CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

No. 10 2013

FLOOD RISK OF LOWER SILESIA VOIVODSHIP

Mariusz ADYNKIEWICZ-PIRAGAS*, Iwona LEJCUŚ
Institute of Meteorology and Water Mangement – National Resarch Instytute
Wrocław Branch, Regional Research Department,
Parkowa St. 30, 51-616 Wrocław, Poland

Floods are natural events of a random nature that cause damage in property, agriculture, and industry. Floods in the upper and middle Odra basin, particularly on a large scale, are characterized by their specificity of arising and shaping. Analyses of historical material prove that the largest floods are during the summer season, especially in July and August. Those events are caused by wide and intensive precipitation lasting 2-3 days. Moreover spatial ranges in the Odra basin and runoff sequence are also the important reasons. Other important factors for the flood risk scale in a region is knowledge of the flood risk index established on the basis of observed floods or that of Maximum Probability Flood. In this paper flood risk in the territory of Lower Silesia Province was evaluated on the basis of chosen indices of flood risk.

Keywords: Odra catchment, flood risk zones

1. INTRODUCTION

Flood is a natural disaster that threatens the safety of people and animals, and cause damage to human property, and losses in the national economy. It is natural and random phenomenon. It can cause torrential rains, short thunderstorms, rapid melting of snow, strong winds on the coast from the sea towards the land and the freezing of rivers. Flood is a high water, during which water overflows the level of embankment crown and flood river valleys or depressed areas, thereby causing damage and financial and non-economic (social, moral, etc.) losses [Dubicki, Malinowska-Małek 1999].

However, high water level is a raise in water level in streams, reservoirs, at sea, which does not cause damage or loss in the adjacent areas. Spate acquires the character of flood after exceeding the boundary level, when flooding river valleys and areas of depression, causing losses. Level of risk of flooding

* Corresponding author. E-mail: mariusz.adynkiewicz@imgw.pl

depends on the state of development of the river valley and is conditioned by two factors: the size of spate and the size of the losses caused by the flood.

High water is not formed at the same time along the entire length of the watercourse, but usually moves along its course, creating a freshet wave. This primarily applies to larger rivers, which have their origin in the mountains or highlands. As the wave moves along the course of the river, the wave front is reduced, and the length is extended and, at the same time, the wave height is decreased. In addition, freshets can occur depending on the origin of formation at different times of the year. On a national scale high water most often occur in March, April and July, and less frequently in February and June. In the basin of Odra River, 59% of the annual climax falls on the winter half-year (including 27% in March), and 41% on the summer half-year (including 14% in July) [Byczkowski 1996].

2. CAUSES OF FLOODING

Floods on the Odra River, especially those of large size, have specific sources of origin and the process of forming. Analysis of historical floods on the Odra revealed that the greatest high water occur mostly in the summer months, with particular intensity in July and August. These freshets are caused by the presence of extensive and intensive rainfalls lasting for at least 2-3 days. In addition, analysis of the summer floods showed that the cause of their formation is not only a high rainfall, but also the time of its occurrence in different areas of the river basin, and the order of runoff from individual sub-basins and their functions in the formation of the wave. Summer floods may occur in the mountains, foothills and lowlands areas. The most difficult to predict are precipitation floods, derived from torrential rains usually of thermal origin. Occur locally on a small mountain and lowland streams, and cause the most damage. The largest share of the outflow formation is the size and shape of the basin, orography, slopes inclination, the permeability of the ground and land cover. Widespread floods, which are associated with frontal rains, have much wider range. They occur both in mountainous and lowlands areas, and may cover the entire river basin. Amount of rainfall within a few days, recorded during the floods, may exceed the monthly norm.

Conditions conducive to the occurrence of snowmelt flooding is the rapid melting of snow due to the sudden increase in air temperature and heavy rain accelerating the melting of snow, which, with a high degree of frozen ground increases surface runoff. The period of the formation of these floods are the winter and early spring months, with particular intensity in March.

Winter floods differ in cause of formation, course, location, range, time of occurrence and associated conditions. Divided into: jam floods and frazil-ice floods. Water rises are caused by jams during ice flow in rivers, in places

predisposed, such as the narrowings, sandbars, islands, in places with sudden changes in flow direction, in bridge profiles, in the upper sections of the damming barriers (reservoirs) are the causes of ice–jam floods. Occur in lowland and mountain rivers. However, frazil-ice floods are formed by great intensity of formed anchor and frazil ice. Then the whole river profile is jammed, the water piles up, causing local severe flooding. Most often floods of this type occur in December and January at low water levels.

