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A BRIEF HISTORY OF THE WATER SUPPLY SYSTEM AND WATER QUALITY IN THE CITY OF LODZ

HISTORYCZNE ZMIANY STRUKTURY SIECI WODOCIĄGOWEJ NA TLE UTRZYMANIA STANDARDÓW WODY PITNEJ DLA MIASTA ŁODZI

Abstract: Poland's third largest city, Lodz, underwent rapid industrial and demographic growth in the 19th and 20th centuries, followed by a steep decline over the last three decades. This paper describes how the water supply system has been adapted over the last century to meet these challenges, and in particular how the source of water (surface or underground) and structure of the supply system has been adapted to maintain drinking water quality. The Lodz water supply has been managed since 1925 by the firm Zaklad Wodociagow i Kanalizacji Sp. z o.o. The water supply system was designed by the Englishman William H. Lindley (in 1909), but because of World War I and the global depression that followed work began only in 1934. After World War II further deep wells were constructed, followed by a pipeline network and treatment plant. A 50-kilometre pipeline bringing surface water from the Pilica River was completed in 1955, followed by the Sulejowski Reservoir on the same river (1968–1973). Algal blooms on the reservoir presented a major challenge, and deep wells were turned to as a solution. By 2010 Lodz had 58 deep well intakes, so that in 2013 it was no longer necessary to take taking surface water from the Sulejowski Reservoir.

Keywords: Lodz water supply system, exploitation of water, drinking water quality

Introduction

Poland's third largest city, Lodz (2011 population 728,892; metropolitan population 1,428,600), is located in the drainage basin of the Vistula and Oder (Odra) rivers, in the catchment area of two substantial watercourses: the Bzura, a tributary of the Vistula, and the Ner, a tributary of the Oder. This richly watered area was favourable to settlement and the emergence of the first textile manufactories. The rapid development of Lodz as a textile centre in the nineteenth and early twentieth centuries resulted in the intensive exploitation of the region's natural water resources and a drastic decline in the

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quality of groundwater. The industrialisation of the city, river regulation works, and the changing course of the rivers together with the drainage of wetlands led to major changes in the hydrographical map of the region.

The creation of an urban water supply system satisfied the basic needs of residents and industry, but the continued growth of the city necessitated a search for ample and reliable (albeit distant) sources of drinking water and the construction of an infrastructure of wells, water treatment plants and a network of distribution pipelines. New technologies were constantly developed to ensure the inhabitants were supplied with the appropriate amount of water of the highest possible quality.

In 1909 the Lodz city authorities commissioned the renowned English civil engineer Sir William Heerlein Lindley (1853–1917) to design water and sewerage systems for the city. He pointed out the following potential sources of water:

1. Water-bearing chalk layers of the Upper Jurassic in the area north of Tomaszow Mazowiecki – Sulejow, and subterranean water in the vicinity of Lodz.
2. Water-bearing layers of the Quaternary period to the northwest of the Pilica River and the south and southwest of Lodz.
3. Surface water from the Pilica River.

Besides the needs of industry, which had its own water intakes, Lindley estimated the city's future daily water requirements at 154,000 cubic metres, assuming a million inhabitants each consuming 130–200 litres per day.

Lindley's design was ready by 30 October 1909, and in November plans at a scale of 1:10,000 of water mains and sewers were completed using the then novel technique of heliography.

In 1901, Lodz had a population of 310,000, but in 1908 the Russian authorities incorporated several villages and suburbs within the city boundaries, so that by 1911 the population exceeded 450,000. During the First World War the German occupying authorities conducted another large incorporation of lands within the city limits in 1915. Lodz was then the most densely populated city in Poland, with 10,439 inhabitants per square kilometre. A large number of these people were reliant solely on water from individual shallow wells, which were often contaminated. The sub-surface aquifer supplying these wells was slowly running dry as a result of widespread demand and ever increasing consumption from numerous textile factories.

Development of the Lodz water supply network

In 1925 the operation, treatment and distribution of the Lodz water supply was entrusted to the Municipal Water and Wastewater Company (ZWiK). However, as a result of World War I and the global economic crisis, work on the Lodz water supply system began only in 1934, under the supervision of the engineer Stefan Skrzywan, and the cheapest possible version – based on deep wells – was chosen.

