EMPIRICAL DETERMINATION OF RUNOFF CURVE NUMBER FOR A SMALL AGRICULTURAL WATERSHED IN POLAND

Kazimierz Banasik, Warsaw University of Life Sciences – SGGW, Department of Water Engineering, Sedimentation Laboratory, Warsaw – Poland, kazimierz_banasik@sggw.pl; Donald Woodward, USDA-Natural Resources Conservation Service, Washington D.C. (retired), dew7718@comcast.net

Abstract: The Curve Number method developed by Soil Conservation Service for predicting flood runoff volume from watershed has not been extensively tested in Poland. We used over sixty rainfall-runoff events, collected during 29 years (1980-2008) in a small (A=23.4 km^2), lowland and agricultural watershed in the Center of Poland, to determine runoff Curve Number and to check change tendency. In 1990s the investigation was a part of Polish- US project (PL-ARS-195). The watershed is characterized by mean annual rainfall and runoff of 606 mm and 107 mm, respectively. The observed CN, ranging from 59.8 to 97.1, declines with increasing storm size, which could be classified as a standard response of watershed. Variability of CN during a year is also demonstrated. Analyses showed that empirical CN computed for events of precipitation larger the 20 mm is very close to CN estimated on base of land use and soil types for the watershed.

INTRODUCTION

The Curve Number (CN-) method for estimation of storm runoff volume was developed in the 1950s by the USDA Soil Conservation Service or SCS (now the Natural Resources Conservation Service or NRCS), and has been commonly used (Woodward at al., 2006; Walker at al., 2000; Soulis at al., 2009). Investigation on application of the method for small watershed in Poland started some 30 years later and was mainly carried out by research teams from Warsaw University of Life Sciences – SGGW (Banasik & Ignar, 1983; Ignar, 1988; 1993; Ignar et al., 1995; Banasik, 1994; 2009; Banasik at al., 1994). In this analyze we used over sixty rainfall-runoff events, collected during 29 years (1980-2008) in a small (A=23.4 km^2) lowland agricultural watershed in the Center of Poland, to determine runoff Curve Number and to check change tendency. In 1990s, the investigation was a part of Polish-US project "PL-ARS-195" (Banasik 1994; Banasik & Woodward, 1992). The aim of the paper was to check applicability of the method for prediction purposes in small watersheds in Poland.

The curve number for investigated area has been estimated by three means:

a) based on land use and soil types i.e. as for ungauged watershed (USDA 1972, 2003. ASCE 2009).
b) based on rainfall-runoff records with the use of largest storms (Hawkins at al. 1985) and
c) based on all rainfall-runoff events with the use of "asymptotic approach" (Hawkins 1993).

Watershed Characteristics: The Department of Water Engineering and Environmental Restoration of Warsaw University of Life Sciences has carried out field investigation in a small agricultural and lowland river of Zagozdzonka at Płachty since 1962.

The main aims of the study were as follows:

- estimation of the water discharge of the river;
- analyzing water budget in the watershed;
- predicting sediment yield from the watershed.

Monitoring of the river flow at Czarna located upstream of Plachty started in 1980. Since 1991 the investigation has been intensified and the river gauging station at Czarna has been equipped with automatic recorders of rainfall water level and with devices measuring water quality parameters, i.e. temperature, turbidity and sediment transport. Later on, an electronic system of data recording, logging and transmitting has been installed.

Location and area: Zagozdzonka watershed, shown in Fig. 1 is located in central Poland, about 100 km south of Warsaw. Watershed area is 82.4 km^2 at Plachty gauging station (A in Figure 1), whereas the subwatershed area at Czarna (B in Figure 1) is 23.4 km^2.

Rainfall and runoff: The mean annual precipitation and runoff are estimated at 606 mm and 107 mm respectively, on the base of 46-year data records collected by the Department of Water Engineering and Environmental Restoration of Warsaw University of Life Sciences at Plachty, except precipitation data for the period 1963-82. This period data was taken from available publications of Polish hydro-meteorological service IMiGW for the nearest rain gauge Zwoleń. The maximum precipitation of 941 mm were recorded in 1974 and the minimum of 414 in 1991. Maximum annual runoff of 209 mm was measured in 1980 and the minimum of 52 mm in 1992. Annual runoff coefficients – c (i.e. ratio of runoff to precipitation) for the investigated area to Plachty gauge have a range from 0.088 in 1992 to 0.320 in 1979, with mean value of 0.177.