The source of the formation of the Odra floods is the area of upper Odra. The interaction of water outflow from this area with other outflows determines flood sizes. Another cause of high water is an outflow of significant amounts of water from the basin of Nysa Kłodzka. Freshets in the upper Odra and Nysa Kłodzka cause substantial floods on Odra River in its upper and middle part. The formation of the flood wave, which entails a risk of flooding, can also occur during high water in the upper part of the Odra River and its right-bank tributaries, to Barycz inclusive. Substantial flood may also occur on Bóbr and Lusatian Neisse during high spate. In this case, high waters in Nysa Kłodzka and middle Odra tributaries can be moderate. In addition, the overflow of Odra River may occur as a result of high water in middle Odra tributaries, with moderate high waters in upper Odra [Dubicki, Słota, Zieliński 1999, Dubicki 2005].

3. THE BIGGEST FLOODS IN THE ODRA RIVER AND ITS TRIBUTARIES IN THE NINETEENTH AND TWENTIETH CENTURY

Started in the early nineteenth century, systematic observations of water levels allowed collecting more accurate information about the size of the flood on the Odra River and its tributaries. The floods, which were the result of high water on the upper Odra, Nysa Kłodzka, Beaver and Lusatian Neisse, occurred in the years 1813-1855. The largest flood in the middle of the nineteenth century Europe, on the Odra River occurred in 1813. Other major floods occurred between 1854 and 1855 with the highest maximum from Wroclaw to Slubice. They caused numerous broke of levees and significant overflows. Local very severe floods occurred in 1879 in the basin of Nysa Kłodzka, Bóbr, Kwisa and Lusatian Neisse. Major spates on the Odra also occurred in 1888 and 1889.

In the twentieth century, large summer floods occurred in 1903, 1926, 1940,1977, 1985, 1997, 2009 and 2010, snowmelt floods in March 1909 and 1922, and in February 1946, in the autumn in October 1910 and 1915, and in November of 1930. By the time of the most disastrous flood in the Odra River in July of 1997, for the largest, was considered a flood of July 1903, which was only slightly lower (in the middle and lower reach of Odra) than the flood of 1854 [Maciejewski, Ostojski, Tokarczyk 2011, Rast, Obrdlik, Nieznański 2000, Dubicki, Malinowska-Małek 1999].

4. MEASURES OF FLOOD RISKS IN ODRA RIVER AND ITS TRIBUTARIES

Started in the An important element of knowledge about the scale of flood risks is the knowledge of the basin flood measures, established on the basis of the observed flood flows or on the basis of expected probable maximum flow. Measures of flood risk include: flood potential (*Pq / Fp*), flood risk index (*WZP / FRI*) and complementary floodgenerativity index (*WKP / CFI*).

Flood potential (*Pq / Fp*) is one of flood measures used so far, proposed by Balcerski [Lambor 1971]:

$$P_q(F_p) = \frac{WWQ - Q_{brzeg}}{Q_{brzeg}} \sqrt{A} \tag{1}$$

where:
WWQ – the highest observed flow in multi-year,
Q_{brzeg} – flow according to the bankfull waters level,
A – basin area in km^2

This index provides a flood measure in relation to the basin area. It gives the opportunity to compare the risk in different regions, but only when the length of the observation sequences is comparable, and when historical episodes of flooding cover compared areas at the same time. Otherwise there can be no assurance that the maximum observed freshets, in the compared basins, had the same rank. Flood risk increases with the size of the flood potential. Flood potential in Lower Silesia (Fig. 1) varies widely from about 761 (Oława) to 1355 (Głogów) for the Odra River and from about 10 (Bukówka) to 480 (Żelazno) for the tributaries. In general it can be stated that the flood potential for the Odra increases with basin growth. Also tributaries of the Odra River, with larger basin areas have greater flood potential (Fig. 1).

Flood risk index (*WZP / FRI*) is a measure that describes floodgenerativity in terms of flood risk.

$$WZP(FRI) = \frac{MWW - Q_{dozw}}{MWW} \tag{2}$$

where:
Q_{dozw} – nondamaging flow (Qgr - boundary flow of safety = $Q_{max50\%}$) [Ozga-Zielińska 2003]
MWW – maximum probable spate (Q_p = 0,01%) [BERGA 1992].

