www.czasopisma.pan.pl PAN www.journals.pan.pl
POLSKA AKADEMIA NAUK

Archives of Environmental Protection
Vol. 41 no. 3 pp. 53–59

PL ISSN 2083-4772
DOI 10.1515/aep-2015-0030

© Copyright by Polish Academy of Sciences
and Institute of Environmental Engineering of the Polish Academy of Sciences,
Zabrze, Poland 2015

DE GRUYTER OPEN

Variability of the Warta River water discharge in the city of Poznań as influenced by the Jeziorsko reservoir

Antoni T. Miler

The Poznań University of Life Sciences, Poland
Department of Forest Engineering, Poznań

Corresponding author's e-mail: amiler@up.poznan.pl

Keywords: Warta River, variability of water discharge, water quality.

Abstract: The data set of the Warta discharges in Poznań (Poland) is one of the largest in the world as the daily observations of river stages have been conducted without interruptions since January, 1st, 1822. The Poznań measurement profile is situated in the 243.6 km and closes the catchment area of approximately 25 thousand square kilometers. The data used as the input in the paper were daily values of the Warta discharges in Poznań in the years 1822–2012. The climate in Poznań, a city situated in the centre of the Wielkopolska (Greater Poland) region, is relatively stable (Miler et al. 2005). Also the Warta River runoff shows considerable stability, especially in terms of mean annual values. Short-term trends are random in character. It was found that the Jeziorsko reservoir (total storage volume of 203 000 000 m^3, officially put to use on September, 9th, 1987) significantly reduced daily variability of the flows and reduced peak discharge of the flood wave in the summer of 1997 on the Warta River at Poznań. The calculated periodogram for mean annual discharges of the Warta River in Poznań shows that there are main periodicities of ca. 10 year lengths. The research of the Provincial Inspectorate for Environmental Protection (WIOŚ) in Poznań shows a gradual improvement of water quality in the Warta River in Poznań.

Introduction

Changes in river flow are caused by natural factors, i.e. climate change and anthropogenic factors, e.g. construction of hydroengineering structures on the rivers. The measurement profile of the city of Poznań is located at 244 km of the Warta River course and it closes a catchment of approx. 25 thousand km^2. A characteristic feature of the layout of this catchment is its lowland location and the fact that lakes are relatively scarce.

The aim of this study is to present a comprehensive assessment of variability in the Warta River discharges in Poznań in the last almost 200 years (from the beginning of systematic observations and measurements) in view of the 25-year operation of the Jeziorsko reservoir.

Methodology and scope of the study

In this study the input data comprised daily discharges of the Warta River in Poznań in the years 1822–2012. It needs to be stressed that the set of values of the Warta River discharges in Poznań is one of the greatest data sets in the world, as systematic observations of the stages have been conducted since as early as 1821. The data for the years 1822–1990 were obtained from a study by Olejnik (Olejnik 1991 – published data), while for the years 1990–2012 the data were obtained from the Institute of Meteorology and Water Management (branch in Poznań). All these data (approx. 70 000), after being entered in the Excel spreadsheets, were analysed in terms of their continuity and several dozen corrections were made, resulting from obvious errors in the course of editing.

The meteorological data (precipitation and air temperature) for Poznań from the years 1848–2012 were independently analysed e.g. by the author (Miler et al. 2005, Miler 2013, Okoński et al. 2012). It was shown that climate in Poznań, located in the centre of the Wielkopolska region, shows relatively high stability.

The impact of the Jeziorsko reservoir located in the central section of the Warta course with total capacity of 203 million m^3 (put to use in 1987) on river discharges in Poznań was analysed by the author for the 10-year period of operation of this reservoir (Miler 1999a, Miler 1999b, Miler 1999c, Miler 2001) . A considerable impact of the Jeziorsko reservoir was shown on the regime of the Warta River discharges, i.e. a reduction of daily variation in river discharges, an increase in the mean low and a lowering of the mean high river discharges. The period of at least 25 years is equally reliable in hydrological analyses. For example, the World Meteorological Organization (WMO) recommends 30-year reference periods.

Time trends and variability were developed in a standard manner using the following methods: least squares (time trends) and parametric tests (*t*-Student test – mean values, *F*-test by Snedecor – variances). In statistical calculations the typically applied significance level α=0.05 was used (Statistica 10). The analyses presented in this study concern hydrological years (1 November – 31 October). Hydrological years were evaluated as proposed by Kaczorowska (Kaczorowska 1962).