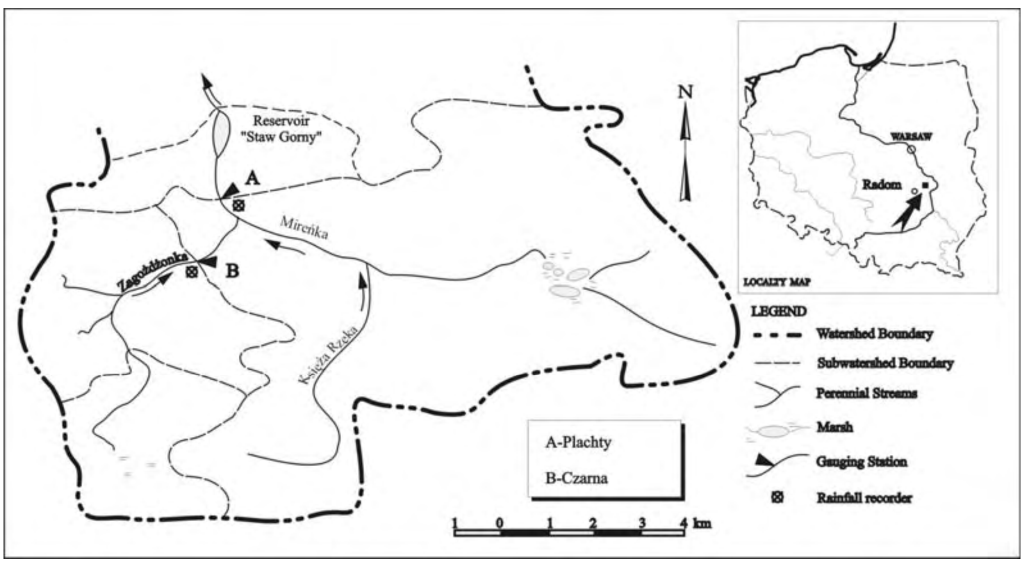

Figure 1 Locality map of the watershed.

Topography: Zagożdżonka watershed is of lowland type. Absolute relief is 26.5 m in the upper subcatchment (shown as B in the Fig.1), and 34 m in the entire watershed (A). The mean slopes of main streams are from 2.5 m to 3.5 m per 1000 m.

Land use and soils: Local depressions, which do not contribute to direct runoff and sediment yield from the watershed constitute a significant part of the area, i.e. 3.8 km^2 upstream of Czarna and 19.8 km^2 upstream Plachty gauge station. Land use is dominated by arable land (small grain and potatos) and sandy soils are the dominant type in the watershed area. The structure of soil types and land use in the Zagozdzonka watershed. above the Czarna gauging station is shown in the Figure 2.

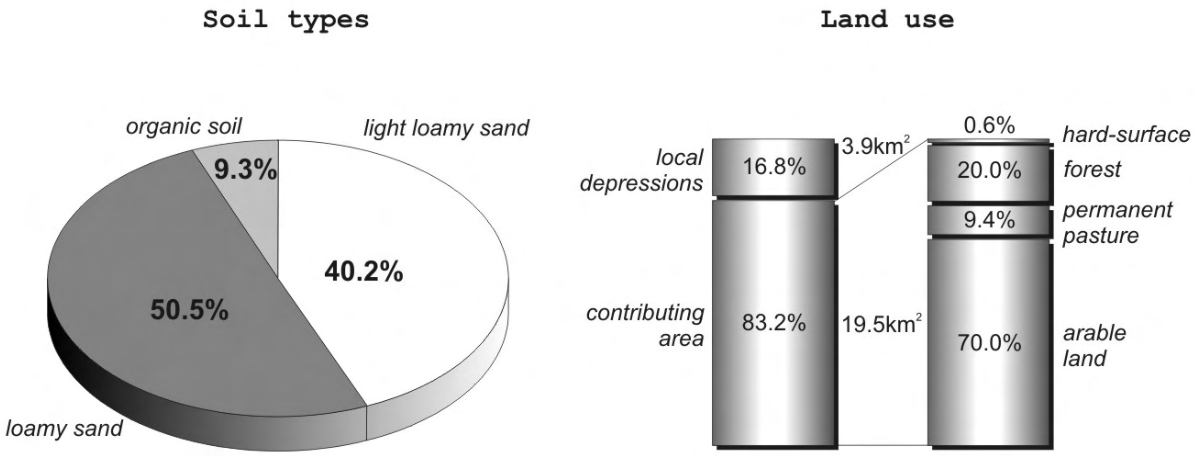

Figure 2 Soil types and land use in the Zagozdzonka watershed upstream of the Czarna station.

Measurement and characteristics of the rainfall-runoff events: The rain storm characteristics were recorded by one or two rain gauging stations. located at Plachty and/or Czarna. and additionally checked by one, two or three rain collectors located within the watershed. Since 1980 there had been mechanical recorders in use and in the 1990s electronic equipment was installed, and continuously upgraded. River flow has been estimated based on the water level continuous records upstream of sharp-crested weir (Fig. 3) and its rating curve, checked also by hydrometric current meter measurements. Views of the stream gauging station are shown on the Figure 3 and 4. General characteristics of the collected data can be seen in the Table 1.