WZP (FRI) defines the actual level of flood risk, recognizing that the threat occur only after exceeding the boundary flow, determined by local conditions. *WZP* (FRI) succinctly describes the scale of local flood risk.

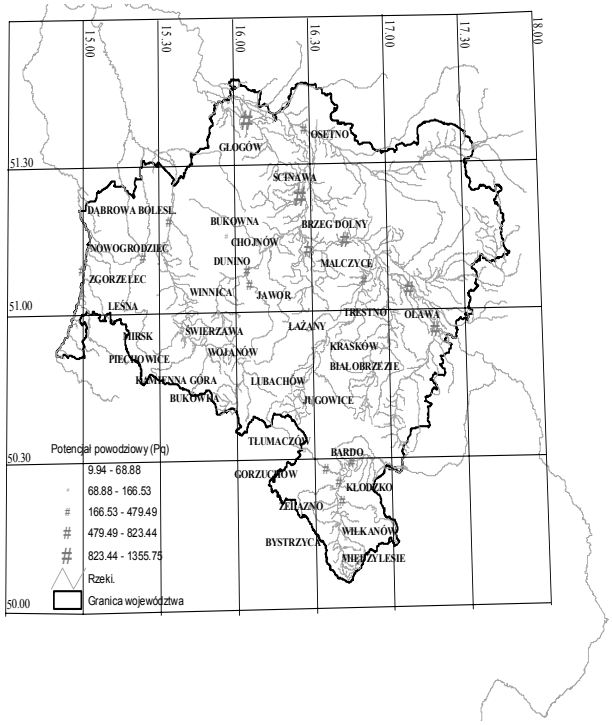

Fig. 1. Variability of flood potential in gauging cross-sections within the Lower Silesia Province

Designation of this measure allowed for the identification of areas with the greatest flood risk potential for the Lower Silesia province. Indicator of flood risk should be considered as high. It is in range from 0.7903 on Widawa in Zbytowa section to 0.9887 on Bystrzyca in Lubachów. For the middle Odra, it is in range from 0,8486 (Oława) to 0,9118 (Ścinawa) (Fig. 2.).

Complementary floodgenerativity index (*WKP*/CFI) is a measure that describes floodgenerativity in terms of the largest flow so far observed.

$$WKP(CFI) = \frac{MWW - WWQ}{MWW} \tag{3}$$

gdzie:
MWW – maximum probable spate (Q_p = 0,01%) [Berga 1992]
WWQ – the highest observed flow in multi-year,

WPK/CFI rate, determines the level of current "non-attainment" of maximum floodgenerativity, which is a measure of MWW. It is therefore complementary (supplemental) part of floodgenerativity, which can be expected in a situation of occurrence of flows that are larger than the largest previously observed, i.e. from WWQ. In other words, it determines the level of potential

possibility of exceeding the highest flow observed previously [Ozga-Zielińska 2003].

Value of complementary floodgenerativity indicator, which provide the degree of non-attainment of MWW, in the province of Lower Silesia for the Odra basin ranges from 0.0 to 0.947. For Odra within Lower Silesia province this indicator is relatively low, ranging from 0.0 in Trestno to 0.3 in Scinawa. This indicator has very high values for some of the tributaries of Odra River. For most of them it reaches values above 0.4, and for Ślęza, Bystrzyca Widawa and Kwisa it exceeds 0.9 (Fig. 2).

5. FLOOD RISK ZONES

According to the Water Law (Article 79, paragraph 2) for the purpose of flood protection planning, the Regional Water Management Boards are required to determine the borders of flood waters range, of a certain probability of occurrence. These areas [D.U. 115 z 2001 r] are considered i.a. in the preparation of development plans of the province and in the study of conditions and directions, and they are called the flood risk zones. These areas include littoral zones of rivers, which at the time of the flood are flooded by an overflowing river. The extent of these zones is determined by the flow adopted as dependable for the zone. Flood risk zones are associated with flood protection zones, and in fact they are determined to establish protection zones [Ozga-Zielińska 2003].

5.1 Flood risk zones for water of Q1% probability

Floodplains for Lower Silesia region were determined on the basis of existing maps that identify areas of potential flooding for Q1% flows, and by interpolation of probable water table elevations calculated for gauging cross-sections. Interpolation between gauging sections was performed with the use of cross-sections of the river bed and valley. Water table elevations in individual sections were calculated using the computer program "HYKOR" developed by R. Dąbrowski and R. Eliasiewicz of Agricultural University.

