World Meteorological Organization

STUDY OF HISTORICAL FLOODS IN CENTRAL AND EASTERN EUROPE FROM AN INTEGRATED FLOOD MANAGEMENT VIEWPOINT

POLAND

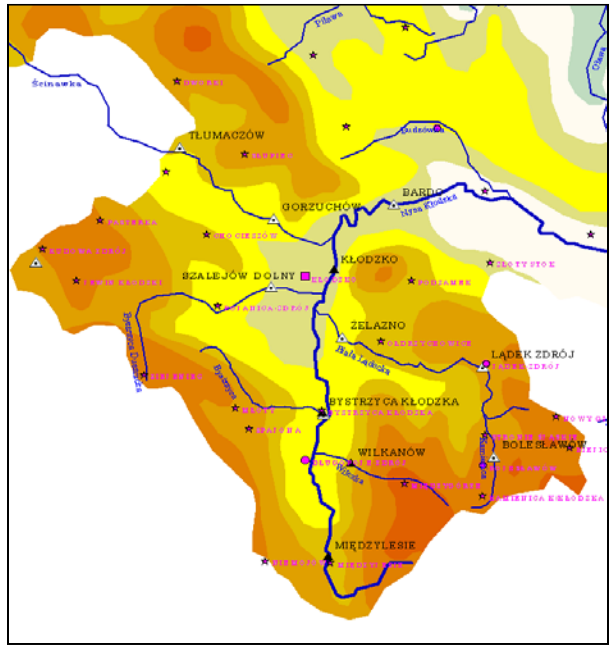
Submitted by: Institute of Meteorology and Water Management, Warszawa

For the WMO/GWP Associated Programme on Flood Management

1. FLASH FLOOD IN THE KLODZKO RIVER BASIN IN 1997

1.1 Flash Flood in the Nysa Klodzka River Basin

- Where: Nysa Klodzka River Basin
- Date: 06.07.1997 (first culmination - peak)
- Rainfall: intensity 10 - 27 mm/60 min (max 7.07.97) from 5.07 (20.00-22.00) through 60-70 hours to 9.07.97 (from 453,5 mm in Międzygorze station and 482,2 mm in Kamienica station – 3 days) ; the second rainfall wave from 17.07 for 5 days (smaller in the Nysa Klodzka. River Basin)
- River water level: locally exceeded alarm level by 500 cm (on upper tributaries 290-300 cm)
- Outflow: in the outlet to the Odra river: 1200 m^3/s
  - 80% of water that has fallen on the Nysa Klodzka catchment has flown out to rivers;
  - high and long lasting exceedance of alarm water levels (4-6 days the first wave and 10-15 days the second wave, at the mouth of the Nysa Klodzka river for 30 days)
  - 2 flood waves (6-10.07 and 19-23.07), peaks: 8.07 and 20.07



- Losses: information available only in specific provinces or in the entire Odra River Basin

1.2 CHARACTERISTICS OF THE CATCHMENT

1.2.1 Natural characteristics

Geographic location

Country: southwestern part of Poland.

The Sudety Mountains and the Piedmont of Sudety Mountains. Location: between 50 – 51° northern latitude and 16 – 18° eastern longitude.
The Klodzko Valley (Kotlina Klodzka) which belongs mostly to the Klodzko administrative district – hydrologically the upper Nysa Klodzka catchment - is located close to the southwestern border of Poland and surrounded by mountain ranges. From the eastern, southern and western side, the catchment borders upon the Czech Republic.

<u>Characteristics of the catchment, soil conditions and hydrogeological aspects, vegetation, basic climate and hydrological characteristics</u>

Shape of the catchment is irregular but asymmetrical, longer from west to east, length ca. 120 km, width north/south ca. 70 km.

The Nysa Klodzka River takes its source in Puchacz slopes (975 m. above sea level). It flows through the Klodzko Valley being a tectonic trough filled with sandstone and cretaceous marls (bottom of the valley is 350-450 m a.s.l.). Bottom of the valley is a surface which cuts off rock series of different ages covered with loess (it makes a basement for good soil development, so that of agriculture). The Nysa River and its tributaries cut into that surface to the depth of 50 to 80 m., and valleys are accompanied by a couple of distinct terraces. Within the valley, river deposits and glacial muds have been preserved (boulder clays) as well as some glacial-lake (varve loams). At the border of Nysa Klodzka catchment within the Klodzko Valley, there are the following mountain ranges: Orlickie with Bystrzyckie Mountains from the south-west, Snieznik Massif and Bialskie Mountains from the south-east, Zlote Mountains from the east, Bardzkie Mountains along with Sowie ones from the north as well as Stołowe and Kamienne Mountains from the west. The Nysa Kłodzka River has many tributaries. Its left-bank tributaries include Bystrzyca, Lomnica, Bystrzyca Dusznicka, while right-bank ones include: Polna, Bielica, Szklarka, Goworowka, Domaszkowski Potok, Nowinka, Wilczka, Plawna, Rownica, Biala Ladecka and Jaszkowka rivers. Main river network consists of the following rivers: Nysa Klodzka, Bystrzyca, Bystrzyca Dusznicka oraz Biala Ladecka, whose valleys are distinctly separated from one another. Rivers flow depends on tectonical lines and different rocks-strength.

Surface of the Nysa Klodzka catchment up to the Bardo water gauge (catchment of the upper Nysa Klodzka) amounts to 1689,0 km^2, while the whole catchment is of 4565,7 km^2 and up to Skorogoszcz water gauge (outlet to the Odra river) it is 4514,5 km^2.
Below Scinawka river mouth, Nysa Klodzka is leaving the Klodzko Valley and flows through Bardzkie Mountains gorge. Nysa Klodzka enters the area of the Sudety Mountains tectonic foreland (Przedgorze Sudeckie) about 1.5 km below Bardo water gauge. Upstream of the Nysa town the river flows into the Slask Plain.

The climate is relatively cool and humid. Frequent southwestern winds are of the „föhn" character, which crossing the mountain barrier cause drying and heating of air masses. In the valleys, during the winter months, temperature inversions occur frequently. Vertical variability of climate conditions creates specific configuration of vegetation layers. Low prealps (subalpine forests) layer extends from the altitude of 400 m, upper one (spruce forests) up to 1250-1300 m, subalpine (with dwarf mountain pine) up to 1500m. Alpine layer covers only some of the highest hills of Karkonosze Mountains. Sudety Mountains create individual, separate geobotanic section. Highmoors are well developed, tundra relicts occur like lapponian willow, cloudberry, snow saxifrage, a plant of the genus Pedicularis, swamp pine tree and others.

Time and spacial variability of meteorological factors as well as land orography result in difficult hydrological conditions of the Nysa Klodzka catchment. Due to its specific character and landscape diversity, the topography of the Klodzko Land area is irregular. Therefore, the surface runoff is relatively large and its volume depends mainly on the slope of land draining waters to streams and rivers. Average catchment land slopes are from 2.1% (Nysa Klodzka up to the cross-section in Klodzko) to 13,4% (the Wilczka catchment).

The Nysa Klodzka River together with its tributaries forms a fan-shaped system. Such system causes that water level in the Nysa Klodzka River in Klodzko responds rapidly to the runoff from the mountainous areas. Consequently, the flood waves from left and right-bank tributaries join the flood wave in the Nysa Klodzka, and the resulting discharge poses a dangerous flood threat to the town. Due to significant slope of lands adjacent to river valles and large longitudinal slope of the streams, the time of flood wave movement along the river is very short. Longitudinal stream slopes in the Klodzko Land area vary from 10.2 ‰ (Nysa Klodzka to Klodzko water gauge) up to 46 ‰ (Wilczka).

Steep slopes and large longitudinal slope of river beds cause rapid water discharge to lower-laying areas, thus creating severe flood threat to the Kłodzko district. The main source of the flood threat is torrential rainfalls which occur in the summer half of the year. Floods are characterised by rapid flood water lever increase, short duration, and high velocities resulting all together in heavy water damages. It is estimated that flood water arrival times in particular places at this area vary from 1 to 9 hours.

The Klodzko Valley was often affected by large floods. Over recent centuries some floods occurred with similar extent as that in 1997. One of the most severe was the 1938 flood, when water level of 560 cm was recorded at the water guage in Klodzko. Even higher water level occurred in the year of 1883, reaching 585 cm. But the highest water levels and flows were caused by rainfalls in July 1997 (Dubicki et al., 1999).

