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A New Method of Water Supply in Crisis Situation

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Abstract: When it is not possible to supply water through the water supply network, it is necessary to use other resources of the water supply company, e.g., water tanker. This requires maintaining the efficiency of alternative water sources (in terms of quality and quantity). This work focuses on the possibility of using water accumulated in water pipes in a crisis situation. This work proposes a drain well to supply the population with water in a crisis situation. Thanks to this solution, the function of water supply drainage can be combined with the possibility of obtaining water accumulated in water pipes in crisis conditions. In addition, the standards for water demand in a crisis situation are analyzed. This work extends the view on the problem of water supply to residents in a crisis situation by taking into account a new solution that allows the consumption of water accumulated in water pipes.

Keywords: water supply system; lack of water supply; crisis situation; power blackout

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1. Introduction

The water supply system (WSS) is an important element of critical infrastructure, which is subject to increasingly stringent requirements in terms of resistance and maintaining operation in crisis situations. It should be understood as a situation that has a negative impact on the level of people safety, property, or the environment, which causes significant limitations in the operation of public administration bodies due to the inadequacy of the available forces and resources [1]. In the event of a crisis situation in the WSS, caused, e.g., by a power blackout, failure of the pumping station, failure of the main pipe, or warfare, the pressure in the water supply network drops, which prevents the supply of water to recipients [2–5]. Water accumulated in water pipes cannot be used.

In addition to natural hazards related to extreme weather conditions and technical hazards related to the functioning of the WSS, there are more and more new civilization-related hazards [6–8]. These hazards are primarily related to cybercrime; the energy crisis, which intensifies the risk of long-term failures of electrical power supply; the current geopolitical situation; and tension on the international arena [9,10]. The indicated threats, combined with climate change, mean that the probability of an event related to the lack of water supply to consumers is increasing. The negative psychological effect caused by the water crisis should also be emphasized, including anxiety and health concerns [11,12]. This should motivate the managers of the WSS to both improve the hazard detection system and build the potential to reduce the negative effects after their occurrence.

For several years, there has been a noticeable change in the way of thinking about accidents in water supply systems. The traditional, reliability approach "an accident is an unpredictable event that occurs randomly" has been supplemented by the statement "an accident is an event that causes losses that can be predicted". The approach based on hazard prevention significantly reduces the probability of an accident and the magnitude of its consequences. Risk management and related risk mitigation measures are required by the Directive (EU) 2020/2184 of the European Parliament and of the Council [13]. This approach is also in line with the recommendations of the World Health Organization on water safety plans [14] and EN 15975-1 [15] and EN 15975-2 [16].

A power blackout is a sudden and unexpected power system failure that occurs over a large area and causes a long-term interruption in electricity supply [17]. A power blackout is one of the greatest hazards to the continuity of drinking water supply. Currently, it is impossible to operate the WSS without access to electricity. The operation of the WSS is indispensably connected with the use of electricity and its absence makes it impossible to supply water, both in terms of quantity and quality [18]. The lack of preparation for the occurrence of such events may result in the need to suspend the operation of the WSS. It is becoming more and more common to equip water supply devices with backup sources of electrical power supply, which will enable operation in crisis conditions. Particularly, strategic water supply facilities and selected emergency wells should be able to be supplied from power generators that are permanently installed or moved in the area of the WSS. A significant limitation in this case is the accumulation of an appropriate fuel supply.