To smooth the time courses the consecutive 11-year mean was adopted:

$$x_{i,śr.11} = \frac{\sum_{j=-5}^{5} x_{i-j}}{11} \quad (1)$$

where: x_i – values of time series.

An 11-year averaging was used, which results from the primary periodicity of solar activity.

Any time series may be described as follows:

$$F(t) = A_0 + A \cdot t + \sum_{i=1}^{\infty} (B_i \cdot \sin(\frac{2 \cdot \Pi}{T_i} \cdot t) + C_i \cdot \cos(\frac{2 \cdot \Pi}{T_i} \cdot t)) + \varepsilon(t) \quad (2)$$

where : A_0 – constant value, A – trend for changes, t – times, B_i, C_i – amplitudes, T_i – period, i – the number of harmonic, $\varepsilon(t)$ – random component.

Periodogram $P(i)$ is defined as follows:

$$P(i) = (B_i^2 + C_i^2) \cdot \frac{N}{2} \quad (3)$$

where: N – series size, B_i, C_i – see above.

The values of this periodogram were calculated in order to assess variability of mean annual river discharges. Values of P(i) indicate which of the harmonics plays a considerable role.

Empirical probability (in percent) is typically defined as:

$$p(m,N)\% = \frac{100 \cdot m}{N+1} \quad (4)$$

where: m – successive element of the stemplot (ordered in the decreasing order), N – series size.

In the estimation of the curve: probability (p) – maximum annual river discharge, together with the higher discharges ($Q_{max,p}$) the Hoerl model was used:

$$Q_{\max,p} = a \cdot b^p \cdot p^c \quad (5)$$

where: a, b, c – coefficients (CurveExpert 1.4).

The river flow regime is typically characterised by 4 characteristic first degree river discharges: minimum, mean, high and average (medium), in successive years. For a multiannual period, within each first degree series we may similarly distinguish 4 characteristics. Eventually we have 16 characteristic second degree river discharges.

Results and discussion

The Warta River at the Poznań cross-section in the years 1822–2012 is characterised by a complex regime, i.e. there are maximum river discharges mainly in March and April (spring thaw raised water stages), but also in the summer months (rainfall raised water stages) and sporadically in other seasons (Fig. 1).

A considerable impact on the character of the Warta River discharges in Poznań is played by the Jeziorsko reservoir, put to use in 1987. Since that time a marked lowering of first degree high river discharges (WQ) has been found, although no marked changes are observed in mean (SQ), low (NQ) and average river discharges (ZQ) (Fig. 2).

The above change may not be associated solely with climate change (Climate Change, 2007), since after 1987 reductions were recorded in the empirical probability of precipitation (higher precipitation totals) and air temperatures (higher temperatures) (Fig. 3). (Greater precipitation is compensated for by higher temperatures).

There is a probability of high river discharges (WQ) in the period of the Jeziorsko reservoir operation (river discharges decrease) (Fig. 4).

Seasonal river discharge (averaged for successive days in the year) of the Warta in Poznań clearly indicates effectiveness of the Jeziorsko reservoir in limiting the spring high water stages (Fig. 5).

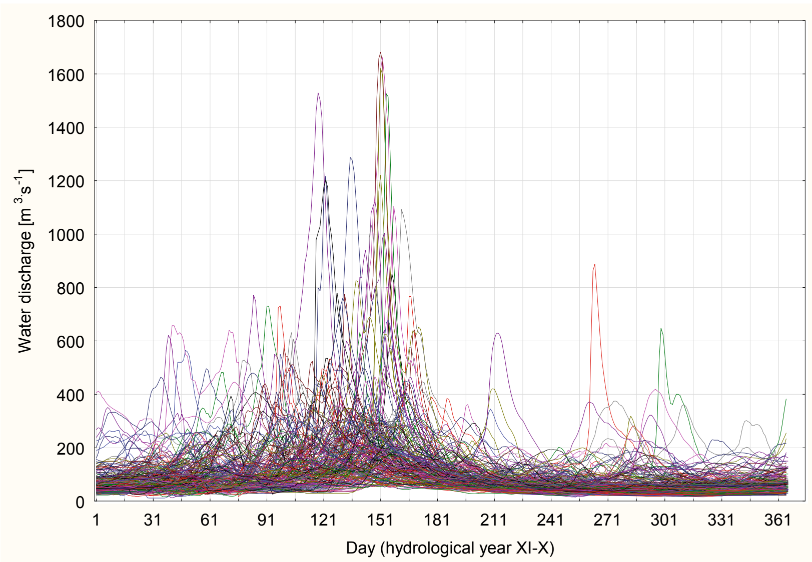

Fig. 1. Daily water discharges of Warta River in the Poznan cross-section in 1822–2012