1.2.2 Social characteristics

Klodzko administrative district covers the area of 1640 km^2 with 185 000 inhabitants and it is divided into municipalities (gminas):

L.p.	Towns / Municipalities	Population in thous.	Surface km^2	Arable lands %	Forests %
1.	Bystrzyca Klodzka	21,5	338,6	47,2	46,2
2.	Duszniki Zdroj	5,5	22,3	26,5	58,4
3.	Klodzko Municipality	18,3	252,3	66,7	22
4.	Klodzko Town	30,1	25	61,2	1,6
5.	Kudowa Zdroj	10,9	34	39,5	47
6.	Ladek Zdroj	9,6	117,4	44	49,6
7.	Lewin Klodzki	2,1	52,2	45,8	46,6
8.	Miedzylesie	8	189,3	60,9	31,9
9.	Nowa Ruda Town	26,6	37	61,3	17
10.	Nowa Ruda Municipality	13,2	139,7	49,6	41,1
11.	Polanica Zdroj	7,5	17,2	27,2	51,5
12.	Radkow	10,1	139,9	57,9	34,9
13.	Stronie Slaskie	8,9	145,4	19	76,4
14.	Szczytna	7,9	133,2	30,1	63

KLODZKO district in 1999
Source: Information derived from the Lower Silesia year-book, 2000 (Statistical Office in Wrocław)

Regarding the land use pattern in the Klodzko Valley, there is a clear predominance of arable lands and forests. By the end of 1999, 15 102 economic enterprises were registered, including 1387 in industry and 686 in agriculture and forestry.

1.3. HYDROMETEOROLOGICAL ASPECTS OF FLOODS

1.3.1 Meteorological characteristics

Synoptic situation

Second half of June 1997 was cool and rainy. Potential conditions for the occurrence of significant flood arose. Also meteorological conditions were becoming more and more dificult.

Since the beginning of July Poland remained in warm and moist air, and over the whole Europe low pressure systems predominated.

At first, the influence of low-pressure embayment appeared with system of fronts associated with low pressure systems from the British Islands. Then Poland was influenced by shallow low pressure system with centers over Mazowsze and Hungary. In the eastern part of the country the atmospheric front was active. On 5th of July, the western and south-western provinces (voivodships) were situated in the cold polar-maritime air, and over the remaining country warm and very moist tropical air was inflowing. Meeting of two air masses resulted in heavy rainfall. The center of low shifted (moved) to northern Malopolski Region, low was deepening and presssure was decreasing. On July 8, the central and southeastern Europe remained influenced by low pressure from the Hungarian Lowland. Low pressures over the Hungarian Lowland usually bring the highest precipitation to the southern Poland.

The above meteorological situation favoured precipitation occurrence, initially weak and occasional showers, along with rain storms. When two thermically different air masses met, precipitation became intensive and associated with many storms. They strucked the whole country, reaching the highest precipitation totals to the south of Warsaw latitude. The similar situation was in Austria, Czech Republic, western Slovakia, Hungary and countries of the former Yugoslavia. For Poland, the most threatening proved to be intensive rainfall in the Czech part of the Odra basin, where from the flood wave came up exceeding the highest on record by at least 2 meters.

Precipitation preceding the main wave began on July 3 to 4. The highest precipitation totals were observed between 6 and 8 July. Precipitation wave was moving distincly from west to east. Rainfall higher than 100 mm occured in the triangle Jelenia Gora –Warsaw -Nowy Sacz. Rainfall exceeding 200m occurred in the Sudety and Karpaty mountains: from Karpacz at the foot of Karkonosze ranges in the west, to Dunajec and Biala Tarnowska in the east. Spacial extent of rainfall was very large when compared to floods observed till then. Rainfall exceeding 250 mm was recorded at the gauges located in the upper parts of Nysa Klodzka, Mala Wisla (Small Vistula), Sola, Raba and Dunajec river catchments as well as in Brama Morawska.

Over the upper Odra river catchment, thickness and water saturation of clouds were the highest. The compact area of clouds reached the altitude of 8 – 9 km. Storm clouds were additionally uplifted due to orographic forces of the slopes of Karkonosze, Orlickie, Jesioniki and Beskidy ranges and moreover, following high speeds of inflowing perpendicular air masses. The following days (July 8 to 9) low pressure from the Black Sea filled step by step and migrated to the north. Precipitation decreased and disappeared gradually.

During the night of July 17/18, over the southern Czech Republic the next low pressure was formed, covering Slovakia, Austria and southern Poland. The highest precipitation was observed in Karkonosze mountains, and it was intensified by the inflow of northern air masses. On 19 July morning low center from Morawy moved to Poland and arrived to Raciborz vicinity. It was moving to the northern east. Depth of cyclon was increasing and cloudiness developed over the whole Central Europe. High water saturation and large vertical extent of clouds over southwestern Poland caused heavy intense rainfall over the whole area of the upper and the middle Odra river catchment. In the Lower Silesia rain storms occurred, and the most intense precipitation was observed in the catchments of Bobr, Bystrzyca, Nysa Klodzka and Barycz rivers. On July 20, the cyclon covered the whole territory of Poland, Czech Republic, Western Belarous, Southern Ukraine and Hungary. The Central and Southern Poland were still affected by intense precipitation. Since July 21, low prssure filled-in and precipitation gradually disappeared.

Identification of the causal factors of the floods (rainfall), time and space parameters (dimension, duration and intensity)

Rainfall which directly caused flooding began on July 5 at 16.00 – 19.00 in the Upper Odra River Basin and at 20.00 – 22.00 in the Nysa Klodzka catchment, that is 33 hours after the flood warning was issued by the Institute of Meteorology and Water Management (IMGW).

Rainfall concentrated in the upper Odra region and eastern part of Nysa Klodzka basin, covering large area in the south-eastern part of the Beskidy mountains, especially Beskid Wysoki (High Beskid) through Odrzanskie Mountains, Wysoki and Niski Jesienik, Snieznik Massif till axis of Nysa Klodzka River and Sowie Mountains, covering the upper catchment of Bystrzyca River and its northwestern tributaries.

Second rainfall center was located in left, mountanious part of Odra River basin in the following mountains: Wysoki Jesenik, Opavskie, Zlote Mountains and Snieznik Massif and in the area of Biala Głucholaska, Opava, Widna, Swidna and Raczyna catchments, as well as these of Biała Ladecka and Wilczka. Precipitation recorded in this region fluctuated from 316,2 to 513.0 mm.

Extremely high rainfall appeared in the eastern part of the Nysa Klodzka catchment. During about three days, beginning at 21.30 on July 5, 1997 over the area of Zlote, Bialskie Mountains and Snieznik Massif the precipitation from 453,5 mm in Miedzygorze to 482.2 mm in Kamienica were observed, and from

316,2 to 366,9 mm at other stations of the region. Its extraordinary intensity should be noticed. In Stronie Slaskie, Kamienica, Ladek Zdroj from 10 to 27 mm of rainfall has fallen in 60 minutes. The highest intensity occurred on July 7, 1997 between either at 16.00 and 17.00 or at 17.00 and 18.00. Before noon or at noon hours, the highest intensity was recorded rarely.

High rainfall affected also Glubczycki Plateau, where from water was directly drained to the Odra River (189,8-312,6 mm), as well as eastern part of Sudety Piedmont draining to Nysa Klodzka. The eastern part of Kotlina Klodzka with Bystrzyca, Bystrzyca Dusznicka and Scinawka basins was also affected by exceptionally high rainfall, with 5-day precipitation totals fluctuating from 84,9 to 231,3 mm.

Second rainfall wave began on July 17,1997 and lasted over the following 5 days, that is till July 22, 1997. Its center was situated in the Bystrzyca, Kaczawa, Bobr and Kwisa catchments. In upper Odra and Nysa Klodzka catchments they were lower by about 40 % (5-day volume amounted to 100 – 200 mm).

Measured depths of precipitation were over 250 % of standard for July recorded in years 1961-1990, locally exceeded 300% in the Nysa Klodzka catchment (Miedzygorze – 346,2 %, Kamienica – 339,6 %, Stronie Slaskie – 295, 9 %). In relation to the long-term annual mean the rainfall reached 20 %, locally to 40 % of this amount, and during July 18-22, 1997 it reached 35 %.

1.3.2 Hydrological characteristic

Information and findings from the field reconnaissance

The study of the beginning of the rainfall and of the water level rise in the upper Odra and Nysa Klodzka tributaries has shown, that depending on the catchment size, the runoff time varied from 3 to 7 hours.