Figure 3 View of the stream gauging station at Czarna from downstream.

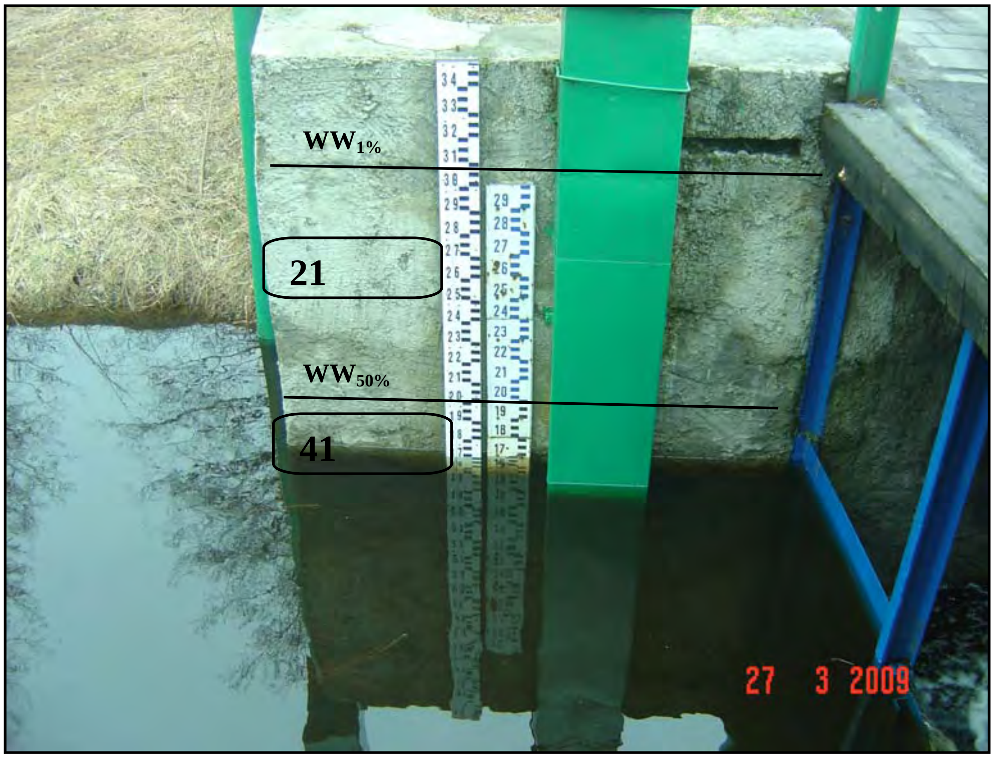

Figure 4 Upstream view of the gauging station at Czarna (the notation $WW_{50\%}$ corresponds to the 2-year flood and $WW_{1\%}$ corresponds to the 100-year flood water level; 21 and 41 are the numbers of analysed events with the respective water levels i.e. between the $WW_{1\%}$ and $WW_{50\%}$ and below the $WW_{50\%}$).

Table 1 Characteristics of the 62 measured rainfall-runoff events at Czarna.

Category	Unit	Value: avg./event	Value: range
Rainfall depth - P	mm	23.7	3.0 - 96.0
Runoff (effective rainfall) depth - H	mm	2.9	0.2 - 16.5
Peak discharge - Q_{max}	m^3/s	1.32	0.13-11.4
$Q_{max}/WQ_{50\%}$	-	1.27	0.12-11.0
Curve number - CN	-	82.6	50.6-97.1

$WQ_{50\%}$ is two-year-flood discharge = 1.04 m^3/s

ESTIMATION OF THE CURVE NUMBER

Theoretical values of curve number: Based on topographic maps in scale 1 to 25,000, which contain information about three land use types: forest, pasture and arable land (Fig. 2), and on statistical data for the region about the structure of land use on arable land (potato about 25%; small grain about 65% and alfalfa about 10%), as well as information based on soil maps in scale of 1 to 300,000, the CN for the watershed as weighted mean, applying the USDA-SCS (1972) procedure, was estimated as 74.6 (Banasik, 1994).

CN based on rainfall-runoff records with the use of largest storms: Using measured rainfall-runoff data, the empirical CN-value is estimated by the use of the relationship (Hawkins 1973):

$$CN = \frac{25400}{S + 254} \tag{1}$$

where S is the watershed storage parameter (in mm) computed from the formula:

$$S = 5\left(P + 2H - \left(4H^2 + 5PH\right)^{0.5}\right) \tag{2}$$

where P is rainfall depth (mm) and H is the runoff, called here also the effective rainfall (mm). The 30 largest of all 62 recorded rainfall-runoff events, according to descending rainfall depth, of Zagozdzonka River at Czarna gauging station are shown in Table 2.