The initial phase required the drilling of five wells and construction of a 100-km network of pipes. A pumping station and iron removal facility was to be built at Dabrowa connected by pipelines to wells and a drinking-water reservoir at Stoki, from which, via three water mains and a network of distribution pipes, water would be fed by gravity to the city.

A capital intensive part of the project was the underground reservoir at Stoki, built between 1935 and 1937 (which continues to serve the city to this day). It consists of huge twin tanks, each square in plan with sides of 60 metres, and 7 metres in height, with a water level of up to 5 metres, giving a capacity of 15,000 cubic metres per tank. The structure is an architectural marvel, with the vaulting of each tank consisting of 100 brick domes supported on 81 columns. Each dome is a brick structure with a square base of 5.5 metres along the edge.

At the outbreak of the Second World War in 1939 work had progressed as follows: only three wells had been drilled, work on a filtration and pumping station had commenced, 9.4 km of mains pipeline had been built, along with an equalizing tank at Stoki with a capacity of 30,000 cubic metres and about 62 km of distribution pipes. However, the municipal water system had not yet undergone its first trials.

It was only after the war, towards the end of 1945, that 204 properties (lived in by almost 20,000 people) were connected to the municipal water system. By the end of 1949, 21.6 km of municipal pipelines had been built, along with connections to individual buildings. At the same time a further three wells reaching down to the Upper Cretaceous aquifer were put into operation.

The increasing number of domestic connections was, however, fast creating a water shortage. A temporary solution was to build street hydrants and bring water into the city in tanker trucks. Even so, water rationing had to be introduced in 1950: Lodz was the only city in Poland to have daily quotas for private customers – initially 80 litres, later 100 litres per person.

In 1951 the government took the decision (long awaited by the city authorities) to commence work on a pipeline linking Lodz to an intake on the Pilica River at Tomaszow Mazowiecki. Construction of the first leg of the pipeline took three years. At this time a stretch of 2 km of the banks of the Pilica river were channelled and a weir was built to regulate flow. A pumping station was built to bring the water to a treatment plant about 1.5 km away. Here the river water was treated, and when crystal clear flowed through a special pipeline, halfway to Lodz, to a pumping station at Rokiciny, and then on to the reservoir at Stoki. In this way the water supply was increased to 92,000 cubic metres per day.

The next stage was the creation of a reservoir at Smardzowice, created by building a large dam on the Pilica River to produce a 17 km-long artificial lake, with a capacity of 75 million cubic metres and an area of 23 km^2. The lake was filled with water in May 1973, and a pumping station was built nearby in the village of Bronislawow. Six months later, more than 132,000 cubic metres of water were being drawn every day from the reservoir (in 1977, daily abstraction reached nearly 258,000 cubic metres, the highest from a single source during the entire history of the Lodz water supply system).

In the late 1990s the idea emerged of gradually replacing surface water with underground water from wells drilled in the vicinity of the lake. Seven wells were drilled in Bronislawow drawing water from the Upper Cretaceous aquifer. These have a capacity of more than 18 million cubic metres per year (50,000 cubic metres daily).

In 2000 the Lodz water system was modernized to streamline operations. In view of the topography of the area in which the city lies, the system was divided into two pressure zones. The northern part is gravity fed with water from the reservoir at Stoki. Here the water is a mainly sourced from deep wells together with a small amount of Pilica River water from the intake at Tomaszow Mazowiecki. The southern part of the city, which is smaller both in terms of area and population, is supplied entirely from deep wells in Bronislawow.

In all there are 43 wells within the city or on its outskirts; in 22 of these wells the water is so good that it requires no treatment. Lodz also makes use of eight wells in Rokiciny, seven in the vicinity of the Sulejowski Reservoir, and the intake on the Pilica River at Tomaszów Mazowiecki, though by 2010 the total contribution of the latter to the Lodz water supply amounted to only about 10 % [1].