In the Nysa Klodzka catchment, due to very steep land slopes and extremely high rainfall intensity (from 10 to 27 mm/60 minutes) water level started rising immediately when precipitation began. Time from the occurrence of maximum precipitation intensity (Stronie Slaskie) to the occurrence of peak flow in Ladek Zdroj amounted to 3 hours, in Bystrzyca Klodzka on Nysa Klodzka 5 hours, and in Kłodzko only 9 hours. So significant and sudden water level rise caused damages in municipal infrastructure, hydrotechnical structures and observation network. Change of rainfall intensity rate caused, that flood waves on Nysa Klodzka and its tributaries were on a constant increase but with separate peaks. First peak on the right-bank tributaries occurred in the morning of July 7, 1997, the next one in the early morning of July 7, 1997. Between 20.00 and 21.00, following torrential rainfall from 15.00 to 18.00, and especially at 17.00 – right-bank tributaries of Nysa Klodzka, Wilczka and Biała Ladecka as well as upper Nysa Klodzka reached their peak levels (200 – 350 cm with flow Q = 150 – 225 m^3/s in Miedzylesie and Ladek Zdroj).

Flood waters supplied with left-bank tributaries discharged with the big strength into Klodzko, reaching in some places second floor of buildings.

Flood wave on Nysa Klodzka supplied with waves of Scinawka and Budzowka rivers reached cross section on Bardo river closing catchment of upper Nysa Kłodzka (being at the same time indicative water gauge for inflow to Otmuchow reservoir) after 12 to 13 hours, following the maximum intensity of precipitation. Bardo, then Kamieniec Zabkowicki and other villages were flooded. Flood wave damaged buildings and water structures.

Flood wave parameters

Extreme water levels and water flows

Maximum water levels on record were exceeded on the Nysa Klodzka River and its right-bank tributaries. On the Odra river tributaries in the Czech Republic, these values ranged from 85 to 204 cm, while on Nysa Klodzka and its tributaries they varied from 28 cm in Skorogoszcz to 248 cm in Bystrzyca Klodzka.

Duration of water levels exceeding alarm values on the Odra tributaries lasted for the first flood wave from 4 to 6 days and locally from 9 to 11 days. Second wave on tributaries was significantly higher, therefore duration of water levels exceeding river bank level was longer. The alarm levels remained exceeded for exceptionally long time up to 30 days, especially on these tributaries where storage reservoirs were emptied (outlets to the Odra river, including Nysa Klodzka).

On the Nysa Klodzka alarm water levels were locally exceeded for 500 cm (Bardo). On the majority of Nysa Klodzka gauges they were exceeded by 312 to 467 cm.
Also on upper tributaries of the Nysa Klodzka high exceedances of alarm water levels from 155 to 290 cm were recorded.

Catastrophic water flows occurred on Nysa Klodzka and its left-bank tributaries. They reached from 741 m^3/s in Bystrzyca Klodzka, through 1340 m^3/s in Klodzko, to 1790 m^3/s in Bardo. On Biała Ladecka and Biala Głucholaska rivers as well as on Scinawka flows fluctuated from 425 m^3/s to 700 m^3/s. Flooding intensity, not recorded earlier volume and wave height, damaged everything on its way, that is buildings, streets, roads, bridges, fields and forests. In Klodzko, due to limitation of flow velocity, the wave reached, in relation to the average level, the height of about 10 m.

Like in flow volumes the differences occurred also in the probability of their occurrence. Probabilistic analysis of maximum annual flows from 1946-1997 was made. Flows which occurred during flood in July 1997 are significantly different from flows recorded till then (1947-1997). On the Nysa Klodzka and its tributaries maximum flows reached probability of occurrence rating from p = 0,01% (1 to 10 000 years) to p = 0,06%.

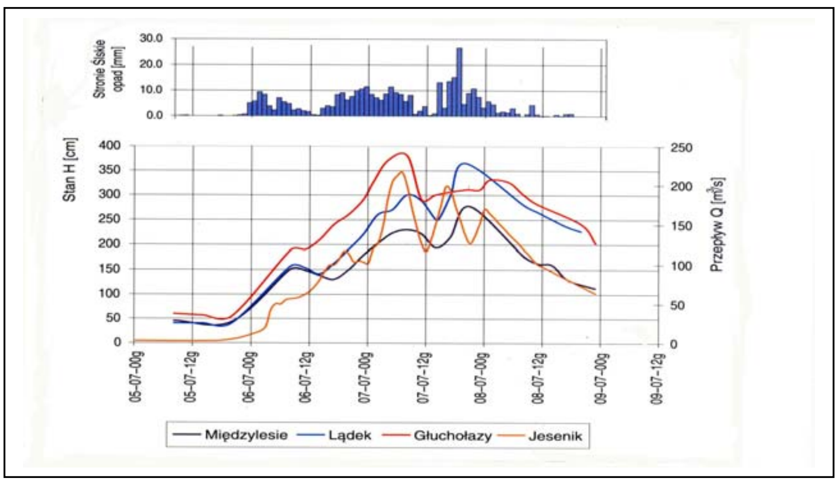


Fig 1. Hourly precipitation amounts in Stronie Slaskie - Biała Ladecka catchment and hydrographs of water levels in Miedzylesie on the Nysa Klodzka, in Ladek on the Biala Ladecka, in Glucholazy on the Biala Głucholaska and flows in Jesenik on the Biala Głucholaska from 5 to 9 July 1997.

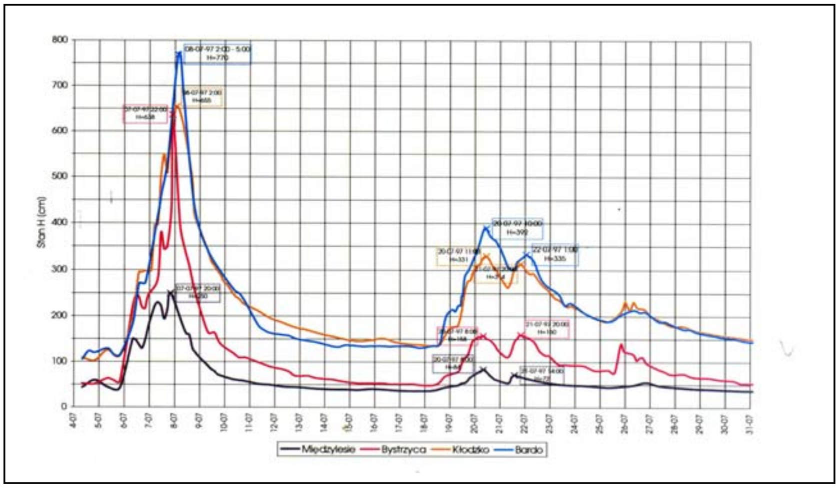


Fig2. Hydrographs of water levels on the Nysa Kłodzka river from 4 to 31 July 1997.
Flood wave volumes

The next very important elements which can characterise a flood magnitude are rainfall and flood wave volumes. Depending on a catchment size as well as a rainfall depth, particular catchments received different volumes of water.

In the Nysa Klodzka catchment till the Otmuchow reservoir, during a first and a second flood wave, rainfall volume was calculated at 574 mln m^3, while till the Nysa reservoir covering Biała Glucholaska, Raczyna, Swidna and Widna catchments it was estimated to be 249,8 mln m^3. Due to very high rainfall intensity and its continuous character, the runoff of precipitation water was also very high. Runoff coefficients from upper Odra and Olza catchments, along with those from the right-bank tributaries of Nysa Klodzka, fluctuated from 0,59 to 0,93, while from those of Nysa Klodzka from 0,54 to 0,88. The maximum depth outflowing the Nysa Klodzka catchment fluctuated from 190 to 333,2 mm (Głucholazy), depending on rainfall intensity. It means that on average, 80% of water volume received by the Nysa Klodzka catchment was discharged to the rivers.

1.4 EARLY WARNING AND RESCUE SYSTEMS

1.4.1 Hydrological and meteorological forecasts before or during the flood and the way of distribution

Hydrological and meteorological protection means a set of tasks, including meteorological forecasts, information on current hydrological situation, hydrological and meteorological warnings on flooding threat, information on predicted flood situation, hydrological forecasts concerning peak flows, their timing and waves volume for free flowing rivers and those reaching storage reservoirs. The effectiveness of such activities depends on many factors, among others on regular information inflow from observation and measurement network, including meteorological stations, water gauges, precipitation and groundwater posts.

Regional data bases of importance in the Odra River catchment are IMGW Branches in Katowice, Poznań and SHMU in Ostrava and Usti on Elbe River. Central data bases of hydro-meteorological institutes in Warsaw and in Prague participate actively in the flood protection system. This way the whole catchment of Odra, along with its upper course in the Czech Republic and Warta catchment with surface of 109 729 km^2, are covered by the hydro-meteorological protection system of the Institute of Meteorology and Water Management, Wroclaw Branch.