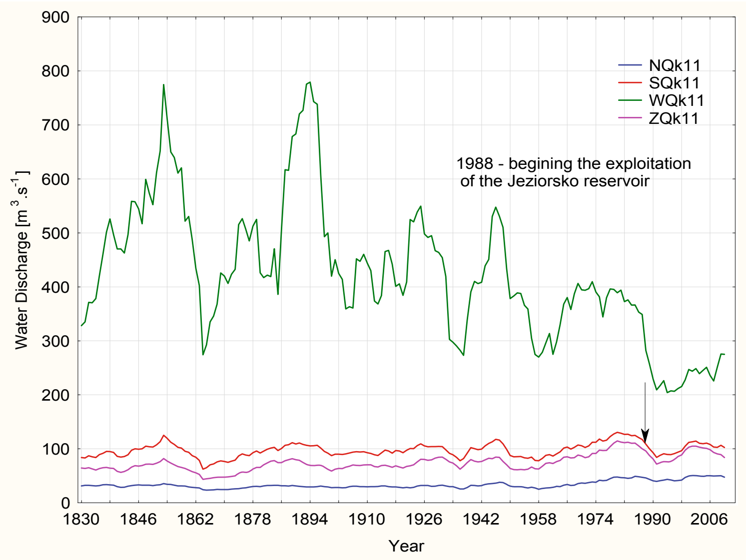

Fig. 2. 11-year smoothed means of first degree characteristic water discharges of the Warta River in Poznan

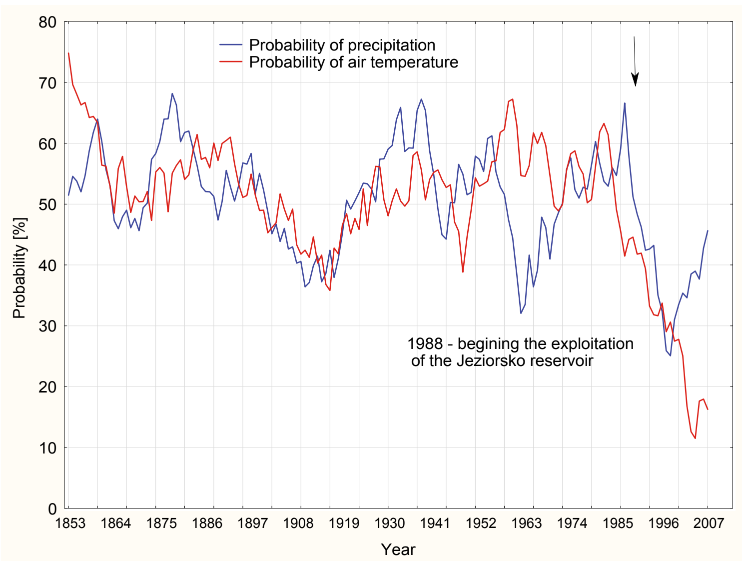

Fig. 3. 11-year smoothed means of probability of total yearly precipitation and mean air temperatures in Poznan in 1848–2012

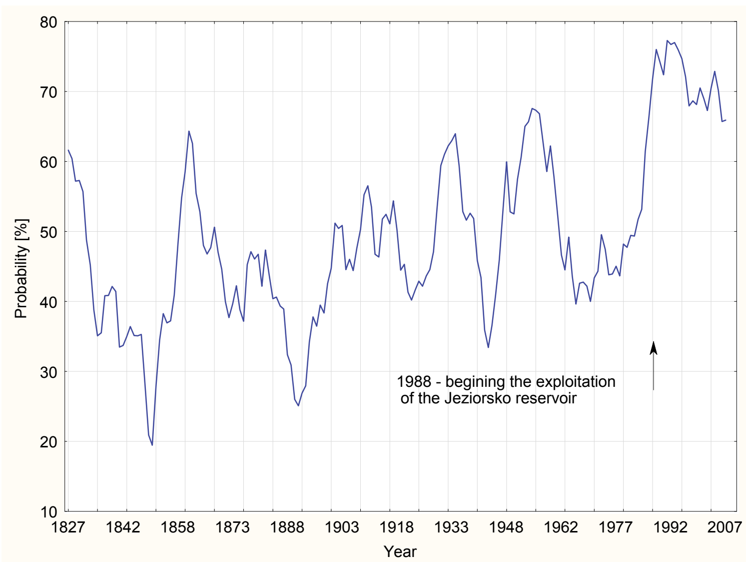

Fig. 4. 11-year smoothed means of probability of maximum yearly water discharges (WQk11) of the Warta River in Poznan