Hazards related to contamination or limited access to drinking water, especially in the era of hybrid hazards, are important aspects of planning and of the strategy of states, armed forces, organizations and corporations [19,20]. This requires the diversification of water resources and the search for new opportunities to obtain water, especially in crisis situations [21]. There are known solutions to limit the lack of water supply in the event of a crisis situation. One of them is the delivery of water to recipients using appropriate means of transport, e.g., water tankers or vehicles for transporting pallets of bottles [22]. This is a commonly used solution. However, it requires the maintenance of emergency water sources (in terms of quality and quantity) and the provision of transport and water distribution equipment [23]. The second solution is the use of automatic water packers. However, these devices have low efficiency and require constant access to drinking water. Water can also be drawn from water tanks if they are equipped with appropriate connection pipes. All current solutions used in the event of a lack of water supply are based on obtaining water from external sources and delivering it to recipients, bypassing the water supply network. These methods work well during failures of short duration, i.e., up to one day. A number of solutions in the field of water treatment and distribution in crisis conditions are available to the Armed Forces of individual countries [24,25]. These solutions can be used by civil defense when it is necessary to supply water for consumption to the injured population. An important aspect is also maintaining the efficiency of alternative water sources [26,27]. It should also be emphasized that in the event of a crisis, people buy significant amounts of food and mineral water from shops, as well as flashlights, batteries, and candles. In the context of progressing climate change, significant research is being conducted on the effectiveness of new sources of water acquisition, including [28–30]. Strengthening the ability to adapt to climate change, extreme weather events, drought, floods, and other disasters (including a power blackout) is consistent with the UN Sustainable Development Goals [31]. Scientists, risk practitioners, and policymakers are increasingly concerned about the resilience of critical infrastructure in the context of natural hazards and disasters [32].

The occurrence of a long-term, large-scale power blackout will make the solutions used so far in the field of crisis water supply ineffective. The delivery of water by tankers will be difficult due to problems with fuel supply. In cities, due to the inoperative traffic lights, there will be chaos in transport. Due to these problems, some people will not show up for work, which will result in staff shortages. The possibility to buy drinking water in stores will be limited. Many stores, especially chain stores, will be closed due to the downtime of computer systems and interruptions in the supply of goods. There will be no cashless sales, and most people will not have access to cash because ATMs will not work. People accustomed to non-cash payments have modest cash reserves [9]. It can therefore be expected that the issue of effective water supply to the population in the event of a crisis situation, and, above all, large-scale failures of electric power systems, will gain in importance. The search for new, technical solutions for water supply in a crisis situation is appropriate from the point of view of ensuring an appropriate level of safety [33,34].

The aim of this work is to present a new concept of a drain well to supply the population with water in a crisis situation. This solution makes it possible to obtain water accumulated in water pipes in various parts of the city. The scope of this work does not include accumulated water quality assessment. The quality of the accumulated water is of key importance for the possibility of its distribution among people. The quality of water accumulated in the water supply network in Poland is confirmed through water quality tests carried out regularly by the appropriate Poviat Sanitary and Epidemiological Station. Therefore, the quality of the water will be appropriate at the beginning of the crisis situation. As the duration of the crisis situation increases, the risk of secondary water pollution will increase. Analysis of the potential risk of secondary contamination of water and the methods of mitigating it is important in the study of water use possibilities. The aspect of water quality will be taken into account during the next stage of research, i.e., prototype testing.

The problem of crisis demand for water is also analyzed, which has a significant impact on the assessment of the technical possibilities of providing water to the population in crisis situations. This paper contributes to a broader view of water supply in the event of a crisis situation by taking into account a new, previously unconsidered solution for the collection of water accumulated in water pipes. They contain a large amount of drinking water. Due to too low pressure during a crisis situation, especially a power blackout, it cannot be delivered to residents in a conventional manner. The contribution of this study is the creation of the possibility of drawing water from the water supply network using a drain well, which improves the possibilities of water supply to residents in a crisis situation (in terms of quantity). This study also yields several other important benefits, including faster access to water resources (shorter time to deliver water to consumers) and increased support for emergency management services.