Teleinformatic systems mainly used are the following:

- Local computer network *Novell Ethernet* IMGW in Wroclaw,
- Electronic mail *MailBox* IMGW in Wroclaw, which communicates through telephone modems and local computer network,
- Telefax mail *Megalex* IMGW in Wroclaw, which communicates through telex interfaces and local computer network,
- Poland-wide pakage network IMGW *MetPak* based on standard X25, package
- Taxing software for automatic reports being send in the fax format through fax modem and computer.

Unfortunately, the communication between observation and measurement posts and collection stations is still provided through telephone and radiotelephone of the old type. This is one of the weakest communication links.

Flood disaster of July 1997 was preceded by locally sunny and hot days. Weather forecasters saw, however, danger of high and intensive precipitation occurrence. Therefore, they prepared and issued first warning with significant 33-hour lead time, about predicted intense precipitation for upper Odra and Nysa Klodzka rivers along with hydrological report elaborated by the hydrologists which reads as follows:

Warning about expected precipitation in the upper Odra and Nysa Klodzka rivers
issued by IMGW on July 4, 1997 and sent out to the people concerned at 12.30. Validity: from 20.00 pm to 20.00 pm of July 5-6, 1997. Significant cloudiness and precipitation, locally intense. In Odra catchment and Kotlina Klodzka valley it can locally reach the height from 45 to 75 mm/day. Minimum temperature from 14 to 11 °C and maximum from 15 to 18 °C. Wind moderate northern and northwestern.
Hydrological warning:
Due to the forecasted precipitation on July 6, 1997 in the Nysa Klodzka and upper Odra catchments, the increase of water levels and local exceedance of alarm water levels are predicted.'

This warning was transmitted on July 4, 1997 to all Provincial Flood Committees in the upper and middle Odra, Main Flood Committee, Regional Directorates of Water Management in Wroclaw and Szczecin, IMGW in Warsaw, Katowice as well as hydrological and meteorological stations operated in the upper Odra catchment and other institutions responsible for flood protection and water management received the above mentioned warning.

It was clearly stated in the warning that precipitation could be locally intense. The forecast had exceptionally good verifiability (from 73-98%, 86,8% in average). Second warning with information on intense precipitation up to 90 mm/day along with hydrological advice about hydrological and meteorological situation and forecasted water levels in Odra catchment was issued on July 6,1997 at noon hours.

Two subsequent warnings on the occurrence of intense rainfall during the second flood wave were elaborated on 16 July at 23.45 and on 17 July at 22.10.

During the rescue activities the Forecasting Office obtained additional input from the computations carried out in the Czech Republic with application of the French ALADIN model (accessible via the Internet) as well as the results of the model study undertaken by the German Hydro-Meteorological Service, especially to meet the needs of Poland and the Czech Republic.

1.4.2 Early warning system

During flood, up to 800 reports about water levels and precipitation were received daily . At the same time about 2050 information contained in forecasts and reports was sent to the users. However, the flood situation was developing so rapidly, that complete flow of information was not possible because water rise flooded all key water gauges and unabled readings e.g. at the mouth of Nysa, Bystrzyca rivers to Nysa Klodzka, Biała Ladecka in Zelazno, in Tłumaczow on Scinawka river, in Wilkanow on Wilczka river. Interruptions in data inflow occurred also due to damage of telephone cables. Observers refused making observations in life threatening situations.

During flood, information on precipitation and water levels, meteorological forecasts, weather reports, hydrological reports and forecasts were transmitted continously to the concerned authorities and institutions by the operational meteorological and hydrological services of IMGW Branch in Wroclaw. In Bardo on the Nysa Klodzka river some units of the Polish Army helped. The solders replaced the observers and put in operation military communication facilities, what enabled to receive quickly information on water levels.

1.4.3 Description of rescue system and how cooperation was arranged among the stakeholders

The flood-control in Poland before 1997 was the responsibility of many institutions at all administration levels: central, provincial and municipal.

The flood management was entrusted to the network of Flood Committees, which were obliged to prepare plans of flood protection and to coordinate activities during flood.

Under the overall direction of Flood Committees, many institutions participated in protective actions, such as the State Fire Brigades, Police and the Army. They were responsible among other things for evacuation of inhabitants and their property, protection of threatened places, etc.

Important role in flood control management played institutions supporting operatipnally the activities of Flood Committees. These were: the Institute of Meteorology and Water Management, Regional Water Managements Offices (RZGW), Provincial Land Improvement and Water Management Boards (WZMIUW), State Fire Brigades, Police and the Army.

1.5 INTERACTION OF NATURAL RESOURCES

1.5.1 Effects of flood on ground waters

The precipitation which took place on July 5-9, was followed by a sudden rise of ground water levels. In the upper and middle Odra catchment this increase exceeded 250 cm. The highest increase, compared to the mean for the period of record for July, was recorded in Biała Glucholaska (834 cm). Great increase was observed also in the Nysa Klodzka basin, dowstream the reservoir in Nysa (115-166 cm). For the Otmuchow reservoir these increases amounted from 16 to 89 cm. The next precipitation wave which dropped from 17 to 21 July caused uplift of ground water level from several to 60 cm. The highest ground waters level was recorded on July, 28. Long term average value was exceeded by 11 to 127 cm (Nysa Klodzka) and by 899 cm (Biala Glucholaska catchment).

1.5.2 Water quality problems related to flood

The analysis of water quality has shown that water quality degraded during flood temporarily. Locally small increase of about 10-20% was recorded for concentration of BZT_5, ChZT – Cr, nitrogen, a little greater concentration of phosphates (with the stabilisation of remaining physico-chemical parameters) Waste treatment utilities were damaged, so that significant deterioration of Coli and phosphates indicators was recorded.

1.6 FLOOD CONTROL MEASURES

1.6.1 Structural measures

The Kotlina Klodzka valley due to its specific topography has limited possibilities to create flood pretection system. Mountainous character of predominant part of Nysa Klodzka catchment influence the selection of storage reservoirs and dry flood reservoirs as the most effective elements of such system. In the region of Klodzko Land there are two dry flood reservoirs in Miedzygorze and Stronie Slaskie. They were built following heavy flooding in 1903. Flood reservoir in Miedzygorze is situated on the lower

Wilczka stream. It is inteded only for flood protection of villages lying downstream, expecially Wilkanow, Niedzwiedno and Bystrzyca Klodzka. During the periods of higher precipitation and quickly rising flood flows in river the reservoir is filled. When the flooding threat does not exist, the reservoir remains empty. Flood reservoir in Stronie Slaskie is located on the lower Morawka, left-bank of Biala Ladecka river. It plays a similar role as the reservoir in Miedzygorze. It is inteded to protect Stronie Slaskie and Ladek Zdroj towns.

Both reservoirs have small overall capacity. Maximum capacity of the reservoir in Miedzygorze amounts to 0,83 mln m^3 , while in Stronie Slaskie of 1,36 mln m^3.
Existing embankments protecting some houses were 6.5 km long in 1997.

1.6.2 Nonstructural measures

In Klodzka Valley before flood no one undertook practically any activities to reduce results of flood by limiting of built-up areas in the floodplain, by protection of buildings, by increasing natural retention.

1.7 POPULATION BEHAVIOUR

The population demonstrated very high self-rescue capability. Generally, people respected directives issued by the Flood Protection Authorities. The perception of local population of the risk of future floods is still high.

1.8 FLOOD DAMAGES

1.8.1 Losses of life

In 1977, many villages in Kotlina Klodzka were flooded with the resulting heavy damages. Out of 55 people who lost their lives in Poland during the 1997 flood, 13 were killed just here. All together about 20 000 families were affected by the flood in the Kotlina Klodzka.

1.8.2 Material damages

An example of how significant were material flood damages in particular towns, is shown in the table below which describes losses for one of fourteen municipalities in the Klodzko-Bystrzyca Klodzka district.