The analysis of the areas flooded by waters likely to surpass Q = 1%, shows that the areas potentially at risk in Lower Silesia covers the adjacent areas along the following sections of rivers:

- River Odra within the province of Lower Silesia,
- River Nysa Kłodzka from Międzylesie gage the border of province,
- River Oława from Henryków to the estuary,
- River Ślęza from Marcinkowice to the estuary,
- River Bystrzyca from the reservoir Lubachów to the estuary,
- River Widawa from the voivodship border to the estuary,
- River Kaczawa from Świerzawa gage to estuary,

- River Barycz from Łąki gage to the estuary to River Odra,
- River Bóbr from the reservoir Bukówka to the estuary.

These areas were prepared on the basis of „Development of range of controlled flooding of rivers in the RZGW area, taking into account Q1%, and the maximum states of the observation period" [Tokarczyk 2002].

5.2 Flood risk zones of 1997

Floodplains Danger zones for historical floods were determined on the basis of flooded areas during the flood of July 1997 in the Lower Silesia province, and prepared on the basis of "General protection strategy against flood of the upper and middle Odra basin after the great flood of July 1997". During this flood areas along the following rivers have been flood:

- Odra River within the Voivodeship of Lower Silesia,
- River Oława from Kazanów, to the estuary to Odra River, with estuary sections of tributaries: Podgorka, Krynka, tributary in Biskupice and Gnojna,
- River Ślęza from Sienice to the estuary, along with estuary sections of tributaries: Krzywula and Księginka and rivers Oleszna and Mała Ślęza,
- River Bystrzyca from the reservoir Mietków, along with the River Strzegomka from Pyszczyn, and Czarna Woda from Garncarsko,
- River Widawa from the province border to the estuary,
- River Barycz from Milicz to Sułów Milicki, and from Bartków, including the estuary section of tributary Łacha.

It is estimated that during the food in 2010 the maximum flow in Wroclaw Floodway System amounted about 2200 m^3/s (compared to 3600 m^3/s in 1997) and was the limit for the flow of the water system. Without limiting the flow on the reservoirs of Nysa Kłodzka cascade, losses in the region of Lower Silesia would be incomparably higher, including Wroclaw itself [Kosierb 2011]. Probability of flood discharge waters in July 1997, is much higher than the likelihood of potential floods of Q = 1%. In addition, during the flood of 1997 there were numerous damaged embankments and hydraulic devices, which have contributed to the growth of the flooded area [Tokarczyk 2002] Hence the flood of 1997 can still be considered as the biggest and most catastrophic [Kitowski, Lubacz 2010].