Table 2 Characteristics of the largest (30 of 62) rainfall-runoff events (according to descending rainfall depth) at Czarna.

Ordinal number **i**	Chronology number of the event	Month DD	Year	Rainfall P_i (mm)	Runoff H_i (mm)	Curve number CN_i	Max retention S_i (mm)	Mean retention S_m (mm)	P_i / S_m	CN_m
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	28	May 15	96	**96,0**	16,49	59,83	170,48	170,48	***0,56***	59,84
2	30	July 8	97	**66,3**	10,46	67,26	123,64	147,06	0,45	63,33
3	53	May 27	02	**60,9**	0,49	50,61	248,13	180,75	0,34	58,42
4	38	April 19	99	**49,0**	11,17	77,85	72,28	153,63	0,32	62,31
5	42	July 26	00	**48,3**	1,37	60,76	163,23	155,55	0,31	62,02
6	20	Aug. 2	88	**48,0**	0,89	59,19	175,28	158,84	0,30	61,52
7	1	June 1	80	**46,2**	2,7	66,10	130,24	154,76	0,30	62,14
8	24	Oct. . 9	94	**45,6**	2,33	65,50	133,72	152,13	0,30	62,54
9	16	June 2	85	**39,5**	1,55	67,18	124,16	149,02	0,27	63,02
10	22	April 2	94	**39,4**	4,68	74,93	84,93	142,61	0,28	64,04
11	17	June25	85	**39,2**	1,93	68,62	116,16	140,21	0,28	64,43
12	5	Aug. 8	80	**39,0**	4,82	75,49	82,51	135,40	0,29	65,23
13	43	Sept. 17	00	**36,4**	0,51	64,76	138,66	135,65	0,27	65,19
14	8	Oct. 8	80	**35,6**	11,78	86,89	38,32	128,70	0,28	66,37
15	59	May 3	05	**32,3**	1,21	71,20	102,66	126,96	0,25	66,67
16	32	June14	98	**31,9**	3,51	78,10	71,20	123,48	0,26	67,29
17	35	June 11	98	**31,3**	0,98	71,04	103,61	122,31	0,26	67,50
18	23	April 6	94	**31,0**	7,11	84,80	45,53	118,04	0,26	**68,27**
19	31	July 30	97	**28,1**	1,31	75,05	84,51	116,28	0,24	68,60
20	10	Oct. 14	80	**27,5**	15,4	94,55	14,64	111,19	0,25	69,55
21	9	Oct. 10	80	**26,1**	13,94	94,38	15,12	106,62	0,24	70,43
22	13	July 4	84	**25,8**	0,68	74,19	88,48	105,80	0,24	70,60
23	50	April 24	01	**25,4**	5,16	84,75	40,59	102,96	0,25	71,16
24	60	July 29	05	**24,1**	0,59	75,16	83,83	102,16	0,24	71,32
25	21	July 9	91	**23,4**	0,36	74,26	87,95	101,59	0,23	71,43
26	6	Aug. 13	80	**23,4**	8,24	91,48	23,64	98,60	0,24	72,04
27	34	Nov. 1	98	**23,3**	2,06	81,67	56,95	97,05	0,24	72,35
28	36	June 12	98	**22,3**	0,87	78,36	70,19	96,09	0,23	72,55
29	14	Aug. 6	84	**22,0**	0,32	75,33	83,36	95,66	0,23	**72,64**
30	3	July 26	80	**20,6**	4,45	88,94	31,57	93,52	0,22	**73,09**

As Hawkins et al. (1985) indicated, that the mean value of CN estimated from all rainfall-runoff data gives an overestimate of discharge when used in prediction, they proposed a technique of computation in which only descending rainfall events, which satisfies the relationship 3, i.e.:

$$P_i / S_m \geq 0.46 \tag{3}$$

In this relationship P_i it the total rainfall (mm) for the storm ranked as (i) when rainfall depth has been placed in order from largest to smallest; S_m is the mean value for S for storm (i) and all larger events i.e.:

$$S_m = \sum_{j=1}^{i} S_j \Big/ i \tag{4}$$

As one can notice from the data in column 10 of table 2, there was only one event which fulfills the condition 3. So, at the early stage of the investigation (Banasik, 1994; WAU, 1995), we decided to increase the number of events for estimation of the representative curve number, by using all runoff events caused by rainfall larger as initial abstraction of theoretical curve number. The initial abstraction i.e. 0,2S for the CN_{theor}=74.6 is I_a=17.3 mm. As there were two other catchments investigated, with lower theoretical CN, i.e. with higher I_a, so we decided to use, as a threshold rainfall depth of events to be include in the consideration, a value of 20 mm. CN estimated from the 62 recorded events of the period 1980-2008 is 73.1 (Table 1 and Figure 5). For comparison purposes we estimated also CN for rainfall events of depth larger then 30 mm, and for a group of events, which number is equal to number of years of recording period i.e. 29 (see column 11 in Table 1), and mean for all 62 events. The value of the computed CN is 68.3, 76.6