2. Demand for Water in Crisis Situations

2.1. Rules for Calculating the Demand for Water in Crisis Situations

In Poland, there are currently no generally applicable regulations regulating the rules for calculating the amount of water demand in crisis conditions. Such regulations are also not covered by current European Union directives. The rules for calculating the demand during the period of limited supplies were set out in the Polish order of the Ministry of Economy and Labor and Social Policy No. 2/95 [35], which is no longer in force. The unit demand for water for the population in the period of necessary supplies was 7.5 L per capita per day; in the case of minimum supplies, 15 L per capita per day; and for public utilities—50% of the normal demand. Because the above legal act has not been replaced by another act, these values are commonly used to determine the volume of water demand in crisis situations in Poland. These values, as a rule, coincide with the information presented in standards and documents applicable in other European countries. The current study in this field is the manual of the international association Sphere, published in 2018 [36], which describes the minimum standards for conducting humanitarian actions in the event of crisis situations. According to them, for survival, a person needs 2.5–3 L of water per day. In some EU Member States, there are national regulations on crisis water supply (e.g., German [37], Austrian [38]). The general division of indicators of unit demand for water in crisis conditions adopted in this work is presented in Figure 1 [1,39]. Maintaining the demand for water at an appropriate level for the population and key facilities (e.g., food production, health care) is necessary to ensure the survival conditions for the population.

In the initial phase of a crisis situation, any alternative water sources should be treated as potentially contaminated and unfit for human consumption. Only the results of microbiological, physicochemical, toxicological, and dosimetric tests of water allow for the evaluation of its suitability for consumption. On their basis, the anti-epidemic authority issues a certificate determining the suitability of water and determines possible treatment procedures. The rule is that if the physicochemical, toxicological, and radiological analysis shows no contamination, the water can be used after disinfection [27,40].

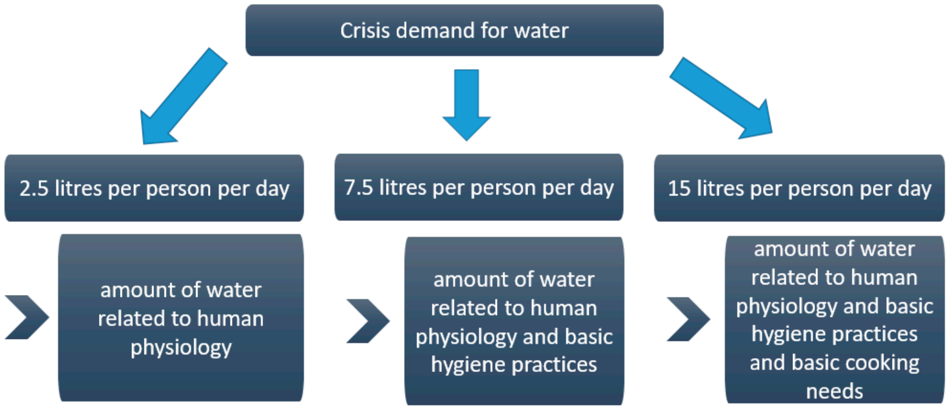


Figure 1. Unitary water demand indicators in a crisis situation.

2.2. Characteristics of the Study Area and Water Balance in Crisis Conditions

This study was conducted in a water supply system located in south-eastern Poland. It is supplied with water by means of a shore-conduit intake with a capacity of 17,280 m^3/d and an underground intake with a capacity of 348 m^3/d. The average daily demand for water in the city was about 5500 m^3/d. The analyzed water supply system supplied water to about 34,500 inhabitants. The water supply network was made in a mixed system. The length of the distribution pipes is approximately 160 km. There are five local pumping stations in the city that increase the water pressure in the water supply network. Within the administrative borders of the city covered by the analysis, there is a division into 16 housing estates [41]. The location of the city against the background of Poland and the administrative division of the city are shown in Figure 2. Taking into account the division into individual housing estates, the demand for water in a crisis situation was determined. The results are presented in Table 1.

Table 1. The balance of the crisis demand for water.

No of Housing Estate (HE)	Number of People Registered	Crisis Demand for Water (m^3/d)		
		2.5 L per Capita per Day	7.5 L per Capita per Day	15 L per Capita per Day
HE 1	814	2.0	6.1	12.2
HE 2	1025	2.6	7.7	15.4
HE 3	1429	3.6	10.7	21.4
HE 4	1090	2.7	8.2	16.4
HE 5	1810	4.5	13.6	27.2
HE 6	764	1.9	5.7	22.9
HE 7	674	1.7	5.1	20.2
HE 8	7013	17.5	52.6	210.4
HE 9	713	1.8	5.3	21.4
HE 10	8158	20.4	61.2	244.7
HE 11	565	1.4	4.2	17.0
HE 12	1234	3.1	9.3	18.5
HE 13	1914	4.8	14.4	28.7
HE 14	4515	11.3	33.9	67.7
HE 15	3611	9.0	27.1	54.2
HE 16	931	2.3	7.0	14.0
In total	36,620	90.7	272.0	543.9

Figure 2. Location of the study area.