Sulejowski Reservoir

Over the years the intensive development of industry in Lodz and overuse of the deep wells led to a fall in the groundwater level by as much as 100 metres. A "dried out" cone of depression was gradually forming beneath the city draining moisture from as far as 20 km away. To allow the water table to replenish itself the decision was taken to build a massive reservoir, over 40 km away, on the Pilica River.

The original concept was to bring the water to Lodz in a 42-km open canal. But this idea was quickly abandoned. Instead, work began on the construction of a pipeline using seamless, large diameter (1.6 m and 2.2 m) steel pipes. The contract could not be fully meet by Polish steel mills, so sections of the pipe were imported from Germany. At the same time the reservoir was built. It was a huge project that involved the relocation of 70 farms, the felling of 1600 hectares of forest, and the transfer of 1.5 million cubic metres of soil. The city waited impatiently for its new source of water. In the 1970s demand for water was increasing by 10,000–20,000 m^3 annually. Again, rationing was introduced, this time on industry.

After the reservoir was put into use it was not long before a number of complications arose and the water quickly became polluted. The original designs had called for a whole network of sewage treatment plants and a safe buffer zone to be put into operation around the reservoir. Unfortunately, funds ran out for the improvement of local sewerage facilities. Although a protection zone was established both directly and indirectly around the water intake, the planned sewage collectors were never built. Additionally, no attempts were made to prevent the unrestricted influx of thousands of holidaymakers treating the drinking-water reservoir as a place for swimming and sailing.

The Suleowski Reservoir covers a huge area but is very shallow – averaging just 3.5 metres – and it did not cope well with the rapid proliferation of algae during sunny weather. From the beginning it has been inadequately protected from the eutrophication process "fed" by nitrates and phosphates draining into it from the local area. Special varieties of herbivorous fish were introduced into the lake but these did not help. The first bloom of cyanobacteria was observed in 1975, a year after the reservoir was filled. Further blooms followed in successive years. Before the late 1980s this was not recognised as a danger to human health. It was only in the 1990s that the serious health risk created by these blooms was identified. Quickly, the decision was taken to close bathing areas during algal blooms.

Research showed that cyanobacterial toxins in the water could be effectively removed during the purification process. Maximum effort was made in bringing water drawn from the reservoir up to legal standards. A treatment plant (at Kalinko) was daily consuming dozens of tons of chemicals, ranging from chlorine, aluminium sulphate and activated silica to lime and activated carbon. It quickly became clear that, in its existing form, the reservoir would never be a source of good clean water.

In the search for an alternative source of drinking water for Lodz it was decided to build deep wells near the Sulejowski Reservoir, at Bronislawow. In all seven wells were successively drilled down to the Upper Cretaceous aquifer, providing a total daily capacity of 50,000 m^3.

Changes in the quality of Lodz drinking water, 1945–2013

To reflect the influence that the source of water has on the quality of the tap water delivered to customers over this period, five indicators of water quality are taken into account in this paper: colour, turbidity, dissolved oxygen, and the content of iron and manganese [1–5]. These are typical of the water quality parameters inspected by the ZWiK laboratory.

Colour and turbidity

The parameters most visible to the consumer are colour and turbidity. Considerable changes have been observed over the years, depending on the original source of the water. Between 1945 and 1960 there were no national regulations providing standards for these parameters, and so no data is available for this early period. When in 1965 the Minister of Health made it obligatory to analyse drinking water for colour and turbidity, it emerged that Lodz water obtained from the Pilica River had parameters close the