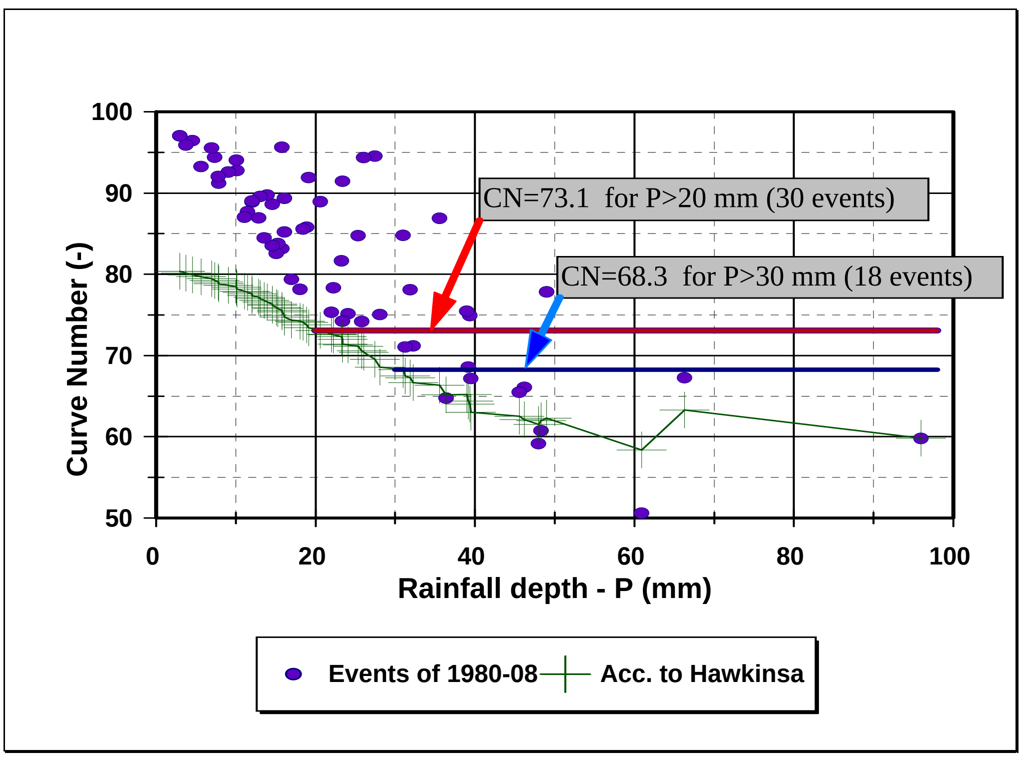

Fig 5. Curve Number versus rainfall depth.

and 82.1, respectively. The results of CN estimation, based on 29-year-period of records as well as results found out in previous considerations, based on 12-, 20- and 25-year period of records, is presented in Table 3.

Table 3 Assessment of CN parameter for Zagozdzonki watershed upstream of Czarna gauging station in current and previous considerations.

Period of records	Parameter CN (-)					References
	theoretical one	based on measured data – estimated as				
		mean for all events	for $P_i > 20$ mm	for $P_i > 30$ mm	of the N^{th} ** element	
1	2	3	4	5	6	7
1980-91	74.6	81.7 (21)	76.6 (13)	69.6 (6)	75.7 (12)	Banasik(1994)
1980-99		80.8 (39)	75.0 (24)	70.7 (14)	74.0 (20)	WAU (2000)
1980-04		82.5 (58)	73.1 (28)	68.1 (17)	72.3 (25)	WAU (2005)
1980-08		82.1 (62)	**73.1** (30)	**68.3** (18)	**72.6** (29)	WULS (2009)

* The numbers in paranthesis are numbers of events (which fulfilled the assumed criterion) used in the analyses

** N – duration of the rainfall-runoff record period (in years)

The data in Table 3 indicate that:

- mean value of CN of all recorded events, equals 82.1 (column 3), is significantly higher than CN_{theor}, equals 74.6 (column 2), i.e. estimated on the base on land use and soil type information,
- the value of CN estimated for a group of events of P>20mm, equals 73.1, is the very close to CN_{theor}, however one may conclude that assuming the threshold precipitation as initial abstraction which was 17,3 mm he may receive even closer CN to CN_{theor},
- the value of CN estimated for a sample number equals to number of years of records, as 72.6 (column 6) is also relatively close to CN_{theor},
- the value of CN estimated for a group of events of P>30mm, equals 68.3, is significantly lower than CN_{theor}.