The district of Bystrzyca Klodzka is located in the southern part of Kotlina Klodzka along the Nysa Klodzka River. The area of 338 km^2 is populated by about 22 000 people. The municipality borders the Czech Republic and is crossed by international highway Warsaw-Prague-Vienna.
The municipality covers 38 villages including two with significant spa values, that is Dlugopole Zdroj and Miedzygorze. Długopole Zdroj i Miedzygorze. The reserve of Wilczka waterfall, Sniezka Park, health resorts, climatic stations and many sources of mineral waters are located there.

item.	Subject	Unit	Damages in zlotys	Damages in Euro (4.08.04)
1	Completely destroyed buildings (houses and farms)	77 pcs	2267000	510585.6
2	Damaged buildings (school and houses)	132 pcs	7269900	1637365
3	Inundated and silted buildings	981 pcs	5077600	1143604
4	Losses in agriculture	486 ha	671685	151280.4
5	Live-stock		84663	19068.24
6	Agricultural machines	508 pcs	668200	150495.5
7	Household equipment		2966850	668209.5
8	Firms		2248982	506527.5
9	Silted wells	453 pcs	135900	30608.11
10	Damaged waterworks	4	2500000	563063.1
11	Damaged water intakes	2 pcs	1000000	225225.2
12	Dams and other hydrotechnical structures		34979300	7878221
13	Bridges and footbridges	63 pcs	2997100	675022.5
14	Roads to be reconstructed	22523 mb	13127700	2956689
15	Roads to be repaired	334058 mb	41791658	9412536
16	Official buildings		1796800	404684.7
17	Gmina housing resources	41 buildings	646780	145671.2
	Total losses		120230118	27078855

1.8.3 Hydrological and meteorological monitoring network

Water level observational network was substantially damaged including 25 water gauges and continous recording equipment, 6 limnographs along with their housings. Hydrometric equipment, that is ropeways for measurement of river flow in Biala Ladecka in Zelazno was also destroyed.

Flood protection structures like dams, dikes, hydrotechnical structures, green crops and arable lands, river and stream banks and beds, roads, bridges, buildings were damaged. The landscape was substantially changed by the slope runoff processes. The greatest landslide was set in motion in Janowiec near Bardo (width 130 m), that is a part of Nysa Klodzka terrace located 30 m over river level. The biggest form of debris- mud flow was found in Miedzygorze on Wilczka river (Nysa Klodzka tributary) about 150 m down the waterfall. Moreover, fluvial processes played an important role (erosion, river accumulation). Wilczka valley was one of the hardest affected by flooding. Large surfaces were covered with stones and sand of river origin in the Biala Ladecka valleys, upper Nysa Klodzka with its right-bank reaches as well as Biala Glucholaska.
The downstream protection of the flood control reservoirs in Stronie Slaskie and Miedzygorze was destroyed. The basic communication was interrupted, therefore the need to supply additional, failure-free and wireless telephone communication arouse.

1.9 THE FLOOD DAMAGES REMOVAL

It took several years to remove flood damages and the related costs were covered from the State budget as well as by the long-term loans received from the international finance institutions.

1.10 ADOPTED MEASURES ON FLOOD PROTECTION

1.10.1 Structural measures

When using technical mesures one can divide flood protection into active and passive ones.
Active protection include mainly the following hydrotechnical structures:
storage reservoirs,

polders with movable gates enabling to control water inflow
dry reservoirs with controlled outflow.
Decrease of the surface runoff velocity to be achieved through increase of forest area, increase of storage capacity of small water reservoirs, ponds and stream as well as by the appropriate measures related to some agrotechnical procedures (related to specific crop production techniques) and agricultural land reclamation.

Another way is the passive flood protection. It consists of structures which protect river valleys or decrease flood wave volume. They include:
embankments (dikes),
uncontrolled flow polders,
dry ungated flood reservoirs,
relief channels and flood gates,
regulated rivers and mountainous streams.

Existing studies were checked upon and thorough justification of storage reservoirs proposed earlier was undertaken. Initial analysis enabled to locate upstream13 small dry reservoirs with overall capacity of 55.5 mln m^3.
During the flood of July 1997, surface runoff volume from Nysa Klodzka and its right-bank tributaries amounted to about 194 mln m^3. Potential capacity of all reservoirs amounts to 55.5 mln m^3, while right-bank ones to 25.5 mln m^3 .When dry reservoirs are built, there will be a real chance to protect against flood the property and inhabitants of these valleys.

1.10.2 Non-structural measures

Non-structural measures include all regulations introduced to determine ways, structure and powers (scope of activity) of flood management arrangements. Orders and bans regarding land use in the floodplain as well as improvements of warning-alarm, rescue and other quick response systems, are included here. Education concerning the ways of limiting consequences of flood effects as well as establishment of coallitions supporting the activities of local administration and development of public relations which can serve proper communication inside and outside the administration, is equally important.

1.10.3 Activities oriented towards limitation of flood losses in Klodzko Land

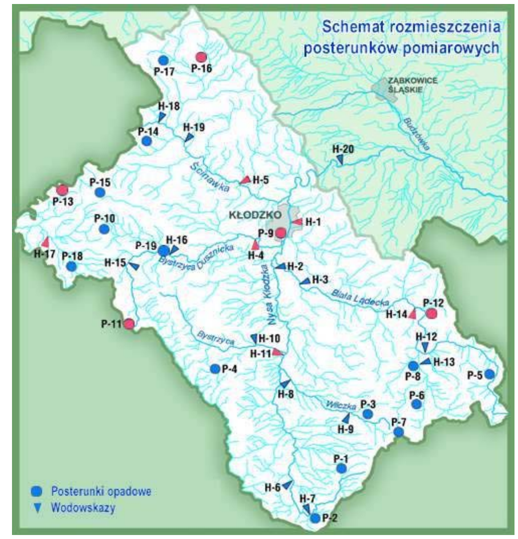
The specific character of Klodzko Land which is largely of a mountainous character, makes difficult to apply proper agrotechnical and land-reclamation techniques. Additional afforestation is also not justified since forests can store water to some extent only. Given sudden surface runoff, its effectivenes is limited. Furthermore, in mountainous regions where valleys are usually narrow, building flood protective dikes, relief channels or polders is not a proper solution. People and property evacuation is difficult because of a sudden character of flooding phenomena, which in mountains last couple of hours only. Therefore, the only proper solution for protecting population against huge losses is to build flood storage reservoirs. Equally important for these regions is to educate inhabitants of river valleys about flood emergency situations.

Local district authorities considered that due to the flood characteristics and speed of flood formation the most important is to build early warning systems. As a result, local flood warning systems are being first built here, from either the central, district or local budgets. Such systems are usually composed of precipitation and water levels monitoring gauges (about 40 posts), as well as of some decision support system for warning and advice being addressed directly to inhabitants. Such initiatives, among others, are supported methodologically by European OSIRIS project with the involvement of the Institute of Meteorology and Water Management.

Local Flood Protection System in Klodzko district is composed of:
19 river gauges for water level measurements (hydrometric posts),

20 precipitation gauges (rainfall depth measurement),
flood management command center located in the district office,
3 sectoral command centers located in:

- District State Fire Department in Klodzko,
- Hydrometeorological Station if the IMWM in Klodzko
- Ambulance Service in Klodzko



Information on measurements are transmitted to 14 municipalities in the Klodzko district. Municipality level flood command offices are located in the municipality offices. The whole measurement system was implemented in March, 2002. Lessons learned from the disastrous floodings in 1997 and 1998 which affected present Klodzko district confirm, that material losses caused by flood exceed many times the cost of building the early warning systems.

2.FLASH FLOOD IN THE CITY OF GDANSK IN 2001

ABSTRACT

Gdańsk, the Polish medieval old city, is situated on the Baltic coast in the lowland area at the mouth of the Vistula River. The city of 460 thousand inhabitants is a very important economic, cultural, scientific and industrial centre. It is one of the most flood-endangered urban agglomerations in Poland.

Detailed analysis indicates that the flood threat in the Gdańsk region may come from three directions. From the old branch of the Vistula (Dead Vistula), which has a direct connection with the Gulf of Gdańsk, from the main Vistula River in case of high discharges, and especially during ice cover in the mouth region, and from the moraine hills in case of high precipitation. These hills are now intensively urbanized, and in July 2001, the severe flash flood, resulting from extremely high rain, invaded Gdańsk causing considerable losses.

In the paper a detailed analysis of this flash flood is presented. Research project concerning this flood started with detailed measurements of all water courses forming Gdańsk Water Node (GWN). Subsequently the mathematical model was developed including a complicated system of rivers and channels in Gdańsk area. Calculations were carried out for various schemes, the aim of which was to find solutions to mitigate similar floods in the future. It was found necessary to construct almost twenty small reservoirs on the streams flowing from the moraine hills to Radunia Channel, to decrease a rapid runoff from this area. Four discharge structures from the Radunia Channel were designed. In addition, two flood polders are also planned in case of an extreme discharge in main rivers and a simultaneous increase of water level in the Gulf of Gdańsk. The network of measuring stations was also proposed.