According to the presented balance, in order to supply the residents of all city housing estates with drinking water, the following should be provided:

- Amount of water related to human physiology (2.5 L per capita per day)—90.7 m^3/d;
- Amount of water related to human physiology and basic hygiene practices (7.5 L per capita per day)—272.0 m^3/d;
- Amount of water related to human physiology and basic hygiene practices and basic cooking needs (15 L per capita per day)—534.9 m^3/d.

In a crisis situation, the guarantee of water supply in the required amount to residents is most often provided by substitute means in the form of water tankers, adapted to transport and distributed water intended for consumption. Another option is to provide water in 1.5 or 5 L bottles. Table 2 presents the required number of water transport vehicles (capacity 8 m^3) and 1.5 and 5 L bottles needed to supply all residents of the city in a crisis situation.

Table 2. The required number of water tankers and 1.5 and 5 L bottles in a crisis situation, especially a power blackout.

Crisis Demand for Water		Number of Water Tankers with a Capacity of 8 m^3 (3 Trips a Day)	Number of 1.5 L Bottles	Number of 5 L Bottles
amount of water related to human physiology	90.7	4	60,467	18,140
amount of water related to human physiology and basic hygiene practices	272.0	12	181,334	54,400
amount of water related to human physiology, basic hygiene practices, and basic cooking needs	534.9	23	356,600	106,980

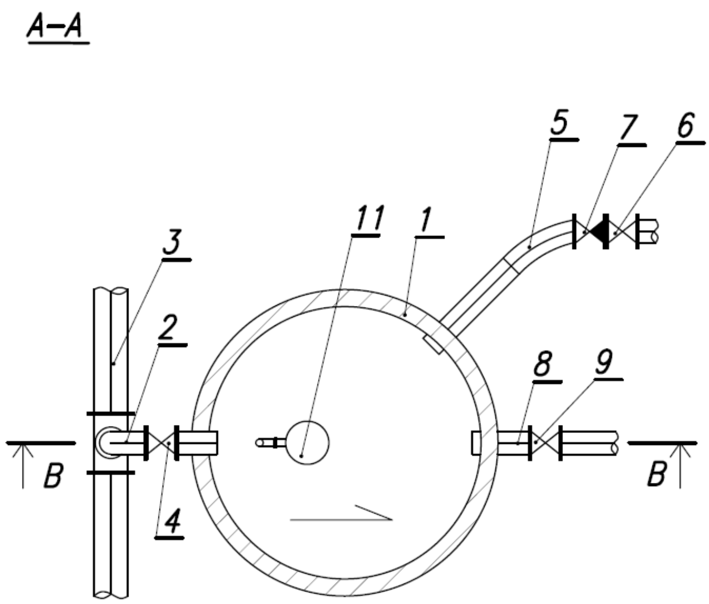
In practice, it is possible to cover the crisis demand for water from external sources and to deliver it using water tankers in an amount that only allows for meeting physiological needs. Water companies do not have enough water tankers to deliver more than

2.5 L per capita per day in the event of a power blackout (even in developed countries). The solution to the need for a quick supply of water during a crisis situation may be the distribution of pallets with 1.5 L bottles (for the needs related to human physiology) in individual housing estates in the city in proportion to the population. The required number of pallets with 1.5 L bottles to provide the amount of water related to human physiology is approximately 120 pallets. Such water should be distributed in selected administrative, educational, sports, or cultural facilities located in a given housing estate. In developed countries, there are recommendations for permanent storage of water at home in an amount of 10 L per capita in the event of a crisis [37,38].