CN based on all rainfall-runoff events with the use of "asymptotic approach": This technique is based on the frequency matching concept, i.e. the rainfall depths and runoff depths are sorted separately, and then realigned on the rank-order basis to form P:H pairs of equal return periods. As Hawkins (1993) indicated, CNs calculated from the recorded data for the matched pairs, according to equation 1 and 2, approach a constant value with increasing rainfall. A standard asymptote occurs if there is a tendency for CN to decline and then approach a constant value with increasing P according to formula:

$$CN(P) = CN_\infty + (100 - CN_\infty)\exp(-P/b) \tag{6}$$

where CN_∞ is a constant approached as $P \to \infty$; and b is a fitted constant.

The 62 pairs P vs CN are plotted on Figure 6. Table Curve software, "Automated curve fitting and equation discovery" of SYSAT has been used to find parameters of the formula 6. One pair, i.e. that of the highest rainfall, has not been included in the analyzed data, as it seems to be outside of the sample (Fig. 6). The equation:

$$CN(P) = 73.4 + 26.6\exp(-P/17.8) \tag{7}$$

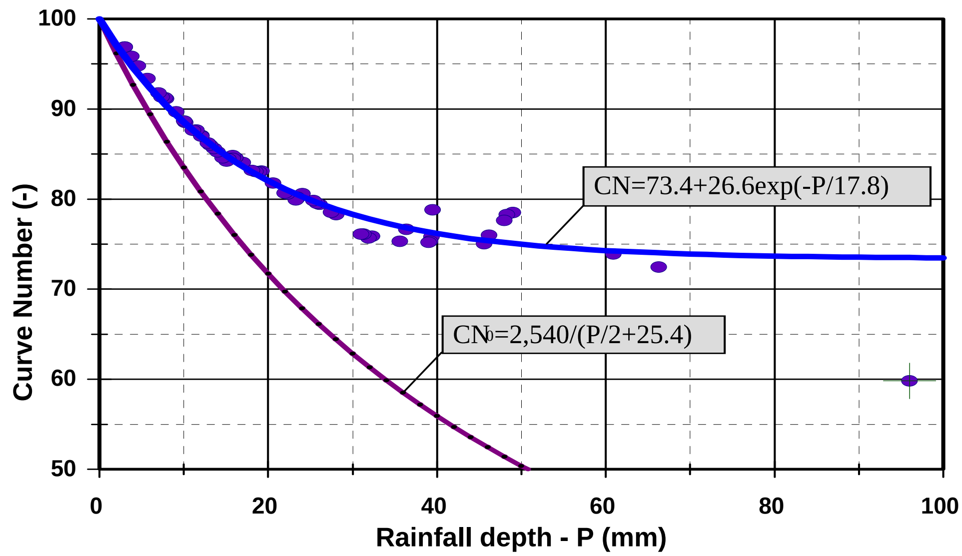

Figure 6 CNs estimated from the P:H pairs, ranged separately, versus rainfall depths for the watershed.

was fitted with r^2 = 96.8% and SE of CN is 1.07. Accordingly, this confirms a standard behavior of the watershed, and CN = CN_∞ = 73.4 should be assigned to the Zagozdzonka watershed upstream of Czarna as a representative value. The lower solid line on Figure 6 is the threshold of runoff at the rainfall depth, or where P=0.2S, and is given by the equation:

$$CN_0 = \frac{2540}{\frac{P}{2} + 25.4} \tag{8}$$

The estimated value of CN_∞ = 73.4 is very close to the theoretical CN_{theor}, which has been 74.6, as well as to CN estimated for rainfall depths larger then 20 mm, which has been 73.1.
This is a confirmation that CN-NRCS method as described in USDA-SCS (1972) Handbook is applicable for estimation of runoff from rainfall events in this and similar ungauged watersheds in central part of Poland.

Seasonal variation of CN: Curve numbers, estimated on the base of measurement from formulas 1 and 2, have been plotted on Figure 7 in function of time of the year. Red dots are for events with peak discharge higher than 1 m^3/s and blue triangular are for smaller events. The approximating line of the measured events indicates variation of the CN, with lower values at the growing season. The variability of the approximation line of CN for all events is from 93 to 71. The minimum appears in the middle of June. Taking into account only larger 21 events, i.e. the events with Q_{max} larger than 1.0 m^3/s, which corresponds to two-year flood, the approximated CN varies from 91 to 65. The minimum appears in third decade of May. It was noted that in some hydrologic models the monthly curve numbers are used. It was felt that use of monthly curve numbers might reduce the error in monthly runoff estimates from various computer models.