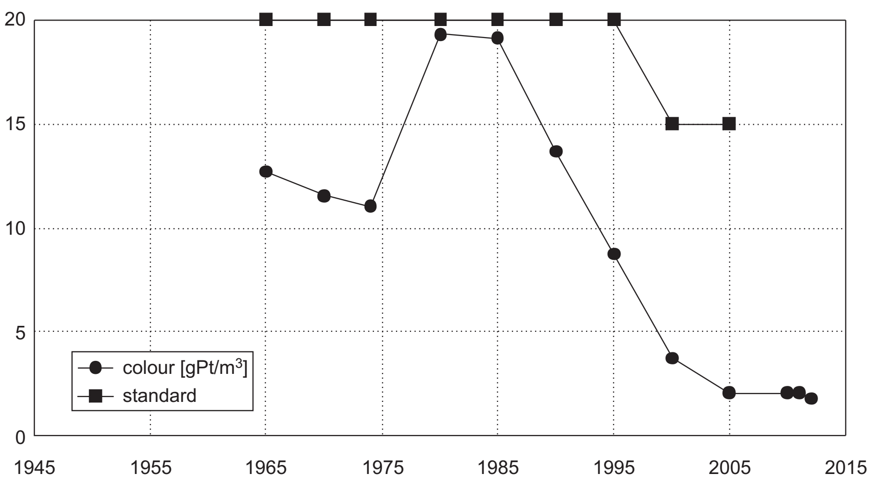

Fig. 1. Colour of Lodz drinking water since 1965

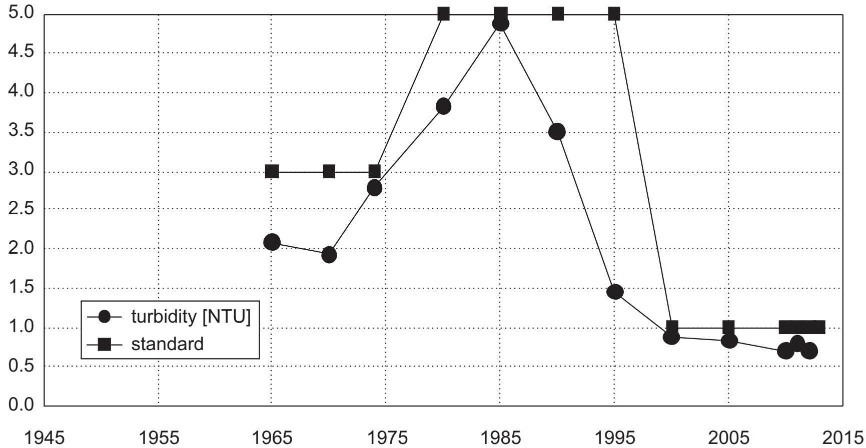

Fig. 2. Turbidity of Lodz drinking water since 1965

maximum legally permitted limits. After the intake on the Sulejowski Reservoir was brought into use the parameters remained at a high level. It was only in 2000, when the majority use of surface water was replaced in favour of underground water the colour and turbidity of Lodz drinking water improved, as is illustrated in Figs. 1 and 2.

Dissolved Oxygen (DO)

The amount of oxygen dissolved in the drinking water is an indicator of the quantity of organic and certain inorganic compounds in the water. For a long time there was no binding standard, and it was only in 2000 that the health minister made it compulsory to record this parameter. Since 1945 dissolved oxygen in the Lodz water system has been

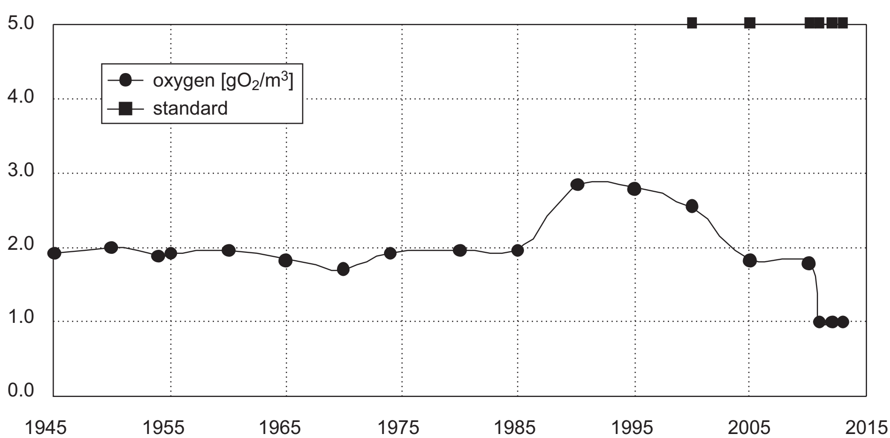

Fig. 3. Concentration of dissolved oxygen in Lodz drinking water since 1945

measured with $KMnO_4$, but only for internal technological analysis when assessing the dose of chlorine required for disinfection. The highest values of DO were recorded in the 1985–2000 period, that is when surface water was being sourced from the Sulejowski Reservoir, which was closely associated with blooms of *cyanobacteria* [6] (Fig. 3).