www.czasopisma.pan.pl PAN www.journals.pan.pl

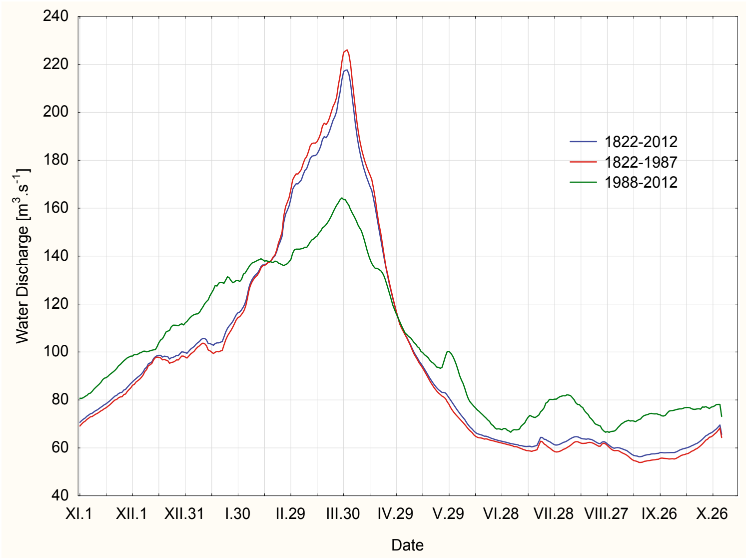

Fig. 5. Averaged daily water discharges of the Warta River in Poznan in periods of 1822–2012, 1822–1987 and 1988–2012