3. The Concept of Obtaining Water from the Water Supply Network in a Crisis Situation

3.1. A Drain Well to Supply the Population with Water in a Crisis Situation

The advantage of the proposed solution is the possibility of using the water accumulated in the water pipes to supply the population with water. A pump is inserted into the well to draw water. The location of the drain well to supply the population with water in a crisis situation does not differ from the currently used drain well, i.e., it is located on the main pipe with a diameter greater than or equal to 250 mm, at the lowest point between two water valves. The introduction of additional equipment to the water supply network does not limit the original function of the drain well, so during normal operation, it can be used to drain the water supply network. It can be easily adapted to different sizes of main pipes. The function of draining the water supply network using a drain well can be combined with obtaining water accumulated in water pipes in crisis conditions. The drain well to supply the population with water in a crisis situation according to this work is shown in Figure 3 (section along the line A-A shown in Figure 4) and Figure 4 (section along the line B-B shown in Figure 3), which shows the drain well during normal operation and during a crisis situation (additionally item 11).



1 – CONCRETE WELL,
2 – PIPE THAT SUPPLY WATER FROM THE WATER MAIN,
3 – WATER MAIN,
4 – WATER VALVE ON THE WATER SUPPLY PIPE,
5 – AN OVERFLOW PIPE THAT DRAINS EXCESS WATER TO THE DRAINAGE PIPE SYSTEMS,
6 – WATER VALVE ON THE OVERFLOW PIPE,
7 – NON-RETURN VALVE ON THE OVERFLOW PIPE,
8 – DRAIN PIPE THAT DRAINS THE WATER INTO THE DRAINAGE PIPE SYSTEMS,
9 – WATER VALVE ON THE DRAIN PIPE,
11 – PORTABLE WATER SUBMERSIBLE PUMP.

Figure 3. A drain well to supply the population with water in a crisis situation—section A-A.

The drain well to supply the population with water in a crisis situation in the embodiment includes a water supply pipe (2) with a water valve (4), an emergency overflow pipe (5) with a non-return valve (7) and a water valve (6), and a drain pipe (8) with a water valve (9). The water supply pipe (2) is located in the upper part of the drain well so that it is above the water table and there is no backflow of water. The emergency overflow pipe (5) determines the level of the maximum water table in the drain well and is located below the water supply pipe (2). The drain pipe (8) is located at the lowest point of the drain well. In crisis conditions, there is a submersible pump (11) in the drain well. The amount of water pumped out will depend on the efficiency of the pump and the amount of water remaining in the water supply system and is regulated by a water valve on the water supply pine. The maximum capacity of the drain well is assumed to be approx. 10 L per second. As the pipeline is emptied, the capacity will decrease. Proper operation of the submersible pump will be ensured by placing the pump below the water table.

