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BARBARA BUDZIŁO*, JACEK FILIMOWSKI*

RELIABILITY ASSESSMENT OF SELECTED DRAINAGE WATER INTAKES**

Intakes with inlets in the form of drains, usually made of perforated pipes, in most cases laid under the bottom of a watercourse using the opencast method, are called subbottom drainage intakes. The drains may be laid directly in the aquifer or in the packing, or put in concrete flumes which are filled with filter material.

The aim of this work is to assess drainage water intake reliability. Materials collected during field investigations made it possible to determine the reliability indexes of some elements of the drainage water intakes.

1. LITERATURE REVIEW

Investigations conducted in the years 1976–2001 by BUDZIŁO [1], [2] proved that a greater part of the drainage water intakes in southern Poland had drains laid under the watercourse bottom, directly in the aquifer or in specially chosen filter packing. Intakes with drains which are laid in the concrete flumes filled with filter material accounted for 28% of the cases investigated. Drainage water intakes are built in various countries of America and Europe [3]–[5], [9]. In some countries, they are called unconventional intakes. The drainage water intakes are especially useful in the regions where sludge-ice phenomena occur. Similarly, drainage water intakes are built under difficult conditions prevailing in rivers in Siberia, especially in Yakutia and Chukotka. Investigations of the intakes of this type have been conducted for a number of years. In consideration of the difficult conditions for drawing water, various solutions were proposed [5], [8], [9].

Research on silting-up has been conducted by SERGUTIN, TURUTIN [8] and PORYADIN [5]. They conclude that this process depends on the ratio of the amount of surface water to the ground water drawn. The regeneration of filter packing may be

* Institute of Water Supply and Environmental Protection, Kraków University of Technology, e-mail: basiab@vistula.wis.pk.edu.pl

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achieved by forcing a jet of water and air under pressure into a drain [1], [2], [5]. This should be done in the following sequence: air is forced in, in order to aerate the packing and to break the silted-up layer, and then the water jet is forced in under pressure. The example of the regeneration of the drain filter layer which finally increases the drain capacity is presented by PORYADIN [5]. The author describes regeneration methods for drains laid directly in the aquifer.

According to VDOVIN [9] a total thickness of packing should be confined within the range between 0.5 [m] and 0.7 [m]. Having taken grain diameters of ca. 25–50 [mm], he recommends washing velocities of 0.7–1.0 [m/s]. In the USA, four intake types (bank river intakes with movable racks, infiltration intakes with drains under the watercourse and perforated pipes above the bottom in the river and in the circulation channel) were investigated, taking into consideration their influence on the environment [6], [7]. Attention was paid to the danger of ecosystem disturbance connected with losses of macroscopic planktonic organisms and juvenile fish due to drawing water from a river. Ease of construction, operational difficulties, anticipated maintenance requirements, reliability and the labour demand of the project were taken into consideration. It was concluded that intakes with drains under the river bottom and perforated pipes laid above the bottom were the most advisable for the protection of fry and plankton. The only disadvantageous influence of intakes of this type on fry and plankton occurs just as the drains are washed (increased turbidity in the watercourse). To sum up the literature review, it may be stated that the hitherto investigations of surface water intakes have not been conducted on a scale which would make it possible to assess the operation of drainage water intakes.

2. METHODOLOGY OF INVESTIGATIONS AND THE FORMULAE APPLIED

In the years 2001–2005, field investigations were conducted in order to collect material which would make it possible to assess the operational reliability of drainage water intakes. The analysis covered specific units of a water intake, such as: water source, draining system, free flow conduit, and collecting well. The material that was collected referred to: structural solutions, operational conditions, failures (type, causes, duration and way of elimination). The material obtained makes it possible to characterize some units of the drainage water intakes with the help of reliability meters, such as the mean working time (T_p) between failures, the mean renewal time (T_n) and the availability index (K). The calculations were based on the following formulae:

- Mean working time between failures T_p:

$$T_p = \frac{1}{N_p}\left(T - \sum_{i=1}^{N_u} t_{ni}\right) \quad [\text{h}], \tag{1}$$

where: N_p – the number of normal working intervals ($N_p = N_u + 1$ or $N_p = N_u$); T – the time interval under analysis (it contains full cycles of work/renewal) [h]; $\Sigma\, t_n$ – a total duration of renewals [h]; N_u – the number of renewals in the analysed time period.