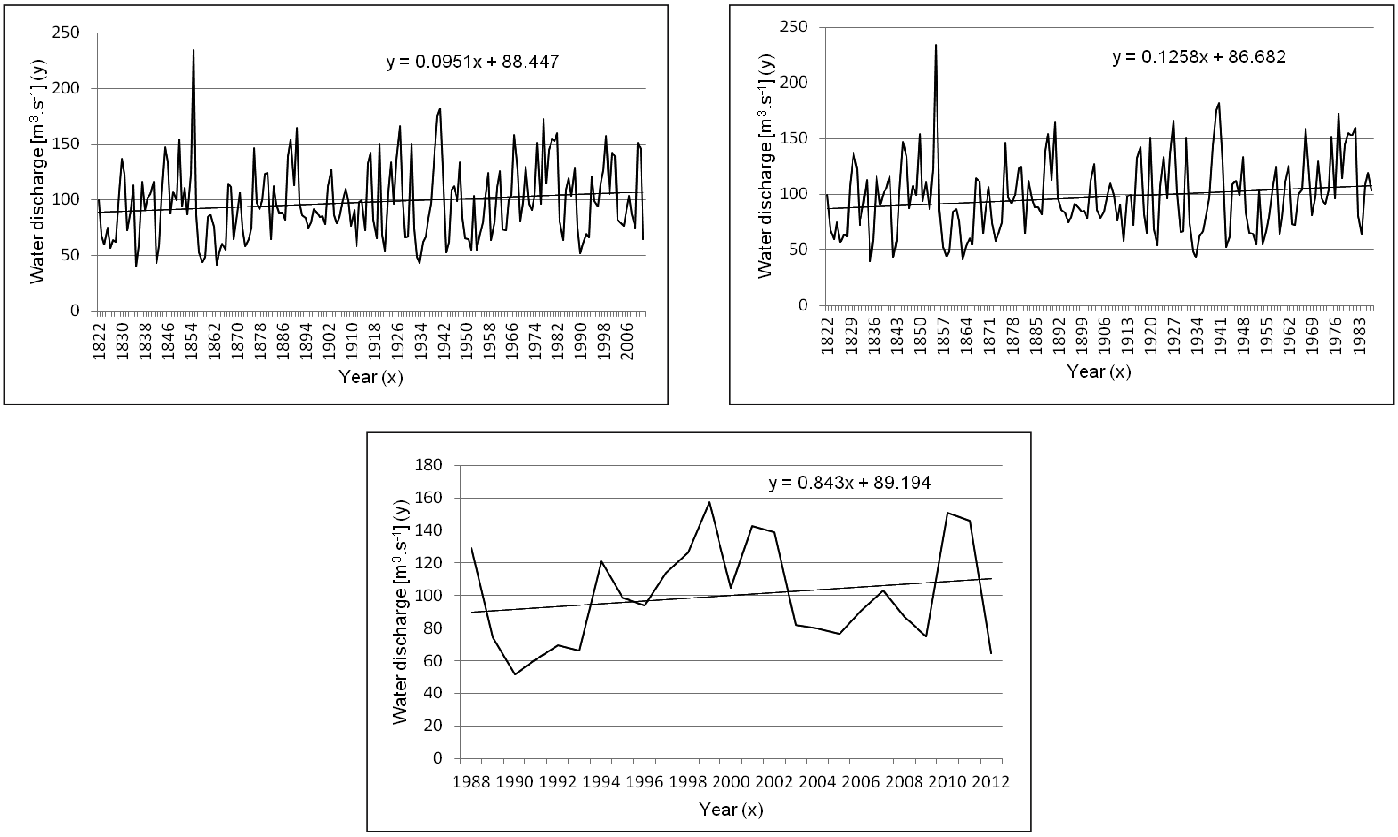

Fig. 6. Mean yearly water discharges of the Warta River in Poznan in periods 1822–2012, 1822–1987 and 1988–2012

River flows of the Warta also show relative stability, particularly in relation to mean annual values. The time trend for mean yearly river discharges is statistically significant in the periods of 1822–2012 and 1822–1987, while it is non-significant in the period of 1988–2012. Short-term (several or around a dozen years) trends seem to be ephemeral in character (Fig. 6).

The values of the periodogram calculated for mean annual river discharges indicate dominant periodicities approx. 10-year. They may have a synergistic effect due to overlapping (Fig. 7).

Table 1 presents selected 2° characteristics of river discharges as well as limits (upper and lower) of mean river discharges in the periods of 1822–2012, 1822–1987 and 1988–2012 for the Warta in Poznań. When comparing the values from the one but last and the last columns the impact of the Jeziorsko reservoir on the reduction of variability of river discharges is evident, e.g. the scope of changes in mean river discharges in the period of 1822–1987 is 111.0 $m^3 \cdot s^{-1}$, while in the period of 1988–2012 it was two-fold lower, only 55.9 $m^3 \cdot s^{-1}$.

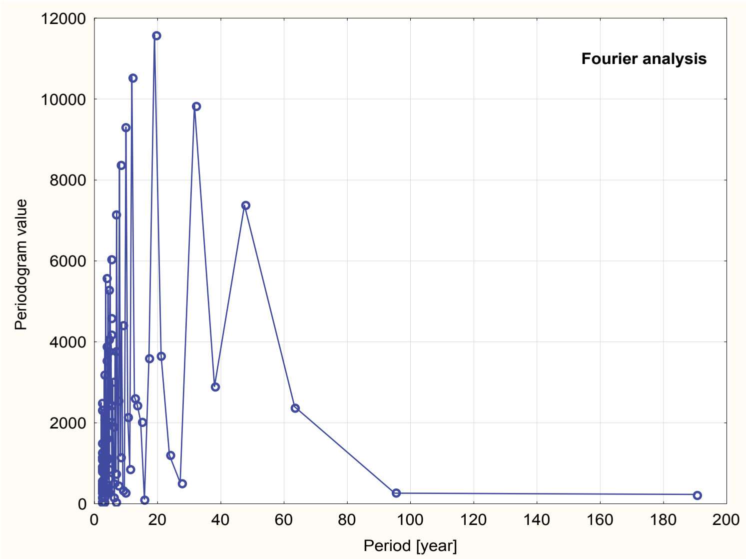

Fig. 7. Periodogram of mean yearly water discharges of the Warta River in Poznan in the period of 1822–2012

Table 1. Water discharge characteristics of the Warta river in Poznan

Water discharge [$m^3 \cdot s^{-1}$]	Period		
	1822–2012	1822–1987	1988–2012
NNQ Lowest of low	11.5	11.5	32.5
SNQ Mean of low	33.9	32.1	45.9
NSQ Lowest of average	39.9	39.9	51.5
SSQ Mean of means	97.6	97.2	100.2
WSQ Highest of mean	234.5	234.5	157.3
NWQ Lowest of high	93.1	93.5	93.1
WWQ Highest of high	1682.0	1682.0	630.0
Upper limit of mean water discharge	163.8	164.0	125.2
Bottom limit of mean water discharge	63.4	53.0	69.3

In the estimation of the curve: probability – maximum annual river discharges, together with higher values eventually the Hoerl model was used (5) (a = 1851.4, b = 0.9875, c = -0.2965). For this equation the best fit was obtained at the simultaneous genetically justified potential extrapolation on the full scope of variation in probability (Fig. 8).

