Long-term Effect of Forest Renewal on the Water Regime in the Small Experimental Watershed Červík

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Abstract: The small, fully forested watershed Červík (CE) is situated in the part of the Beskydy Mts called the Zadní hory Mts Since November 1953, water balance has been measured in this place with the goal to find out experimentally the changes of the outflow sums during and after the intensive renewal of the forest with a partly changed wood species composition. The measured data were statistically evaluated by the method of double mass curve. In 1962, the decision was made to divide the watershed area into two separate parts A and B. The research started there in 1966 after a twelve-year long calibration period without timber cutting. The stands in the sub-watershed CE-A were cut down in three times shorter intervals than it is common and were immediately renewed. In the CE-B part, the stands were not tended in order to observe visible differences in the sums of outflow in comparison with those in the CE-A part. The measured data were analysed by double mass curve and revealed only very small differences while influence of the environment appeared to be more significant.

Keywords: forest hydrology; experimental watershed; accelerated forest renewal; long-term hydrological measurement; changes of water balance

According to the pattern of the Sperbel- and Rappengraben altersheds in Switzerland (Válek 1977), in 1926 similar hydrological representative measurement was initiated within two small representative watersheds of very different forestation: Kýchová and Zděchov, situated in the Vsacké Mts, near the Beskydy Mts. This measurement was going on for 30 years without any forest renewal on both watersheds.

In November 1953, a new forest hydrological research of water balance in the Červík (CE) and Malá Ráztoka (MR) watersheds was launched with the measurements of the main elements of the water balance (climate, runoffs, and outflow sums) in the Moravian Beskydy Mts. (Zelený 1957).

At first it seemed to be easy to measure and evaluate the water balance of forests. However, when other research objects were involved, it became evident that the balance relationships between the elements were so complicated that a long-term investigation would be needed. According to Majerčáková (2006), the CE watershed belongs to the oldest forest hydrological areas of research in the Czech and Slovak Republics.

Description of the Červík experimental watershed

Červík (CE) watershed is situated between 18°22'52"–18°24'27" E and 49°26'40"–49°27'30" N. Its bedrock is formed by sandstone with shale, the surface is covered with brown forest soil about 1 m deep. It lies in the altitude of 640–941 a.s.l. on E exposition, the average slope inclination is 30.4%. The Červík stream flows into the water reservoir Šance finished in 1970. The experimental watershed is situated in the upper source area. The measuring through is 2.5 km off the mouth of the CE stream at the Šance dam. Close above the measuring through is the confluence of two forks of the CE-A and CE-B watersheds, where two additional partial throughs were built.

Total area of the CE watershed above the measuring through is 1.85 km^2, of the partial sub-wa-