2.1 INTRODUCTION

Floods occur as natural phenomena which, negatively affect people living in the inundated areas. Consequently, flood control and flood protection measures are introduced in many places to prevent the negative consequences of this flooding. The flood may be defined as the unexpected or periodic inflow into a defined region of more than average quantities of water due to such phenomena as: storm surges, upland river discharges or heavy local rain. At times, floods from more sources may arrive simultaneously, especially in deltaic areas. Floods in rivers generally show the characteristics of a long water wave. They are characterized by higher water levels and increased flow velocities. These are some parameters which characterize the flood: flood volume (m^3), the highest water level, the river discharge (m^3/s) during flood, and flood duration. To minimize the effects of floods, special methods and constructions are realized to protect the inundated areas.

2.2 CHARACTERISTICS OF THE CATCHMENT AREA

Gdańsk is a great Polish harbor situated on the southern coast of the Baltic Sea in the lowland area at the mouth of the Vistula River. Compared to other parts of the Baltic Sea, the Polish coastline is rather regular, except for the area near the Gulf of Gdańsk. At present Gdańsk is a city with 460 thousand inhabitants and its area is 262 km^2. It is the capital of the Pomeranian province.

Gdańsk lies in an area that creates combination of contrasts. In the west there is a morainal plateau covered with woods, separated by valleys with swift-flowing streams. In the north is the Baltic Sea, the Gulf of Gdańsk, where sandy beaches stretch along the shore, followed by sand dunes. Then, in the south and east there is a low-lying delta of the Vistula River, with a depression, marshes and swamps that have been transformed over the ages into pastures and fields. These lands, called Gdańsk Pomerania, are part of Eastern Pomerania.

Gdańsk and its surroundings are situated in the area known as Gdańsk Żuławy. This region was in the past and is at present endangered by various types of flooding. In the XIXth century and earlier, the main danger of flooding was from the Gdańsk Vistula (Majewski A., 1993, Makowski 1994). The turning point in the flood problems in the Gdańsk region was the construction of a new outlet of the Vistula River to the sea in 1895, called the Przekop Wisły. The Gdańsk Vistula was cut off at Przegalina, and thus the Dead Vistula was created (Jasińska 2002). Now the Gdańsk region has a very complicated system of rivers and channels which constitute Gdańsk Water Node (GWN). This area is shown in Fig. 1.

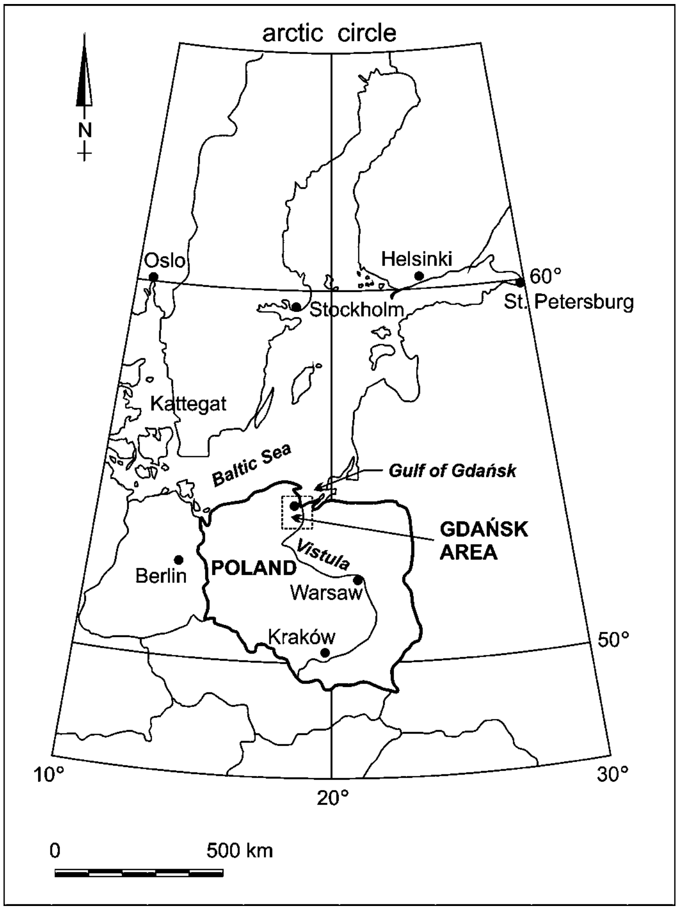


Fig 1. The area of flash flood 2001

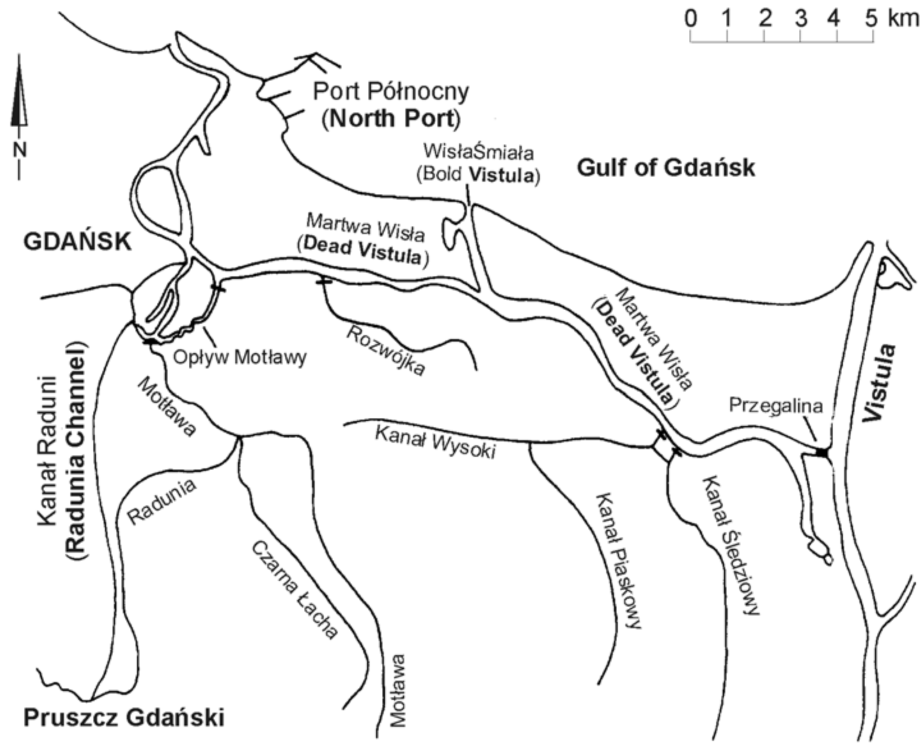


Fig 2. System of channels in Gdańsk Water Node

In the past, frequent floods, which inundated Gdańsk, were caused by various factors. There were mainly winter and spring floods caused by ice jams, which were formed on the final section of the Vistula. During this time it was the Gdańsk Vistula, now it is the Dead Vistula. In the period from the XIVth to XIXth centuries there was considerable amount of floods. In the XIX century the most dangerous floods were: in 1829 –substantial ice jam was at the outlet of the Gdańsk Vistula to the Gulf of Gdańsk and the river changed its direction, creating a new channel through the city of Gdańsk to the sea, in 1840 – a big ice jam formed in the middle part of the Gdańsk Vistula and created a new outlet to the Gulf of Gdańsk named the Bold Vistula (Wisła Śmiała). The system of channels is shown in Fig. 2.

Thus in 1895, a new direct channel of the Vistula to the Gulf of Gdańsk was formed and was protected on both sides by embankments, to facilitate the flow of water and ice to the sea. Since that time, there has been no serious flood caused by the Vistula River in Gdańsk. However, flood danger still exists.

2.3 PRECIPITATION REGIME

Precipitation in Gdańsk is highly non-uniform in space and time. There were frequent intensive rainstorms, which often covered only a small area. The precipitation regime is described on the basis of existing measurement data. There are only three stations for measuring precipitations in Gdańsk, which are operated by the National Meteorological Service. They are unfortunately located on the city boundaries, and therefore, it is difficult to estimate the spatial distribution of the precipitation over the whole area of Gdańsk.