Based on the estimated equation (5) Table 2 presents probability of maximum annual river discharges with higher discharges for the Warta in Poznań for repeatability from once a year to once in 1000 years. The maximum 1000-year river discharge is hypothetical in character.

Changes in values of selected water quality indexes in the Warta since 1999

The specifically imposed legal obligation to conduct analyses and assessments of surface water quality has been introduced relatively recently. Tests are performed within the National Environmental Monitoring system, which results from Article 155a item 2 of the Act of 18 July 2001. However, since 1999 the legal basis for monitoring and quality assessment of flowing surface waters has been changed three times (binding water quality indexes, admissible values of indexes and methods of classification), which greatly hinders a comparison of data from different periods. However, on the basis of analyses conducted by the Provincial Inspectorate of Environmental Protection in Poznań it may be stated that a gradual improvement is observed in the quality of the Warta water at gauge points located in Poznań and its environs: Poznań – Luboń (monitoring in the years 1999–2006), Poznań – Wiórek (since 2007) and Poznań – most św. Rocha (Saint Roch bridge) (since 2007).

To illustrate changes in water quality it may be stated that:

– an increase in water soluble oxygen levels may be observed, at present mean annual values exceed 8.0 mg O_2/l and correspond to purity class I,
– a reduction in BOD_5 may be observed, showing a reduced contamination with organic matter,
– a slight downward trend is found for total phosphorus concentration, while mean annual values fall within the ranges of admissible values,

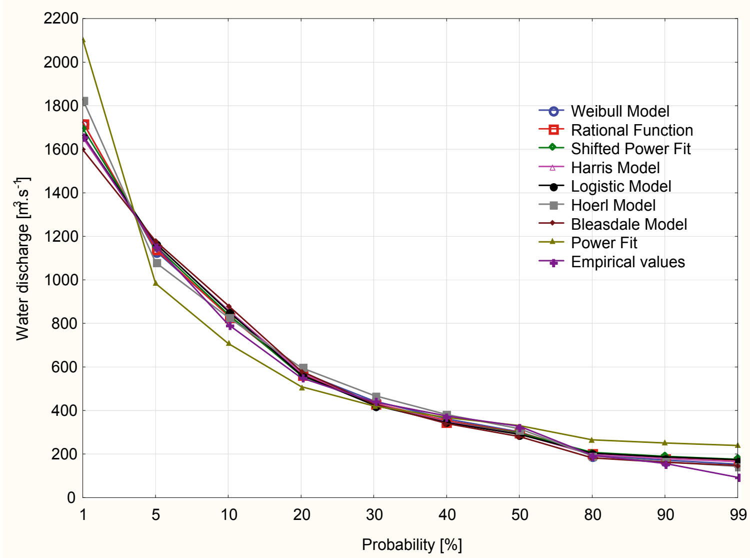

Fig. 8. Estimation of probability values of maximum yearly empirical water discharges (Empirical values) together with higher discharges by selected models; for the Warta River in Poznan

Table 2. Probability of maximum yearly water discharges together with higher discharge of the Warta River in Poznan

P [%]	0.1	1	5	10	20	30	50	99.1
Q_{max} [$m^3 \cdot s^{-1}$]	3663	1829	1080	828	597	469	317	141
T [year]	1000	100	20	10	5	3.3	2	1

P – Probability,
Q_{max} – Maximum yearly water discharge with higher discharges, estimated by the Hoerl model,
T – Period of occurrence.

– total nitrogen content does not show a definite single trend; however, mean annual values fall within the ranges of admissible values,
– the coliform bacterial titre increases systematically, which indicates an improvement of sanitary water quality (Report on environmental quality in the Wielkopolska region in 1999(–2011), WIOŚ Poznań 2000(–2012) (13 reports), Water stages on the Warta in the Wielkopolskie Province in the years 1999–2009, WIOŚ Poznań 2010).