- Mean renewal time T_n:

$$T_n = \frac{\sum_{i=1}^{N_u} t_{ni}}{N_u} \quad \text{[h]}. \tag{2}$$

- Availability index K:

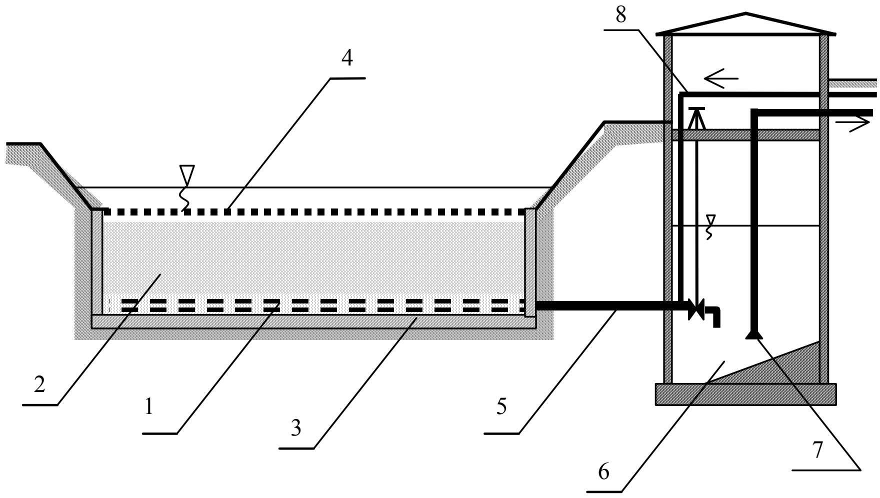
$$K = \frac{T_p}{T_p + T_n}, \tag{3}$$

where: T_p, T_n – as above.

The water intake as a whole is constructed of renewable units which are characterized by the mean working time (T_p) and the mean renewal time (T_n). The condition is: $T_p >> T_n$. Both the failures and the work/renewal time intervals are random. These intervals are mutually independent and have exponential distributions. It is assumed that the flux of failures (equivalently renewals) is made up of the most simple ones (single, stationary and without sequence). The reliability of drainage water intakes was assessed on the basis of the materials obtained from field investigations. For computation purposes, a structural analysis method was applied, using reliability indices. In order to assess the reliability of renewable units, the stationary availability index (K) was determined. This index defines the probability of an event where a unit will still be in a fit condition at a moment considerably distant from the start of its operation in the future. The stationary availability index of the subsystem (K_s) and also the mean working time between failures (T_{ps}) were assumed as measurements of reliability; this is known as two-parametric reliability estimation. The two-parametric reliability estimation of the water intakes under investigation was conducted using the frequency function of failures [1], [2]. Considering the scope of this paper, solely the results of the calculations are presented (see tables 1 and 2).

3. FIELD INVESTIGATIONS OF SELECTED DRAINAGE INTAKES

Investigations of the drainage water intakes (the figure) which were conducted until recently did not include any assessment of the reliability of their functioning. It was therefore decided to undertake repeated investigations which would enable the assessment of the drainage water intakes with regard to reliability factors. The reliability assessment focussed on a single drain, all the drains and also drainage water intakes (i.e., drainage, free-flow conduit and collecting well). In the years 2001–2005, identification of drainage water intakes was undertaken in southern Poland, which confirmed the existence of more than 40 currently-operated drainage water intakes. Out of these, above 80% are operated for municipal purposes. Considering the possibility of collecting reliable information for investigations, 14 intakes were selected. These intakes are compared in table 1. The capacity of these intakes ranges from 0.13 to 0.002 [m^3/s]. The materials that were collected concerned the reliability, the technical parameters and the operational problems of the water intakes investigated (such as drain washing, exchange or renewal of filter packing, collecting-well cleaning and the like).



Drainage water intake with drains laid in concrete flumes:
1 – drain, 2 – filter packing, 3 – concrete flume, 4 – perforated plate or rack,
5 – free flow conduit, 6 – collecting well, 7 – suction pipeline, 8 – washing pipeline

A penetrating analysis of the operational documentation of the investigated water intakes supplemented and verified the recorded data on the basis of information obtained by interviewing plant managers, maintenance technicians and repair team leaders.

The activity documentation of laboratories was analyzed with special regard to information on incidental pollution of water sources and increased water turbidity. On the basis of the data collected, the technical and operational parameters of the water intakes under investigation were determined. Further processing of the materials obtained made it possible to determine the reliability parameters of the water intakes investigated and their drainage. In the case of the drainage water intakes which

Table 1

Technical and reliability parameters of drainage in the water intakes investigated