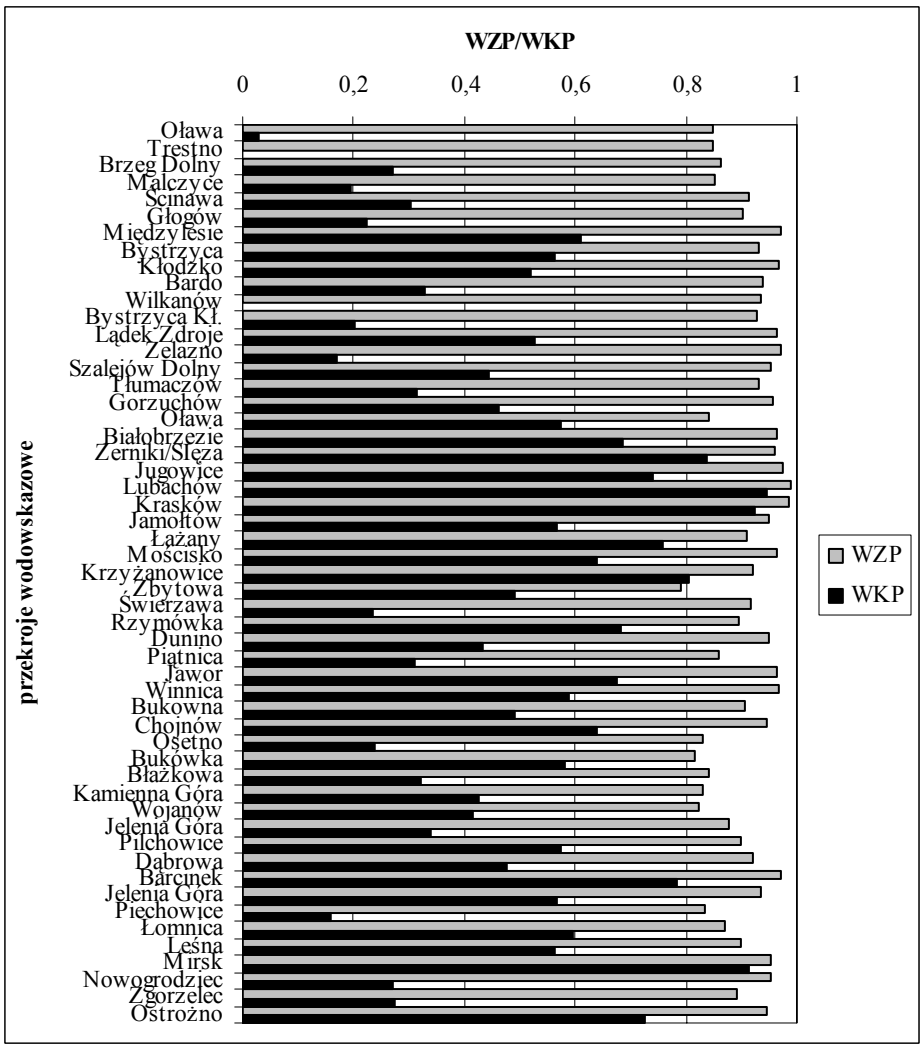

Fig. 2. Variability of WZP (FRI) and WKP (CFI) coefficients in gauging sections in the province of Lower Silesia

5.3 Flood risk zones prepared in the project ISOK

Currently Directive 2007/60/EC on the assessment and management of flood risks requires all EU Member States to develop flood hazard maps and flood risk maps (in accordance with Article. 6 – until end of 2013) and then develop flood risk management plans on their basis (in accordance with Article. 7 and 8 – until end of 2015). Currently, preliminary flood risk assessment is created in the project "Global Monitoring for Environment and Security" (ISOK) financed by

the European Regional Development Fund under the Innovative Economy Operational Programme. The project is implemented by the Institute of Meteorology and Water Management - National Research Institute (IMGW – PIB Flood and Drought Modelling Centers) in consortium with the National Water Management Board (KZGW), Head Office of Geodesy and Cartography (GUGiK), the Government Security Centre (RCB) and the Institute of Communications. Created maps are based mainly on a combination of data from laser scanning of high accuracy and hydraulic modeling, and are aimed to provide a diagnosis of intensity of the flooding and the level of its potential adverse effects. Therby maps of areas of direct and potential flood risk after opinion of the council of municipalities, districts and provincial assemblies are the basis for the verification of land use planning [Kitowski 2011].

6. SUMMARY

Flood risk assessment of Lower Silesia was based on the analysis of the process of formation and the causes of flood, its size, character of the course, time of movement, period of occurrence and the location and territorial extent. Flood risk size was determined on the basis of an analysis of the floodgenerativity status indicators and based on maps of historical potential flooding. The article uses the existing elaborations and observation and measurement materials of IMGW.

The source of the floods occurring in Lower Silesia are mostly summer freshets especially in July and August, caused by high precipitation, especially in the mountain areas of Odra River and its tributaries, especially Nysa Kłodzka and Bóbr.

The greatest flood potential (*Pq / Fp*), in the Lower Silesia region, occurs in the pravalley of Odra River and basin of Nysa Kłodzka, Bóbr and Kaczawa, as evidenced by the designated zones of historical (July 1997) and potential floods (Q = 1%). However, the greatest flood risk (*WZP / FRI*) is concentrated in a few regions of Odra River basin ie basins of Bystrzyca, Nysa Kłodzka, Kwisa, Ślęza and Nysa Szalona. In addition, attention should be paid to the reduction of flood risk by reservoirs, which is especially visible in Bystrzyca - Mietków reservoir (*WZP / FRI* = 0.9887 in Kraskow and *WZP / FRI* = 0.9498 in Jarnołtowie) and in Kwisa, Złotniki and Leśna reservoirs (*WZP / FRI* = 0.9533 in Mirsk and *WZP / FRI* = 0.8986 in Leśna). Flood risk in the section below the reservoirs is much smaller than in the upper part of the basin. Areas with a high ratio of the *WZP / FRI* are the areas where people should not live, nor should not be located any permanent economic facilities without flood protection.