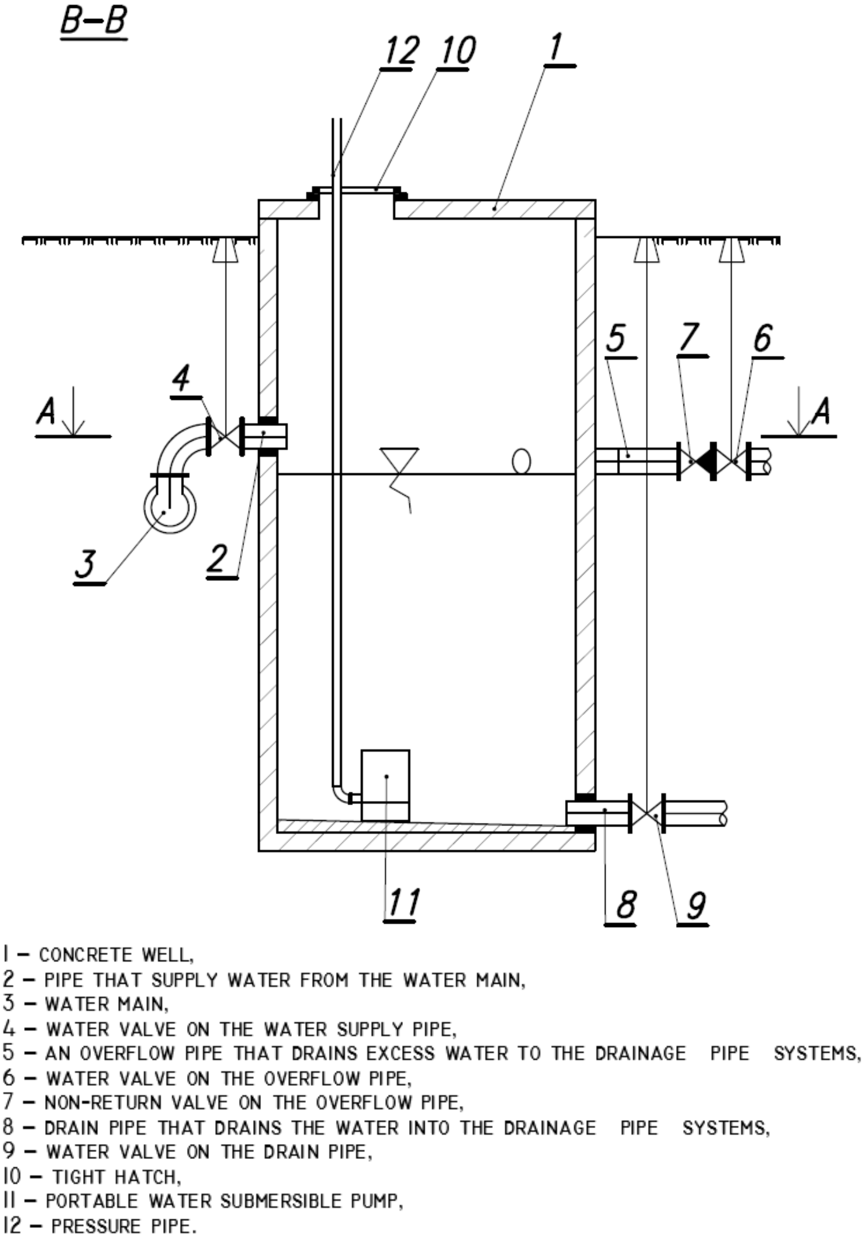


Figure 4. A drain well to supply the population with water in a crisis situation—section B-B.

During normal operation of the water supply network, the water valve (4) is in the closed position. The operation of the presented drain well consists of the fact that in the event of a crisis situation and the associated significant pressure drop in the water supply network, the gate valve (4) is opened and the water accumulated in the water supply pipe gravitationally fills the drain well (1) located at the lowest points of the water supply network. The level of the maximum water table in the drain well is determined by an overflow pipe (5), on which a non-return valve (7) and a water valve (6) are installed. A submersible pump (11) with a discharge pipe is inserted into the drain well, which fills the reservoir located on the surface of the ground. The water level in the drain well is regulated by the water valve (4). The drain well can be drained of water through the drain pipe located at the lowest point of the drain well (8), on which the water valve (9) is mounted. In a crisis situation, the water valve (9) must remain in the closed position, thus allowing the accumulation of tap water in the drain well. Water from the overflow pipe (5) and the drain pipe (9) is discharged into the drainage pipe systems. Protection against the ingress of pollutants from the ground surface is provided by raising the well vault 30 cm above the ground and by using a tight hatch (10).

3.2. Assessment of the Possibility of Meeting the Water Needs of the Population during the Crisis by Using the Developed Method of Obtaining Water from the Water Supply Network

It was analyzed how large volumes of water can be obtained using a drain well in the case of obtaining water from the main pipes with a diameter of 300 to 1000 mm. In each analyzed case, the length of the drained section of the water supply network L = 1000 m was assumed. The results of the calculations are presented in Table 3.

Table 3. The volume of water that can be obtained from main pipes with a diameter of 300 to 1000 mm (length 1 km).