The chemical monitoring of the Warta River in the area of the Jeziorsko reservoir has also indicated the improvement of water quality for the preceding few years period. The water quality of the Warta River in 2006 sampled both upstream of the Jeziorsko reservoir (locations – Sieradz, Biskupice, Warta) and downstream (locations – Księże Młyny, Uniejów) varied between III and IV class of water quality. While during the period 2010–2012 at inlet in the Jeziorsko reservoir was indicated moderate ecological status/moderate ecological potential and good chemical status. The ecological status/potential at the outlet from the reservoir has increased to good ecological status/potential and higher during the period 2010–2012 (Report on state of environment in the Lodz Provence in 2006(–2012), Biblioteka Monitoringu Środowiska, WIOŚ Łódź 2007(–2013) (7 reports)). In accordance with the requirements of the Water Framework, by 2015 Poland is to achieve at least good water condition. In the case of waters in the Warta at least in some sections it seems feasible.

Final remarks and conclusions

The Warta River is characterised by a complex river flow regime (up to several maxima annually). A considerable impact on river discharges in Poznań is played by the Jeziorsko reservoir in the central river course. This impact causes a reduction of river discharge variability, thus an increase in low river discharges and a reduction of high discharges.

Mean river flow in the Warta shows relatively high stability; however, in recent years we have been observing an increased trend towards an increase in mean river discharges. Moreover, variation in mean river discharges indicates the most marked approx. 10-year fluctuation.

A very long (191-year) period of hydrometric observations for the Warta in Poznań seems to facilitate a good estimation of maximum annual river discharge with higher discharges even for the frequency of one in 1000 years.

Based on the analyses conducted by the Provincial Inspectorate of Environmental Protection in Poznań it may be stated that water quality in the Warta determined at gauge points located in Poznań and its environs is slowly improving.

References

Climate Change (2007). Synthesis Report. An Assessment of the Intergovernmental Panel on Climate Change, (https://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf (15.10.2013)).

Kaczorowska, Z. (1962). Precipitation in Poland in multi-years period, *Przegląd Geograficzny,* No. 33, pp. 1–112. (in Polish)

Miler, A. (1999a). The Warta discharges in Poznan in the 10-year period of operation of the Jeziorsko reservoir based on discharges in the preceding period of over 150 years, in: *Operation and Impact of Large Lowland Reservoirs based on the Jeziorsko reservoir*, Przedwojski B. (Ed.). Publishing house Poznan University of Life Sciences, Poznan 1999. (in Polish)

Miler, A. (1999b). Variability of the Warta river discharge in Poznan, *Roczniki Akademii Rolniczej w Poznaniu. Wioracje i Inżynieria Środowiska* 20, Part I, pp. 443–452. (in Polish)

Miler, A. (1999c). Periodicity and time trends in the Warta River discharges in Poznan in the period of documented observations in 1822–1997, in: *Interdisciplinary studies on river basins,* Chełmicki W. (Ed.). Publishing house "Rzeki – kultura, cywilizacja, historia", Kraków 1999. (in Polish)

Miler, A.T. (2001). The impact of the Jeziorsko reservoir on the Warta discharges in Poznan, *Zeszyty Naukowe Wydziału Budownictwa i Inżynierii Środowiska Politechniki Koszalińskiej*, 20, pp. 735–743. (in Polish)

Miler, A.T. & Miler, M. (2005). Trends and periodicity of changes in temperature and precipitation in Poznan in the years 1848–2000, *Zeszyty Naukowe Wydziału Budownictwa i Inżynierii Środowiska Politechniki Koszalińskiej,* 22, pp. 945–956. (in Polish)

Miler, A.T. (2013). *A comprehensive method to assess water relations in forests*, Publishing house Poznan University of Life Sciences, Poznań 2013. (in Polish)

Okoński, B. & Miler, A.T. (2012). Multiannual variation in air temperature and precipitation in the Zielonka Forest, *Sylwan*, 156, 6, pp. 473–480. (in Polish)

Olejnik, K. (1991). *The Warta River discharges in Poznan in the years 1822–1988*, Publishing house Fundacja "Warta", Poznan 1991. (in Polish)

Report on environmental quality in the Wielkopolska region in 1999. Biblioteka Monitoringu Środowiska, WIOŚ, Poznań 2000. (in Polish)

Report on environmental quality in the Wielkopolska region in 2000. Biblioteka Monitoringu Środowiska, WIOŚ, Poznań 2001. (in Polish)

Report on environmental quality in the Wielkopolska region in 2001. Biblioteka Monitoringu Środowiska, WIOŚ, Poznań 2002. (in Polish)