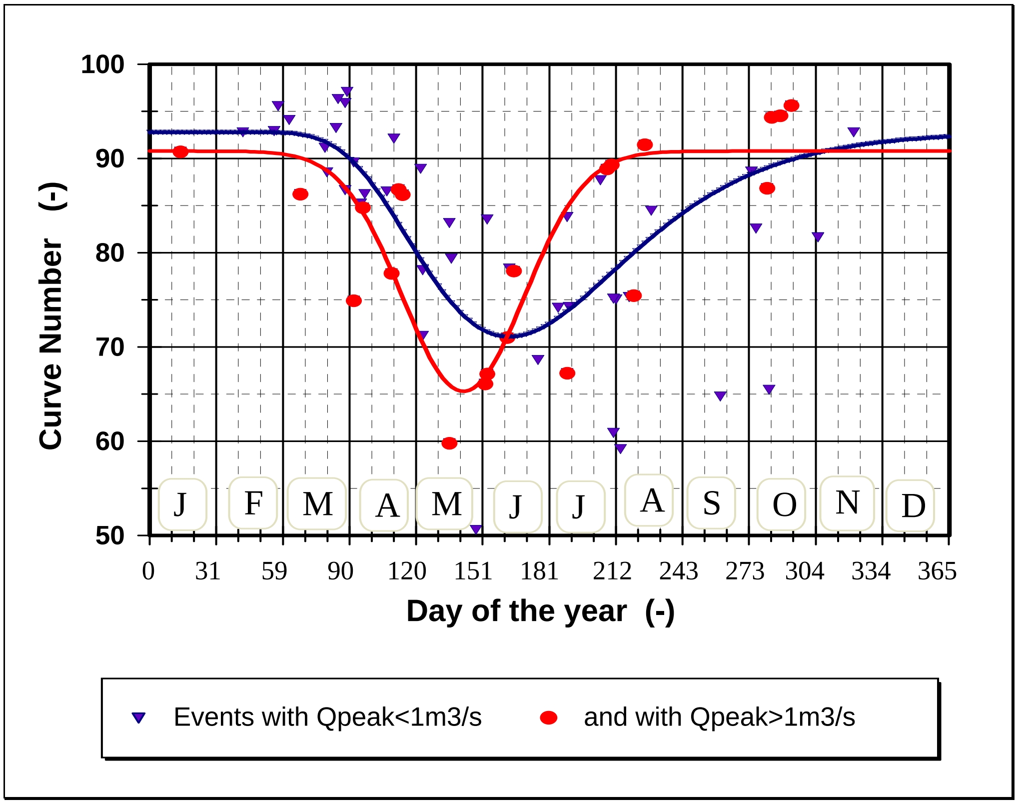

Figure 7 Variation in curve numbers by time of the year for the watershed; red line is for larger 21 events with Q_{max} larger than 1.0 m^3/s and blue line is for all 62 events.

CONCLUDING REMARKS

The applicability of the NRCS-CN method was investigated in a small agricultural lowland watershed in Poland, using over 60 rainfall-runoff events from the period of 29 years (1980-2008). The analysis concluded, that using CN value according to the procedure described in USDA-SCS Handbook one receives representative value for estimating runoff from high rainfall depths. This has been confirmed by applying “asymptotic approach” for estimating the watershed curve number from the rainfall-runoff data. Furthermore, the analysis indicated that CN, estimated from mean retention parameter S of recorded events with rainfall depth higher than initial abstraction, is also approaching the theoretical CN. The observed CN, ranging from 59.8 to 97.1, declines with increasing storm size, which has been classified as a standard response of watershed. The investigation demonstrated also changeability of the CN during a year, with much lower values during the growing season.

The curve numbers developed from the watershed data compared favorably with the information in Chapter 9 of NEH 630 base on the land use and soils information of the watershed. This indicates that hopefully the curve numbers in Table 9.1 of NEH 630 can be used in other locations in Poland. It is also recognized where possible local developed curve number should be used.

This investigation indicated that curve numbers in Poland response similar to those in the United States. They showed seasonal variation in curve numbers and tendency of curve numbers to decrease with increasing precipitation. The research has significantly added to the curve number knowledge world wide. The researchers are to be commented for their efforts to add to the world wide curve number knowledge

ACKNOWLEDGMENTS

The investigation described in the paper is part of the research project no. N N305 396238 founded by PL-Ministry of Science and Higher Education and has been supported by a grant from Iceland, Liechtenstein and Norway through the EEA Financial Mechanism and the Norwegian Financial Mechanism. The support provided by these organizations is gratefully acknowledged.

REFERENCES

ASCE - American Society of Civil Engineers (2009). Curve Number Hydrology: State of the Practice (eds. Hawkins, R.H., Ward, T.J., Woodward, D.E. and Van Mullem. J. A.) American Society of Civil Engineers.