D (mm)	V (m^3)
300	70.65
400	125.60
500	196.25
600	282.60
700	384.65
800	502.40
900	635.85
1000	785.00

If a pipe with a diameter of 300 mm were to be drained, nearly 71 m^3 of water could be obtained from one kilometer of the water pipe. This covers 78% of the daily demand for water to meet the physiological needs of all inhabitants of the analyzed city (2.5 per capita per day). Water accumulated in pipes 1 km long and DN900 or DN1000 in diameter would ensure the amount of water related to human physiology and basic hygiene practices for all city residents (7.5 L per capita per day). The results presented in Figure 1 indicate the advantage of using this method of obtaining water for consumption in crisis situations. In each of the analyzed cases, the amount of water collected in just 1 km of a water pipe is so large that it would constitute a significant part of the total water necessary to provide residents at the time of a crisis situation. Thanks to this solution, the level of water supply safety would increase in the event of the inability to use the water supply network. The optimal solution, which would allow for obtaining large amounts of water, is obtaining water from several water mains located in different parts of the city.

At the end of 2018, 231.3 km of water supply networks and connections were in operation in the analyzed WSS, including the water distribution supply network, 171.3 km; and water connections, 60.0 km. It is estimated that the amount of water accumulated in the water pipes is about the average daily demand for water, i.e., about 5000 m^3 of water. Assuming that only 20% of the water accumulated in the water pipes can be collected, we have a reservoir that allows for the collection of water in the amount of water related to human physiology and basic hygiene practices in a crisis situation (7.5 L per capita per day) for four days.

4. Conclusions

The fact that the WSS belongs to the critical infrastructure is related to the need for water supply companies to ensure the safety of water recipients, e.g., by applying an appropriate safety system and developing crisis response plans in the event of various types of accidents. In order to increase the degree of water supply safety, in the event that the standard use of the water supply network would be impossible, a method of obtaining water from the water supply network in a crisis situation was proposed. It was decided that the optimal solution to obtain large amounts of water would be to obtain water from water mains. Drain wells to supply the population with water in a crisis situation are located on water pipes at the lowest points of the water supply system. The developed solution allows for a significant increase in the safety of water supply in a crisis situation.

A drain well to supply the population with water in a crisis situation is characterized by the fact that when the water in the water supply network remains under low pressure, which prevents the water supply to the residents, it flows to the nearest drain well, where it is transported to storage tanks (e.g., water tankers) by means of a portable submersible pump located on the ground surface. The volumes of water pumped into the water supply network, in the event of a crisis situation, remaining in this network, are large enough to be a significant source of water in a crisis situation.

This work assumes the occurrence of a blackout and ultimately cutting off all residents of the city from the public water supply. For this case, calculations of water demand for the inhabitants of a selected city located in south-eastern Poland were carried out. It was calculated that in order to ensure full supply of the inhabitants of the analyzed city with water, the following should be provided in total: the amount of water related to human physiology (2.5 per capita per day)—90.7 m^3/d; the amount of water related to human physiology and basic hygiene practices (7.5 per capita per day)—272.0 m^3/d; the amount of water related to human physiology, basic hygiene practices, and basic cooking needs (15 per capita per day)—534.9 m^3/d.

The degree of coverage of the demand for water in a crisis situation in the field of road transport is often insufficient, as evidenced by a detailed report on ensuring the security of water supply to large urban agglomerations in the event of a crisis situation in Poland [42]. It is estimated that the amount of water collected from the water supply network of the analyzed city by means of a drain well will allow the collection of the amount of water related to human physiology and basic hygiene practices for a period of four days.

Water companies should be prepared for a crisis situation. The conducted research should focus on reducing problems with access to water in the city after a power blackout. The presented method of water supply in the event of a crisis situation, which allows the use of treated water distributed throughout the supply area, has a very high potential for implementation.

5. Patents

There are patents resulting from the work reported in this manuscript. The Patent Office of the Republic of Poland states that on 3 July 2023, an application for a patent for the invention "Drain well" was accepted. The application was marked with the number P.445447.

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