Complementary floodgenerativity index (*WKP / CFI*) of Lower Silesia province shows that the largest possible flood risks in relation to those already observed, may occur in the basins of Kwisa and Bystrzyca as well as Widawa

and Ślęza. However, this index is significantly lower for the basin of the upper Nysa Kłodzka. This may suggest that in the case of Nysa Kłodzka as well as the Oder the catastrophic floods that would be expected may slightly exceed the largest observed so far.

REFERENCES

1. Berga L., *New trends in design flood assesment*. International Symposium on Dams and Extreme Floods T.III., Spain, Granada 1992
2. Byczkowski A., *Hydrologia*. Warszawa, SGGW 1996
3. Dubicki A. i inni, *Zagrożenie powodziowe*. Opracowanie ekofizjograficzne dla województwa dolnośląskiego. Wrocław, Wojewódzkie Biuro Urbanistyczne we Wrocławiu 2005
4. Dubicki A., Malinowska-Małek J., *Wielkie powodzie w dorzeczu Odry w ostatnim stuleciu*, Wrocław, IMGW (maszynopis), 1999
5. Dubicki A., Słota H., Zieliński J. (red.), 1999: Dorzecze Odry. Monografia powodzi lipiec 1997. Seria Atlasy i Monografie. Instytut Meteorologii i Gospodarki Wodnej, Warszawa
6. Kitowski K. *Planowanie przestrzenne i jego rola w ochronie przeciwpowodziowej.* W: Przyszłe wymagania w zakresie zarządzania ryzykiem powodziowym oraz zrównoważonego gospodarowania wodami w dorzeczu Odry. Wrocław, mater. konf. MKOO 2011
7. Kitowski K., Lubacz E. *Powódź w czerwcu i lipcu 2009 r. w dorzeczu środkowej Odry ze szczególnym uwzględnieniem Dolnego Śląska*. W: Konferencja Dolny Śląsk: Powódź a Śropdowisko – dobre praktyki. Polanica Zdrój. mater. konf. 2010
8. Kosierb R. *Gospodarka wodna na zbiornikach retencyjnych rzeki Nysy Kłodzkiej podczas wezbrania w maju 2010 roku.* W: Przyszłe wymagania w zakresie zarządzania ryzykiem powodziowym oraz zrównoważonego gospodarowania wodami w dorzeczu Odry. Wrocław, mater. konf. MKOO 2011
9. Lambor J., *Hydrologia inżynierska*. Warszawa, ARKADY 1971
10. Maciejewski M., Ostojski M.S., Tokarczyk T. (red.), 2011: Dorzecze Odry monografia powodzi 2010. Seria Monografie, Instytut Meteorologii i Gospodarki Wodnej – Państwowy Instytut Badawczy, Warszawa
11. Ozga-Zielińska M. i inni, *Powodziogenność rzek pod kątem bezpieczeństwa budowli hydrotechnicznych i zagrożenia powodziowego.* Materiały Badawcze IMGW Nr 29, Seria Hydrologia i Oceanologia. Warszawa, IMGW 2003
12. Prawo Wodne, Dziennik Ustaw nr 115 z 2001 r.
13. Rast G., Obrdlik P., Nieznański P. (red.), 2000: Atlas obszarów zalewowych Odry, WWf Deutschland

14. Tokarczyk T. i inni, *Opracowanie zasięgów zalewów rzek kontrolowanych na obszarze RZGW przy uwzględnieniu Q1% i maksymalnych stanów z okresu obserwacyjnego*, Wrocław, IMGW 2002

ZAGROŻENIE POWODZIOWE WOJEWÓDZTWA DOLNOŚLĄSKIEGO

S t r e s z c z e n i e

Powodzie to naturalne i losowe wydarzenia powodujące liczne szkody w rolnictwie, przemyśle i mieniu ludzkim. Analiza materiałów historycznych wskazuje, że największe powodzie w województwie dolnośląskim wystąpiły w sezonie letnim, najczęściej w lipcu i sierpniu. Wydarzenia te są najczęściej spowodowane przez rozległe i intensywne opady w obszarze górnego biegu Odry i jej lewostronnych dopływów (Nysa Kłodzka, Bóbr). W skali określania zagrożenia powodziowego w regionie ważna jest znajomość wskaźnika potencjału powodziowego, wskaźnika zagrożenia powodziowego i wskaźnika potencjalnej powodziogenności. W artykule podano informacje o tworzeniu stref zagrożenia powodziowego, w tym tworzonych w ramach projektu ISOK.