Location/ watercourse	Capacity Q_{av} [dm^3/s]	Number of drains	Length of drainage [m]	Drain diameter [mm]	Drain material	Depth of drain foundation	Number of packing layers	Concrete flume	Regular drain washing	Mean working time	Mean renewal time	Stationary index of drainage availability
Andrychów Targaniczanka	21.5	5	75	300	steel	1.5	2	0	0	2909.3	14.7	0.9949726
Andrychów Wieprzówka	16.2	2	40	300	PVC	1.5	2	0	0	2184.5	8.5	0.9961240
Barwinek No name	0.4	1	1.2	300	steel	1.3	3	X	0	2186.0	4.0	0.9981735
Dukla Chyrowski	4.0	4	8	100	steel	1.6	2	X	X	8752.0	8.0	0.9990868
Dukla No name	2.7	3	6	100	steel	1.6	2	X	X	8754.0	6.0	0.9993151
Jedlicze Jasiołka	72.2	12	240	200	PVC	0.8	2	X	X	972.3	1.0	0.9989726
Kalwaria Cedron	2.0	1	8	200	steel	1.5	2	0	X	4169.9	4.0	0.9990417
Limanowa Łososina	44.0	2	68	400	steel	1.5	1	X	0	4376.0	7.0	0.9984092
Rabka “Old intake” Poniczanka	8.3	1	15	400	steel	0.5	1	0	0	4291.9	5.0	0.9988364
Rabka “New intake” Poniczanka	23.6	2 1	30 +10 40	350	steel	1.1 0.5	2	X	0	4297.1	6.0	0.9986057
Skawina Skawinka	41.7	13	156	150	PVC	1.0	2	X	X	546.5	0.5	0.9990859
Stronie No name	2.0	2	6	150	PVC	1.0	1	X	0	8750.0	10.0	0.9988584
Tymbark Lososina	17.9	3	90	250	stone-ware	2.0	3	0	0	6728.9	14.8	0.9977994
Wadowice Skawa	27.8	1	42	300	steel	1.5	3	0	0	11684.7	5.0	0.9995723
Andrychów Targaniczanka	21.5	5	75	300	steel	1.5	2	0	0	2909.3	14.7	0.9949726

Explanations: X – there is one, 0 – there is none.

Table 2

Reliability indices of investigated drainage and coupled water intakes

Location/watercourse	KS_{rW}	Water intake type	Tp_{UjW} [h]	Tn_{UjW} [h]	K_{UjW}
Andrychów Targaniczanka	0.9987947	drainage	2300.6	17.2	0.9925626
Andrychów Wieprzówka	0.9991420	coupled water intakes (drainage + submerged ones, parallel structure)	28144.0	25.1	0.9991108
Barwinek Stream "without a name"	0.9990868	drainage	714.6	2.30	0.9967911
Dukla Potok Chyrowski Stream "without a name"	0.9937528 0.9990868	coupled water intakes (two drainage intakes, parallel structure)	37756.1	8.2	0.9997821
Jedlicze Jasiołka	0.9989459	drainage	780.6	1.6	0.9979157
Kalwaria Cedron	0.9940277	drainage	1839.2	16.7	0.9909805
Limanowa Łososina	0.9974016	drainage	1601.3	7.9	0.9950620
Rabka Poniczanka	0.9859620	two drainage intakes (series structure)	822.3	14.8	0.9823428
Skawina Skawinka	0.9963000	coupled water intakes (drainage + intake with bottom rack, parallel structure)	2473.2	9.7	0.9960926
Stronie Stream "without a name"	0.9976283	drainage	5466.0	21.4	0.9961077
Tymbark Łososina	0.9989598	drainage	5359.1	18.5	0.9965588
Wadowice Skawa	0.9973302	drainage	2463.2	8.6	0.9965180

worked in assemblies, the reliability parameters of these assemblies were determined. On the basis of investigations conducted (table 1) it has been determined that a greater part of the water intakes have drains made of steel (about 65% of cases), in 4 cases of plastics (PVC), and in one case of stoneware. The drain diameters range from 100 to 400 [mm]. Almost 60% of the water intakes investigated have drains laid in concrete flumes and the remaining ones directly in the ground. The drain foundation depth ranges from 0.5 to 2.0 [m]. Water from drains runs off through free flow conduits in all the water intakes investigated. Pipelines supply water to collecting wells or chambers. The length of the pipelines ranges from 5 to 370 [m]. In twelve water intakes investigated, drains were covered with artificially selected filter, while in two cases native material was applied. In eleven cases, two-layer or three-layer packing was applied, and in the remaining cases – a single-layer one. The users of more than half of the investigated drainage water intakes who do not have their own drainage-washing installations use motor trucks for drain washing, however not more often than twice a year. Above 35% of the intakes examined have their own washing installations. In these cases, the drain washing is done regularly, at least once a week. In one case, the drainage is not washed (the water intake from the stream “without a name” in Stronie) but, once a year, packing renewal is done.