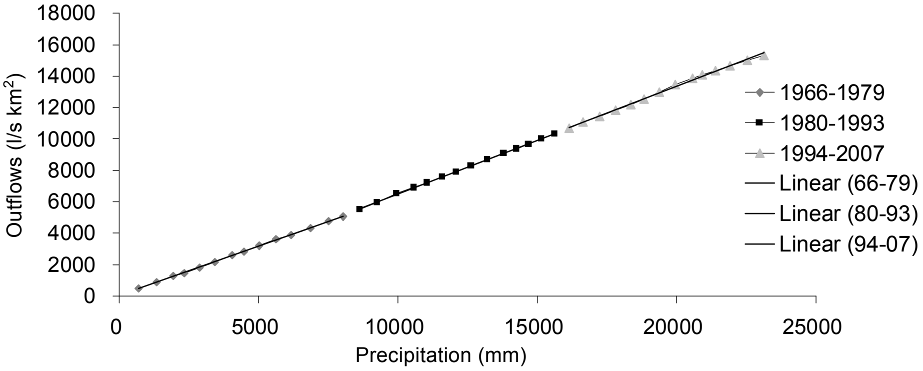

Figure 1. Double mass curve in the whole year; sub-watershed CE-A

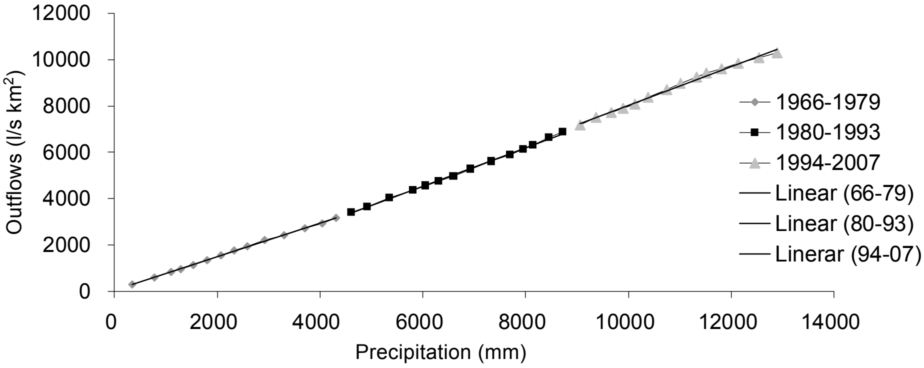

Figure 2. Double mass curve in the cold period; sub-watershed CE-A

tersheds CE-A 0.8824 km^2 and CE-B 0.8425 km^2. There are no significant differences in the geographical characteristics of both sub-watersheds. The CE watershed is to 100% forested and before the intensive renewal of the CE-A sub-watershed the whole CE watershed was calibrated without any intentional management measures. In the course of the experiment, the forests in the CE-A sub-watershed were intensively renewed in strips during 1966–1981; in the following years, the renewal was not so intensive. Before the end of 1994, about 95% of the stands were cut clear and renewed with the spruce with 10% beech proportion in the CE-A sub-watershed. The species composition was not fully changed in accordance with the method – replacing the spruce on 1/3 of the area with beech was not accomplished due to an insufficient supply of beech seedlings. In the CE-A sub-watershed, 95% of the area was renewed; the small part of the non-renewed plot was negligible in view of the research goal. In the CE-B sub-watershed, some calamity clearing was done, but no measures were realised on the plot. The forest inventory data given by the Forest Management Plans show that the experimental goal of the research was fulfilled.

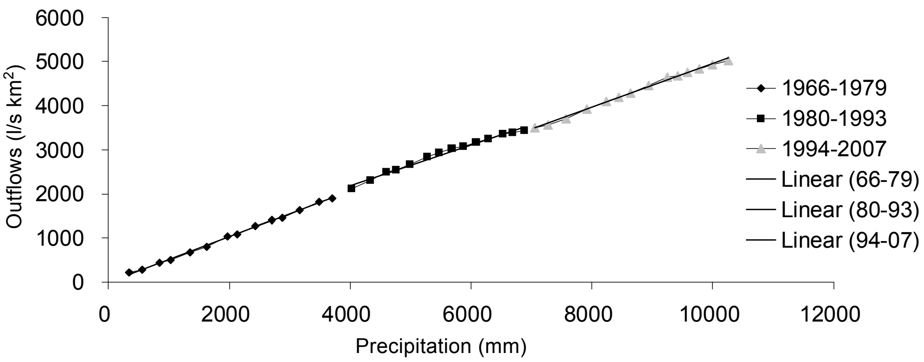

Figure 3. Double mass curve in the warm period; sub-watershed CE-A

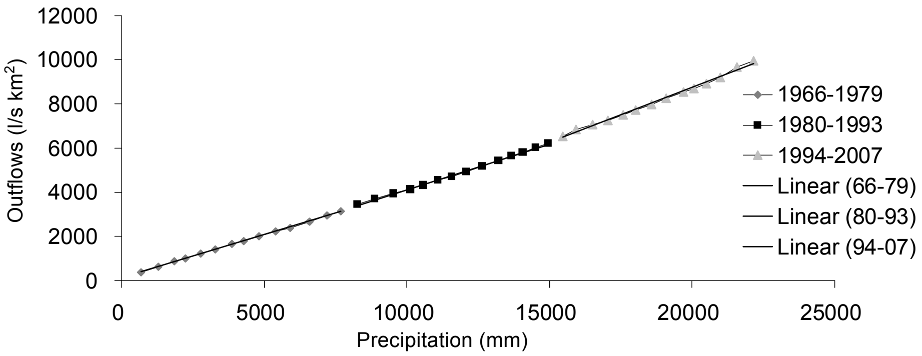

Figure 4. Double mass curve in the whole year; sub-watershed CE-B

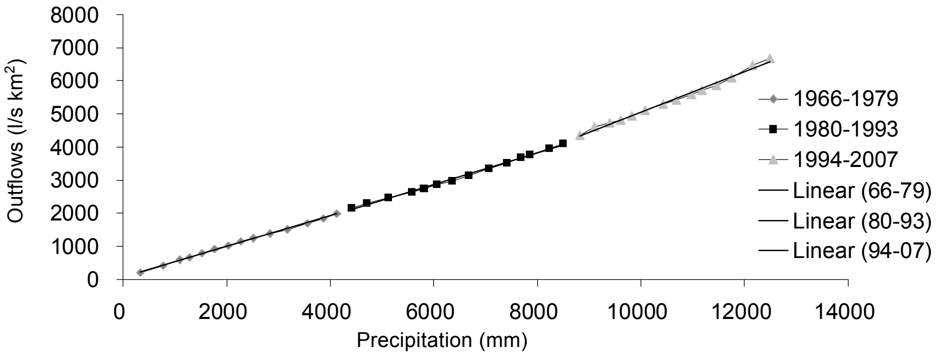

Figure 5. Double mass curve in the cold period; sub-watershed CE-B

Measuring methods

Before the start of measuring in the CE-A and CE-B sub-watersheds in 1966, a calibrating period of the whole CE watershed without stand renewal was realised. During that and the following periods, total monthly precipitations were measured by four totalisers, three of them being situated on the watershed edge, one in the central part. Daily amounts of precipitation and rainfall development as well as some other meteorological parameters were measured by the local observer in the meteo station, since 1998 they have been continuously digitally recorded. Based on the "Horton's method" of measuring, geometrical division of the watershed parts proved to be sufficient. After 1997, however, it was confirmed, that short-time rainfalls, and mainly their intensities, require to be analysed by means of a more detailed method: therefore, we calculated the runoff in l/s.km^2, but we needed to know the precipitation sums in mm after long-time periods as well. In the time of the outflow waves, the discharges should be recorded in one-minute intervals for 24 h. That is why after the catastrophic flood in July 5–9, 1997, followed by a long-term profuse rain, a digital device was installed in the measuring point of the CE watershed, connected to an accumulator. To measure the