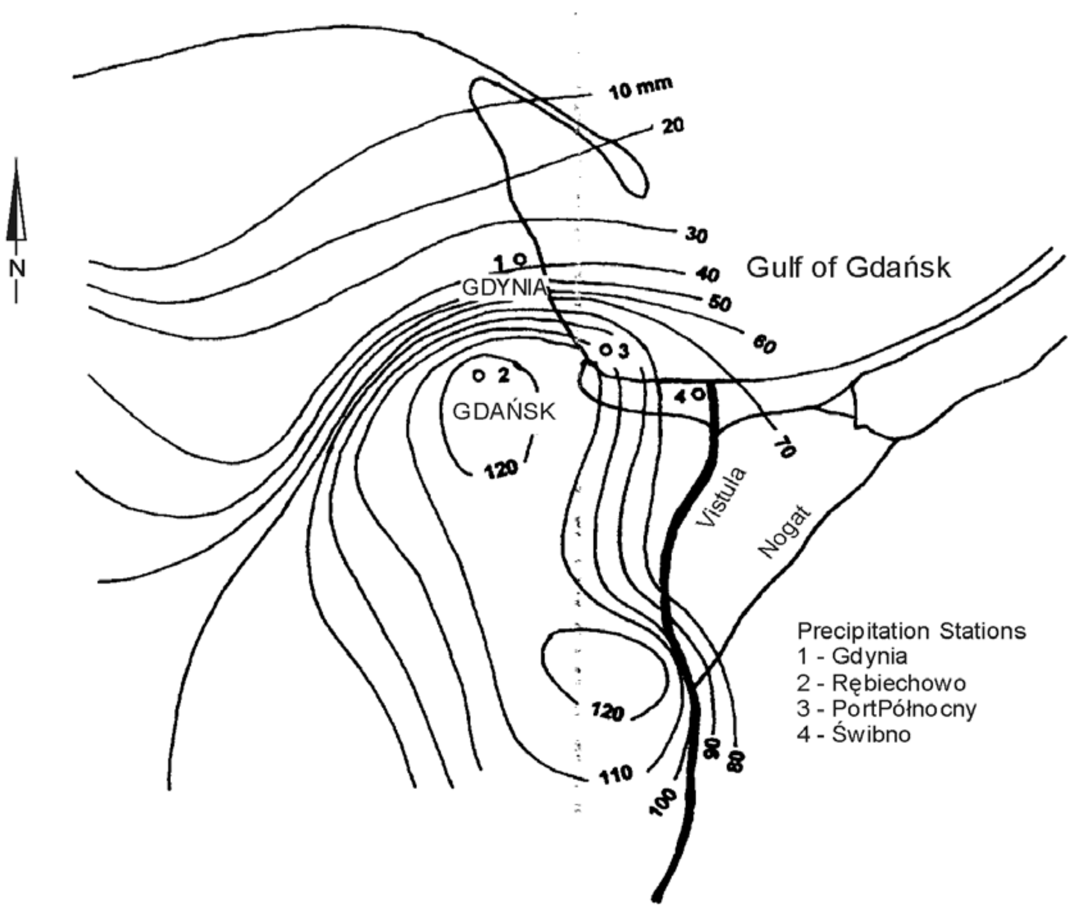


Fig 3. Precipitation distribution in the area of Gdańsk on 9/10 July 2001.

The average annual precipitation in Gdańsk is about 600 mm and, the July average is 68 mm. In recent decades, it was observed that the maximum daily precipitation for a particular year occurred in July. Before 2001, the maximum daily precipitation was recorded in July 1980 and amounted to 80 mm. On the 9th of July over a period of 4 hours practically the whole catchment area of the Radunia Channel received 80 mm of precipitation. The daily amount of precipitation in Gdańsk on 9th July 2001 was 120 mm (Fig.3). This value was estimated to have a probability of 0,5 to 0,3% (once in 200 – 300 years).

2.4 HYDRAULIC CHARACTERISTICS OF THE AREA SUBJECT TO FLOOD

In recent years the expansion of the city of Gdańsk stretched towards the moraine hills. This area was used for new housing developments with new streets and parking lots and caused a decrease in natural retention capacity. At the foot of the moraine hills, which have their slopes directed towards the city, there is an artificial channel - the Radunia Channel built in the XIVth century to supply Gdańsk city with water. The Radunia Channel has an outflow from the Radunia River in Pruszcz Gdański (Fig.4), where a small hydraulic power plant operates.

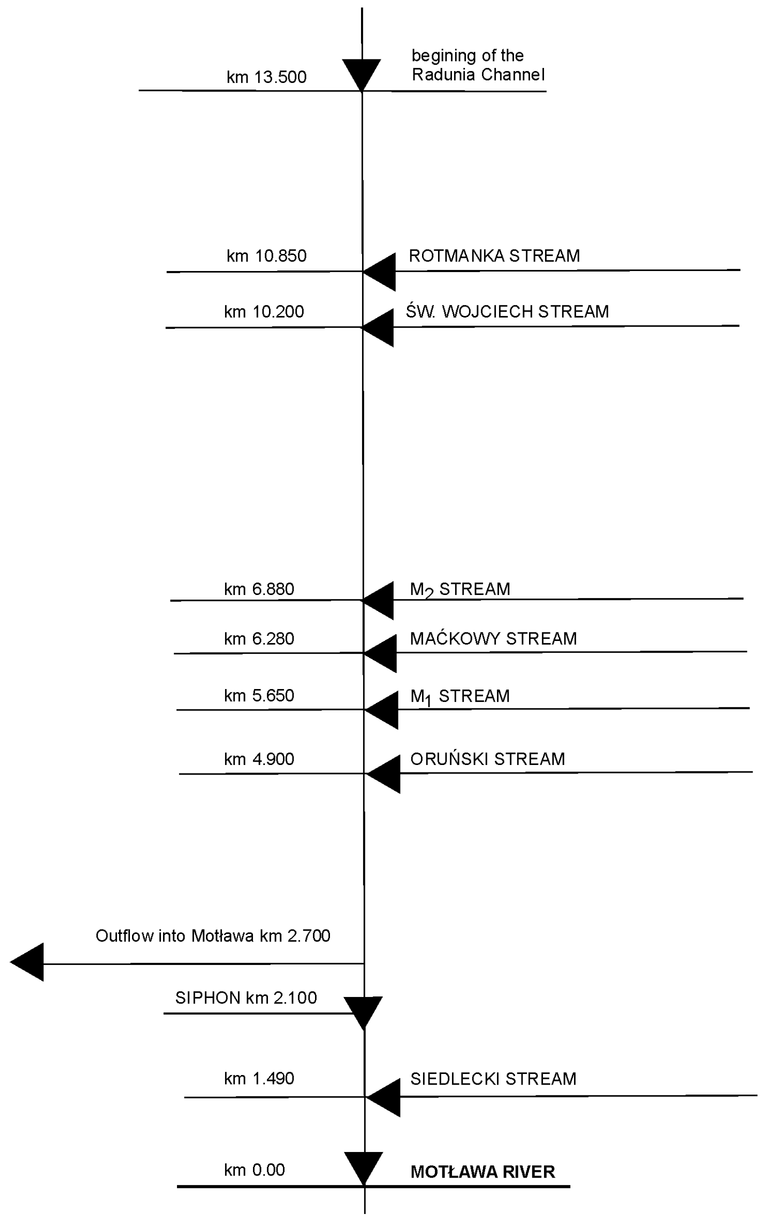


Fig 4. Radunia Channel with inflows and outflow

The length of the Radunia Channel is 13,5 km and its catchment totally on the left hand side amounts to 55 km^2. There are several small natural streams and outlets from storm drainage networks. Their discharges in normal conditions do not exceed one cubic meter per second. The Radunia Channel plays the role of an artificial storage reservoir for water coming from the left catchment area. The total volume of the Radunia Channel is estimated as about 0,3 mln m^3. The bottom width of the channel is around 8 m and has an almost rectangular cross-section. The slope of the channel is 0,5‰, its conveyance at maximum depth of 2,7m was estimated at about 20 m^3/s. The Radunia Channel has an artificial outlet to the Motława River, which is an inflow to the Martwa Vistula in Gdańsk.

The Radunia Channel has an embankment on the right-hand side and runs parallel to the main road leading to Gdańsk from the south. This embankment has the crest width from 3 to 5 m and height of 4 to 5 m. The inner slope of the channel is in many places protected by means of concrete slabs supported on sheet piles. The area on the right bank of the channel is occupied by the old urban part of Gdańsk lying in a depression.

2.5 LOSSES CAUSED BY THE FLOOD AND RESCUE OPERATION

Losses of people property and in the city infrastructure caused by flood were very high and estimated at about 50 mln. USD. More than 300 families were affected by the flood (damaged houses, loss of property). It was necessary to rescue people and their property from complete damage and destruction. Basements of numerous houses were flooded and required draining and drying. About 5000 people received special calamity status, which affords social assistance.