The silting-up of the filter layer, which decreases drainage capacity, is the main cause of failures in the water intakes investigated. This problem occurs more often in intakes where drainage washing is not done regularly (due to lack of own washing installations). Drainage reliability indices for the drainage (i.e., inlet) (table 1) and the water source (table 2) are calculated according to formulae (1), (2), and (3). The calculated drainage availability index for these cases (table 1) (apart from the water intake drainage in Wadowice) ranges from 0.9949726 to 0.9988584. The water intake from the Skawa river in Wadowice is characterized by a high reliability level, in spite of the fact that no regular drainage washing is undertaken there. The drain laid in the aquifer under the river bottom in the packing is fed by superficial and ground waters. An intake of this type is distinguished by better operational conditions and, as investigations indicate, by lesser problems connected with silting. For water intakes furnished with washing installations, the drainage availability index of 0.9989726 to 0.9993151 (table 1) is taken. The stationary reliability index of the individual drains examined ranges from 0.9981735 to 0.9995723. The mean working time between failures for individual drains ranges from 2186.0 to 11684.7 [h], and the mean renewal time ranges from 4 to 5 [h] (table 1). The silting of the filter packing necessitates intake shut-downs in order to restore the nominal drainage capacity. The users of the water intakes examined achieve this goal by washing the drainages, and when this proves unsatisfactory, they either renovate or replace the filter packing. A mean working time between renovations or replacements of the filter packing ranges from 546.5 [h] to 4376.0 [h]. The mean time of the renovation of drains ranges from 4 [h] to 15 [h] (table 1). The reliability charts for the water intakes investigated are developed on the basis of technological flowcharts and the results of the calculations are presented in table 2.

The stationary availability index (table 2) of the drainage water intakes investigated (K_{ujw}) ranges from 0.9823428 to 0.9979157. For coupled intakes, i.e. drainage-submerged ones or drainage-and-bottom-rack ones, this index ranges from 0.9823428 to 0.9997821.

The coupled water intakes for the town of Dukla have the highest reliability level. These intakes are composed of two drainage intakes which are connected by a joint collecting well. They draw water from different sources, independent of one another.

The availability index of water sources (K_{Srw}, table 2) ranged from 0.9859620 to 0.9991420.

4. CONCLUSIONS

An analysis of the results of the investigations enables one to present the following conclusions:

• Adequate choice of filter packing has significant influence on the normal functioning of an intake (the proposed grain coarseness is between 25 and 50 [mm], since such a diameter ensures stoppage of pollutants and regeneration of packing without causing any damage when washing).

• The perforation degree of the drain surface is taken in the range from 10 to 15% and substantially influences the capacity of drains while the spacing of orifices is of only minor significance. Laser-made orifices (widening towards the inside in the section) reduce loss of energy and provide protection from stoppage.

• Systematic drainage washing prevents the decrease of water intake capacity.

• The ratio of the mean flow velocity in the watercourse (V_p) to inlet velocity in the filter packing (V_f) has essential impact on both bottom erosion and protection of living organisms (plankton, fry).

• Drainage water intakes perform their function under difficult operational conditions (ice-sludge phenomena, considerable fluctuations of water levels).

• Systematic drain washing is advisable for increasing the reliability of drainage water intakes.

• Feeding drains with surface and ground waters prolongs the failure-free working period of drainage (the water intake in Wadowice).

• Placement of drains in concrete flumes makes drainage washing easy and at the same time it makes it impossible to feed drains with ground waters.

• The ability of drainage water intakes to draw water with a higher purity level than in other surface water intakes makes users interested in the development and modernization of these intakes.

• Coupled intakes which work with redundancy show a high reliability level and ensure better functioning (for example, drainage intakes and intakes with a bottom rack, or submerged-drainage intakes).

The reliability indices obtained for drainage water intakes are used in the calculational program which enables the choice of an adequate solution from the range of acceptable solutions to ensure the required reliability level and to minimize the costs.

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OCENA NIEZAWODNOŚCI WYBRANYCH DRENAŻOWYCH UJĘĆ WODY

Poddennymi, drenażowymi ujęciami wody nazywamy takie ujęcia, których czerpnią są dreny, zazwyczaj w postaci rur perforowanych założonych najczęściej metodą odkrywkową pod dnem cieku. Dreny mogą być ułożone bezpośrednio w warstwie wodonośnej lub w obsypce, lub umieszczone w wypełnionych materiałem filtracyjnym betonowych korytach.

Celem pracy była ocena niezawodności drenażowych ujęć wody. Zebrane materiały z badań terenowych umożliwiły wyznaczenie wskaźników niezawodności niektórych elementów drenażowych ujęć wody. Przedstawiono wyniki przeprowadzonej oceny niezawodnościowej dwuparametrycznej badanych drenażowych ujęć wody.