Iron and manganese

The presence of iron and manganese in drinking water is characteristic of water sourced from underground: surface waters generally do not contain these elements except in very small quantities. Figures 4 and 5 illustrate how the concentration of iron and manganese in drinking water is dependent on the source of the raw water.

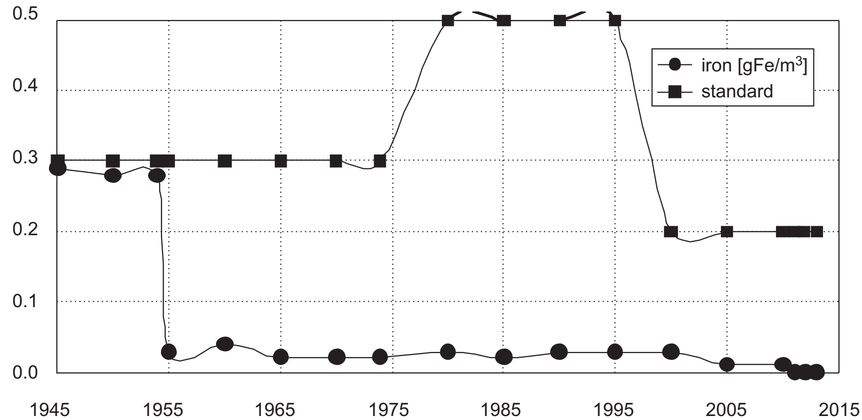

Fig. 4. Iron content of Lodz drinking water since 1945

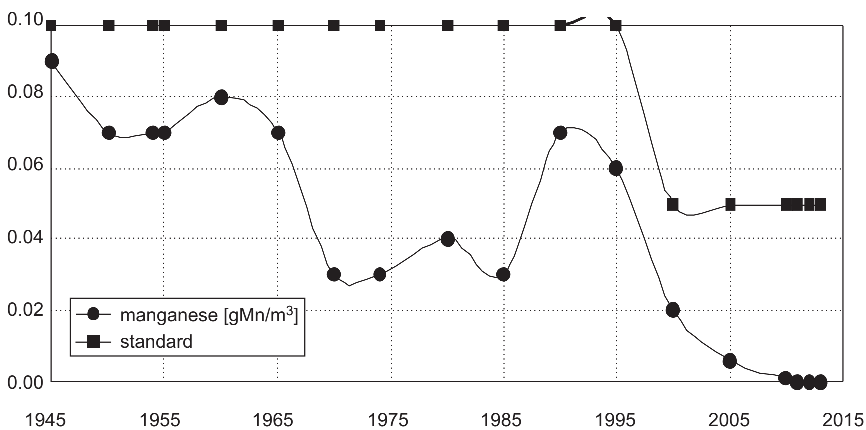

Fig. 5. Manganese content of Lodz drinking water since 1945

Very high concentrations were recorded between 1945 and 1954, when relatively shallow wells were in use.

Over the 1945–2000 period, *ie* when surface water was being used, the problem of high levels of iron and manganese was gradually eliminated. Now, thanks to the abstraction of water from greater depths and the use of new treatment technologies, the concentration of these elements is below the detection limits of current testing techniques.

The prospects for Lodz water production and distribution

The current economic and commercial situation of Lodz is having a significant affect on the economics of operating the municipal water supply. Due to the lowering of demand since 1989 there has been a steady decline in the amount of water supplied to the network – from 350,000 cubic metres per day in 1989 to about 90,000 in 2013. In the meantime, the size of the network has increased by about 260 km. Thus, while the capacity of the network has grown, the amount of water actually flowing in the network has fallen significantly [7, 8]. As a result, any change in the direction of water flow in the pipeline caused by emergencies or necessary adjustments to the operation of the network may result in deterioration of the quality of water supplied to the public [9]. The priority now is to maintain the system in a good state of repair, and to counteract the phenomenon of secondary pollution of water in the network.