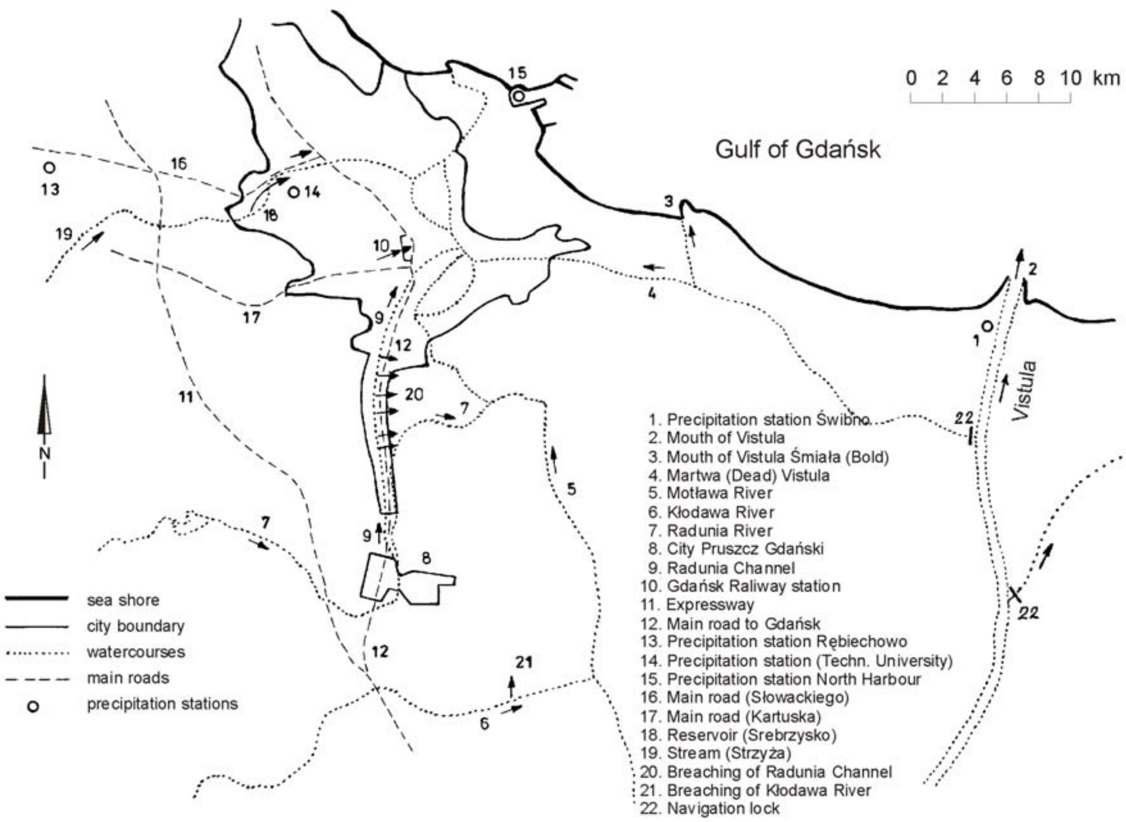


Fig 5. The area of Gdańsk subject to flood

As the result of huge precipitation and caused by them high inflow of water to the Radunia Channel (about 100 m^3/s over 4 hours), the following structures were destroyed or inundated. The embankment of the Radunia Channel was breached in 5 places, which resulted in flooding of the area of the city situated in the depression on the side of the channel and the main road;

- two main roads approaching Gdańsk from the west turned into torrential rivers;
- Gdańsk main railway station was flooded, which caused one week's break in traffic;
- The main embankment of the small reservoir on the Strzyża Stream in Gdańsk was breached, which resulted in a severe flood along the main street and flooding of the crossing on the road between Gdańsk and Gdynia.

The embankment of the Radunia Channel was quickly repaired to prevent further flooding of downstream areas. Simultaneously, pumping was carried out to drain the flooded areas. A difficult and slowly proceeding action was to repair of the streets and remove sediments carried in by the flowing water. It was really a dangerous situation at this time in Gdańsk.

After the flood the local authorities decided that it was necessary to undertake some works to improve flood protection in the Gdańsk area in future. The analysis of the existing spatial situation of the city indicates that the present infrastructure does not allow any general change in the network of channels in the Gdańsk area.

2.6 FLOOD MANAGEMENT STUDIES

To develop some methods of flood control and flood protection in a chosen area it is necessary to collect a large amount of data on topography, bathymetry, geology, hydrology, hydraulics and regional and urban development plans. It is also necessary to take into account the ecological conditions. The Institute of Hydro-enginnering in Gdańsk, together with three other institutions undertook this work the aim of which was flood management for the Gdańsk region (Majewski et al. 2003, 2004) and almost all the above mentioned data were collected and analyzed.

First of all, it was necessary to carry out the measurements of topography and bathymetry for all rivers, streams and the Radunia Channel that constituted the Gdańsk Water Node (GWD). The cross - sections of 6 main rivers and the Radunia Channel were measured, and this altogether constituting more than 250 profiles, also being the longitudinal profiles of all the rivers. The data were necessary especially for the preparing of the mathematical model of the very complicated system of channels and streams as well as for design work

A very important part of this work was to collect hydrological data and carry out their analysis. In the analysis all the data collected by the National Meteorological Service (IMGW) in the period 1951 – 2002 and also from shorter periods were taken into consideration. The high water levels and discharges in all inflows of the Martwa (Dead) Vistula were analyzed and special attention was given to the precipitation in the Gdańsk area.

The changes of the water level in the Gulf of Gdańsk, their probability of non - exceedance and influence on the water level in the Martwa (Dead) Vistula were also analysed particularly. Both the simultaneous high water level occurrence in the rivers and the water level increase due to storm surges were analyzed. In the near coastal areas, flooding is mostly caused by a combination of storm surges at sea and increased river discharge due to rainfall in the catchment area. Each of these phenomena may not be very dangerous when they occur separately, but their combination may lead to flooding.

To determine the hydraulic conditions in the rivers, streams and Radunia Channel of the Gdańsk Water Node (GWN) a comprehensive mathematical model of unsteady flow was carried out. The model was based on 1-D MIKE 11 HD (Danish Hydraulic Institute – Water and Environment in Denmark), and the actual topographic and hydrology data were used in it.

Taking into account all the collected actual data and proposed hydraulic structures, the calculations were performed for:

- determination of the maximum discharges and water levels in the main rivers, streams and channels of the GWN in their actual state and existing embankments,
- estimation of the maximum water levels in the main rivers, streams and channel of the GWN for the control flows, in order to determine the crest elevation of the embankment,
- determination of the possibility of conveying discharges of the probability of 1% and 0,3% taking into account additional artificial storage reservoirs and outflows from the Radunia Channel (3 variants) to Radunia and Motława rivers,
- estimation of the hydraulic conditions in the GWN when the flood gates are closed during high storm surges in the Gulf of Gdańsk.

It was found that there is no possibility of significantly increasing the conveyance of the Radunia Channel. On the one hand this is a historical construction, and on the other because there are numerous ecological organizations which are against cutting down trees which grew naturally on the embankment.

2.7 CONCLUSIONS

The analysis of the existing spatial situation of the city of Gdańsk indicates that the present infrastructure prevents the making of any general change in the network of channels in the Gdańsk area. The Radunia Channel is of great importance on flood conditions caused by intensive precipitation in the city of Gdańsk. It was found that there is no possibility of significantly increasing the conveyance of the Radunia Channel.

To determine the hydraulic conditions in the streams of Gdańsk Water Node 1-D model of unsteady flow was developed. In order to decrease the inflow to the Radunia Channel in cases of intensive precipitation it was decided, on the basis of the results of hydraulic calculations, to construct several small reservoirs on all streams discharging to the Radunia Channel and to construct several control outflows from the channel to the Radunia and Motława Rivers. It is also necessary to install several precipitation and water level gauges in the GWN to create a flood warning system.

BIBLIOGRAPHY

- Jasińska E., 2002, Hydrology and hydrodynamics of the Martwa Vistula and the Vistula Przekop, IBW PAN, Gdańsk (in Polish).
- Majewski W., et al., 2003, 2004, The model of water distribution in the Gdańsk Water Node for flood protection in the Martwa Vistula catchment, Internal Report IBW PAN Gdańsk (in Polish).
- Majewski A., 1993, The history of floods in the Vistula delta, Toruń, (in Polish).
- Makowski J., 1994, The biggest flood in Gdańsk and probability its repeat at present, IBW PAN, Gdańsk, (in Polish).