Banasik, K. (1994). Sedimentgraph model of rainfall event in a small agricultural watershe (in Polish). Treaties and Monographs, Warsaw Agricultural University Press, Warsaw, Poland.

Banasik, K. (2009). Predicting the flood hydrographs for small urban watersheds (in Polish), Warsaw University of Life Sciences – SGGW Press, Warsaw.

Banasik K., Ignar S., 1983. „Estimation of effective rainfall using the SCS method on the base of measured rainfall and runoff" (in Polish), Przeglad Geofizyczny (Review of Geophysics), XXVII (3-4), pp 401-408.

Banasik, K., Madeyski, M., Wiezik, B. and Woodward D.E. (1994). "Applicability of curve number technique for runoff estimation from small Carpathian watersheds", In: Development in Hydrology of Mounatnous Areas (eds. Molnar, L., Miklanek, P. and Meszaros, I.), Slovak Committee for Hydrology and Institut of Hydrology Slovak Academy of Sciences, Stara Lesna, Slovakia. pp 125-126.

Banasik, K. and Woodward D.E. (1992). "Prediction of sedimentgraph from a small watershed in Poland in a changing environment", Proc. Water Forum'92, Session: Irrigation and Drainage (ed. Engman, T.), ASAE, Baltimor, USA. pp 493-498.

Hawkins. R.H. (1973). "Improved prediction of storm runoff in mountain watersheds" determination of curve numbers from data". Journal of Irrigation and Drainage Division. American Society of Civil Engineers, 99(4). pp. 519-523.

Hawkins, R.H. (1993). "Asymptotic determination of curve numbers from data", Journal of Irrigation and Drainage Division, American Society of Civil Engineers, 119(2). pp 334-345.

Hawkins, R.H., Hjelmfelt, Jr. A.T. and Zevenbergen, A.W. (1985). "Runoff probability. storm depth. and curve numbers", Journal of Irrigation and Drainage Division, ASCE 111(4), pp 330-340.

Ignar, S. (1988). "The SCS method and its application for effective rainfall determination" (in Polish), Przeglad Geofizyczny (Review of Geophysics), XXXII (4), pp 451-455.

Ignar, S. (1993). Methodology for flood evaluation with assumed probability of occurrence in ungauged watersheds (in Polish), Treaties and Monographs, Warsaw Agricultural University Press, Warsaw, Poland.

Ignar, S., Bansik, K. and Ignar, A. (1995). “Random variability of curve number values for SCS runoff procedur”, Proceedings of the International Conference on Hydrological Processes in the Catchment, held in Cracow, Poland, 24-25 April 1995, pp 127-130.

Soulis, K.X., Valiantzas, J.D., Dercas, N. and Londra, P.A. (2009). “Investigation of the direct runoff generation mechanism for the analysis of the SCS-CN method applicability to a partial area experimental watershed”, Hydrol. Earth Syst. Sci., 13, pp 605-615.

USDA - Soil Conservation Service (1972). National Engineering Handbook, Sec. 4. Hydrology, Wahington D.C.

USDA - Natural Resource Conservation Service (2003). National Engineering Handbook. Part 630, Hydrology.

Walker, S.E., Banasik, K., Mitchell J.K., Northcott, W.J., Yuan, Y. and Jiang, N. (2000). “Applicability of the SCS curve number method to tile-drained watersheds”, Annals of Warsaw Agricultutral University – SGGW, Land Reclamation, No 30, Warsaw, Poland. pp 3-14.

WAU (Warsaw Agricultural University - SGGW), Dept. of Hydraulic Structures (1995). Modeling of the influence on men activity on flod flow and sediment yield from small agricultural watersheds, Internal Report of the PL-ARS-195 Project, Grant No MR/USDA-90-51 (led by K. Banasik, S. Ignar, G.R. Foster and D.E. Woodward), Warsaw.

WAU (Warsaw Agricultural University - SGGW), Dept. of Water Engineering and Environmental Restoration (2000). Modeling of the watershed responses to haevy rainfall in a changing environment (in Polish), Internal Report (led by K. Banasik), Warsaw.

WAU (Warsaw Agricultural University - SGGW), Dept. of Water Engineering and Environmental Restoration (2005). Suspended sediment yield and characteristics in flood events from agricultural areas (in Polish), Internal Report (led by K. Banasik), Warsaw.

Woodward, D.E., Scheer, C.C. and Hawkins, R.H. (2006). “Curve Number update for runoff calculation”, Annals of Warsaw Agricultutral University – SGGW, Land Reclamation No 37, Warsaw, Poland, pp 33-42.

WULS (Warsaw University of Life Sciences - SGGW), Dept. of Water Engineering and Environmental Restoration (2009). Modeling of catastrpfic pluvial floods in small watersheds (in Polish), Internal Report (led by K. Banasik), Warsaw.