Work is now in progress on pilot studies to examine microbial contamination in water networks using a luminescence method [10], based on the detection of ATP (*adenosine triphosphate*) present in all living cells. This will give immediate results for bacteriological tests (instead of the minimum 24-hour delay by traditional methods) and allow an immediate response in the event of biological contamination of Lodz drinking water [11].

Another plan is to improve the monitoring of the water supply system to obtain real-time data on the operation of the municipal network, specifically flow rate, flow direction, pressure and turbidity. This will allow a quick response to operational faults and should eliminate or reduce the effects of adverse incidents. Data from the new monitoring system will be used to build a mathematical model of the hydraulics of the pipe network, which will allow pipes of appropriate diameters to be chosen to adjust the water flow to current and future needs.

Summary

Since it was created in the Lodz water commercial system it has continuously evolved to meet the city's changing needs. The quality of Lodz drinking water has varied over the years depending on the type of water used – surface, underground or mixed. This was especially true between 1945 and 2000 when the priority for the Lodz waterworks was to satisfy the needs of a growing town in terms of quantity of water supplied. This translated into a reduction of quality – in particular, high levels of dissolved oxygen and turbidity. The colour of water at the tap was a common cause of customer complaints, especially while water was being drawn from the Sulejowski Reservoir.

The quality of Lodz tap water continues to be inspected regularly. Water is sampled at treatment stations and when drawn into the water system, and also directly from pipelines at nearly a hundred locations throughout the city. Dozens of parameters are tested at the company's laboratories.

A further safeguard is provided by so called bio-monitors – fish (perch) and mussels that live in aquariums at eleven different facilities belonging to the firm. Water intended for Lodz's households flows continuously through the aquariums, and perch and mussels are extremely sensitive to changes in water quality and to pollutants that might pose a danger to human health. Since 2009 the mussels have been monitored by special equipment that provides constant information on their wellbeing.

Since 2000, that is since the closure of the largest water-consuming industrial customers, the problem has mainly been one of the excess of water in the system. Besides the ageing infrastructure at intake points and treatment plants, dealing with the oversize pipelines and stagnant water in the network has been a challenge. These problems have largely been overcome so that today the water drawn from deep wells is some of the best drinking water supplied to residents anywhere in Poland.

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HISTORYCZNE ZMIANY STRUKTURY SIECI WODOCIĄGOWEJ NA TLE UTRZYMANIA STANDARDÓW WODY PITNEJ DLA MIASTA ŁODZI

Wydział Inżynierii Procesowej i Ochrony Środowiska
Politechnika Łódzka

Abstrakt: Projekt łódzkiej sieci wodociągowej, wykonany przez najlepszego europejskiego fachowca W. Lindleya, powstał już w 1909 r. Realizację rozpoczęto w 1934 r., przy współudziale polskiego inżyniera S. Skrzywana. Po II wojnie światowej dokonano wiercenia dalszych studni głębinowych i zbudowano system wodociągowy oraz stację uzdatniania wody. Zbudowano 50 km rurociągu Tomaszów–Łódź (1955 r.), zbiornik retencyjny na Pilicy (1968–1973) i kolejne studnie głębinowe. W 2010 r. istniało już 58 ujęć wód podziemnych dlatego też w 2013 r. zapadła decyzja o rezygnacji z ujmowania wody powierzchniowej z Zalewu Sulejowskiego. Celem pracy było przedstawienie miejsc pobierania wody i struktury sieci wodociągowej, której budowa ulegała zmianom w zależności od potrzeb i rozwoju dużego miasta, w powiązaniu z uzyskiwaniem wody pitnej najwyższej jakości. Piecze nad eksploatacją i dystrybucją nieprzerwanie od 1925 r. sprawuje Zakład Wodociągów i Kanalizacji Sp. z o.o. w Łodzi.

Słowa kluczowe: wodociąg łódzki, eksploatacja wody, jakość wody pitnej