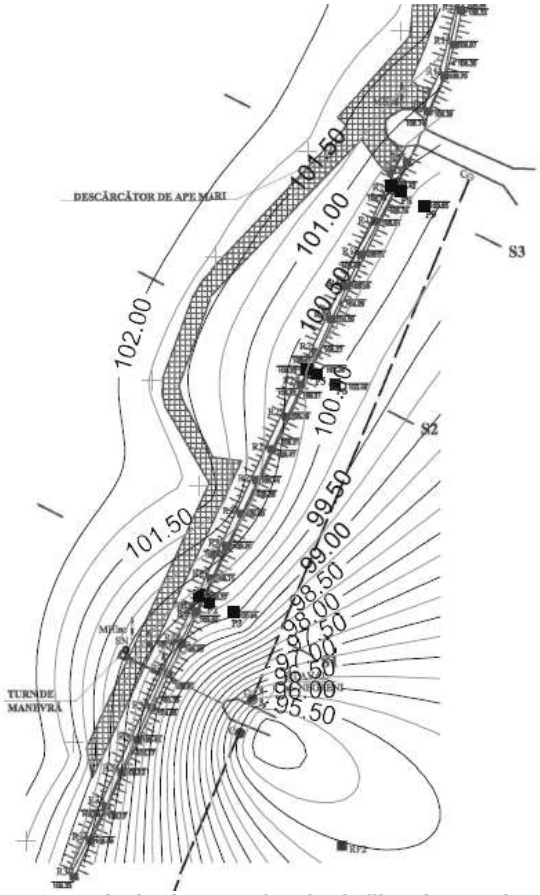


Figure 6 **Hydroisohypses for the infiltration regime**

Observations were made on a number of 39 mobile landmarks for compaction, planted on the dam canopy.

By analyzing the temporal evolution chart of the vertical deformations we have observed a normal evolution of the compaction phenomenon. *(figure 7*).

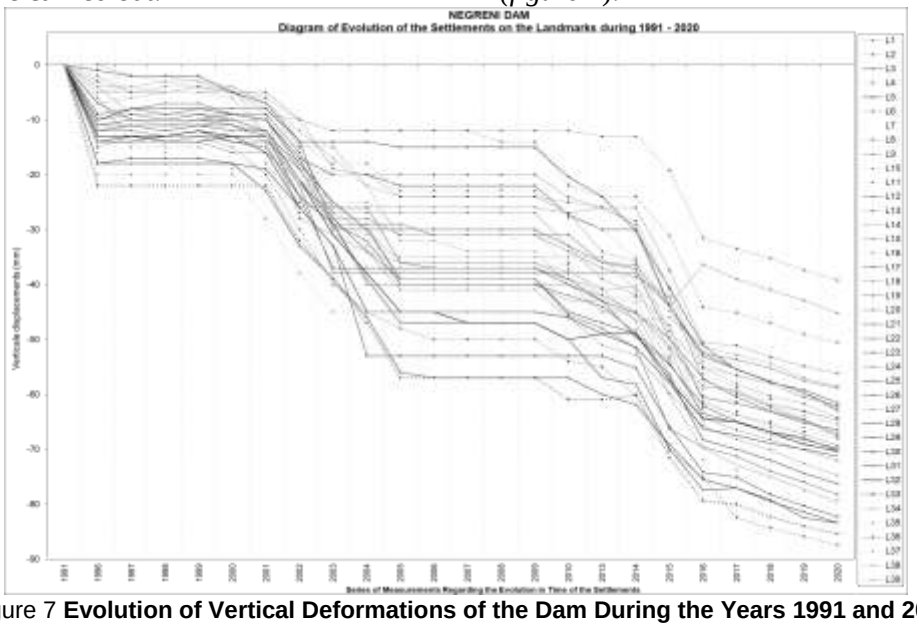


Figure 7 **Evolution of Vertical Deformations of the Dam During the Years 1991 and 2020**

## CONCLUSIONS

The exploitation of Negreni reservoir is done with an increased degree of safety. The behaviour monitoring of Negreni reservoir is recommended to be continued accordingly to the "Project of special monitoring" approved by the National Administration Romanian Waters.

The behaviour in time monitoring performed by interpreting the visual observations and the measurement data from gauges, in relation to external stresses on the dam, allows rapid reporting of exceedances of critical thresholds at monitored elements and of the atypical behaviours of the dam.

The investment works that were implemented, under the project *„Safety re-inforcement of the Negreni reservoir located in river Baseu catchment area, in Botosani county"* have significantly improved the technical status of the dam and ensured the safe exploitation of the reservoir.

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