Report on environmental quality in the Wielkopolska region in 2002. Biblioteka Monitoringu Środowiska, WIOŚ, Poznań 2003. (in Polish)

Report on environmental quality in the Wielkopolska region in 2003. Biblioteka Monitoringu Środowiska, WIOŚ, Poznań 2004. (in Polish)

Report on environmental quality in the Wielkopolska region in 2004. Biblioteka Monitoringu Środowiska, WIOŚ, Poznań 2005. (in Polish)

Report on environmental quality in the Wielkopolska region in 2005. Biblioteka Monitoringu Środowiska, WIOŚ, Poznań 2006. (in Polish)

Report on environmental quality in the Wielkopolska region in 2006. Biblioteka Monitoringu Środowiska, WIOŚ, Poznań 2007. (in Polish)

Report on environmental quality in the Wielkopolska region in 2007. Biblioteka Monitoringu Środowiska, WIOŚ, Poznań 2008. (in Polish)

Report on environmental quality in the Wielkopolska region in 2008. Biblioteka Monitoringu Środowiska, WIOŚ, Poznań 2009. (in Polish)

Report on environmental quality in the Wielkopolska region in 2009. Biblioteka Monitoringu Środowiska, WIOŚ, Poznań 2010. (in Polish)

Report on environmental quality in the Wielkopolska region in 2010. Biblioteka Monitoringu Środowiska, WIOŚ, Poznań 2011. (in Polish)

Report on environmental quality in the Wielkopolska region in 2011. Biblioteka Monitoringu Środowiska, WIOŚ, Poznań 2012. (in Polish)

Report on state of environment in the Lodz Provence in 2006. Biblioteka Monitoringu Środowiska, WIOŚ Łódź 2007. (in Polish)

Report on state of environment in the Lodz Provence in 2007. Biblioteka Monitoringu Środowiska, WIOŚ Łódź 2008. (in Polish)

Report on state of environment in the Lodz Provence in 2008. Biblioteka Monitoringu Środowiska, WIOŚ Łódź 2009. (in Polish)

Report on state of environment in the Lodz Provence in 2009. Biblioteka Monitoringu Środowiska, WIOŚ Łódź 2010. (in Polish)

Report on state of environment in the Lodz Provence in 2010. Biblioteka Monitoringu Środowiska, WIOŚ Łódź 2011. (in Polish)

Report on state of environment in the Lodz Provence in 2011. Biblioteka Monitoringu Środowiska, WIOŚ Łódź 2012. (in Polish)

Report on state of environment in the Lodz Provence in 2012. Biblioteka Monitoringu Środowiska, WIOŚ Łódź 2013. (in Polish)

Water stages on the Warta in the Wielkopolskie Province in the years 1999–2009 (2010). Biblioteka Monitoringu Środowiska, Inspekcja Ochrony Środowiska, WIOŚ Poznań, Poznan 2010. (in Polish)

Zmienność przepływów rzeki Warty w Poznaniu w aspekcie eksploatacji zbiornika Jeziorsko

Streszczenie: Zbiór danych o przepływach Warty w Poznaniu (Polska) jest jednym z największych na świecie zbiorów codziennych obserwacji stanów wody w rzece. Obserwacje te prowadzone są nieprzerwanie od 1 stycznia 1822 roku. Profil pomiarowy w Poznaniu znajduje się na 243,6 km i zamyka zlewnię o powierzchni około 25 tys. km^2. Dane użyte jako wejście w tej pracy stanowiły przepływy dobowe Warty w Poznaniu w latach 1822–2012. Klimat Poznania, położonego w centrum Wielkopolski, jest stosunkowo stały (Miler i in. 2005). Także odpływy Warty wykazują znaczną stabilność, szczególnie w odniesieniu średnich rocznych wartości. Krótkookresowe trendy mają charakter przypadkowy. Wykazano, że zbiornik Jeziorsko (pojemności całkowitej 203 mln m^3, oficjalnie oddany do użytkowania 9 września 1987 roku) znacząco zmniejsza dobową zmienność przepływu oraz zredukował maksymalny przepływ fali powodziowej w lecie 1997 Warty w Poznaniu. Obliczony periodogram dla wartości średnich rocznych przepływów Warty w Poznaniu wskazuje, że główne są okresowości około 10-letnie. Badania Wojewódzkiej Inspekcji Ochrony Środowiska (WIOŚ) w Poznaniu wskazują na stopniową poprawę jakości wody w Warcie w Poznaniu.