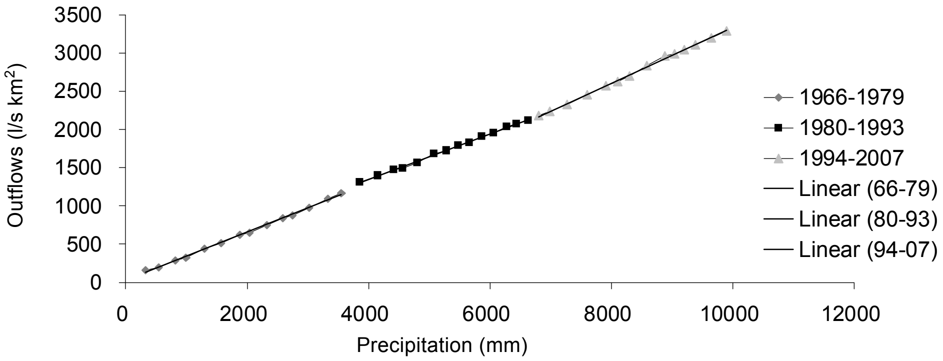

Figure 6. Double mass curve in the warm period; sub-watershed CE-B

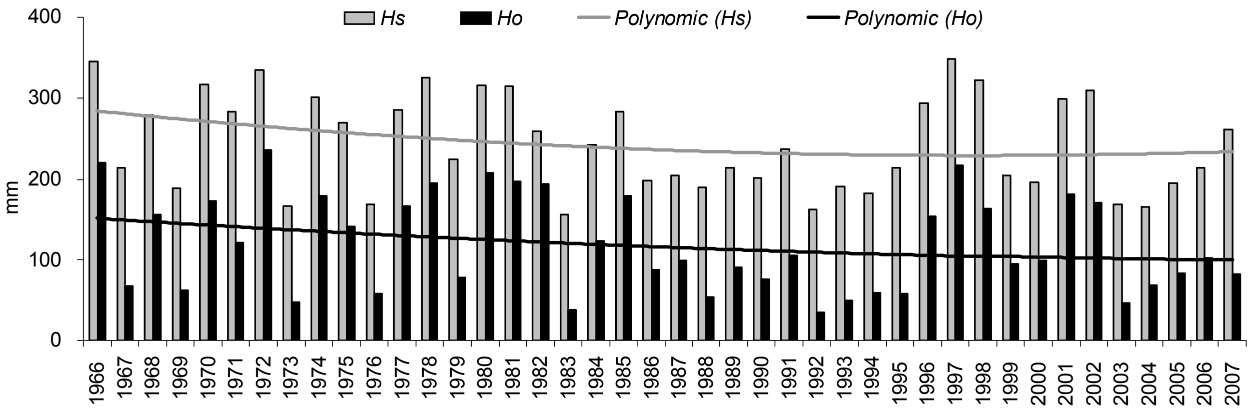

Figure 7. Highs of precipitation (*Hs*) and outflows (*Ho*) in the warm period; sub-watershed CE-A

runoff from the CE-A and CE-B sub-watersheds separately, throughs equipped with floating gauges were built. In 1998 both gauges were completed with digital ultrasonic probes, recording data in one-minute intervals.

Data evaluation

Since the runoff measurements and the following outflow calculations in the CE watershed and CE-A and CE-B sub-watersheds, significant changes of both regimes had been evaluated by statistical methods, significant differences after the accelerated stand renewal having been presumed (Chlebek 1987). Based on the records from October 1, 1966, to December 31, 2007, the time series of the two sub-watersheds CE-A and CE-B were evaluated using the double sum curves after yearly, cold, and warm time periods (Figures 1–6). The double sum curve is based on the analysis of the pair correlation of the sums for the time series compared (Dyck 1976). The curve is linear in homogeneous and consistent series. When the points are deviated and the possible measuring fails while natural effects are excluded, an impact of human activity is presumed (Chlebek & Jařabáč 2006). The linearity of the double sum curves was evaluated graphically – the outflow sums were evaluated. Homogeneity of the time series can be proved by *F*-test. In the CE-A and CE-B sub-watersheds, the data were expressed graphically for the precipitation and outflow sums during the whole year, and in the cold (XI–V) and warm (VI–X) periods.

RESULTS AND DISCUSSION

In Figures 1–6 the double mass curves used in this evaluation present three 14-year periods: the period of intensive felling (1966–1979), the period of forest renewal (1980–1993), and the final period (1994–2007). The intensity of felling in the CE-A watershed is demonstrated in Figure 9. After 1966, the total outflow sum was significantly influenced

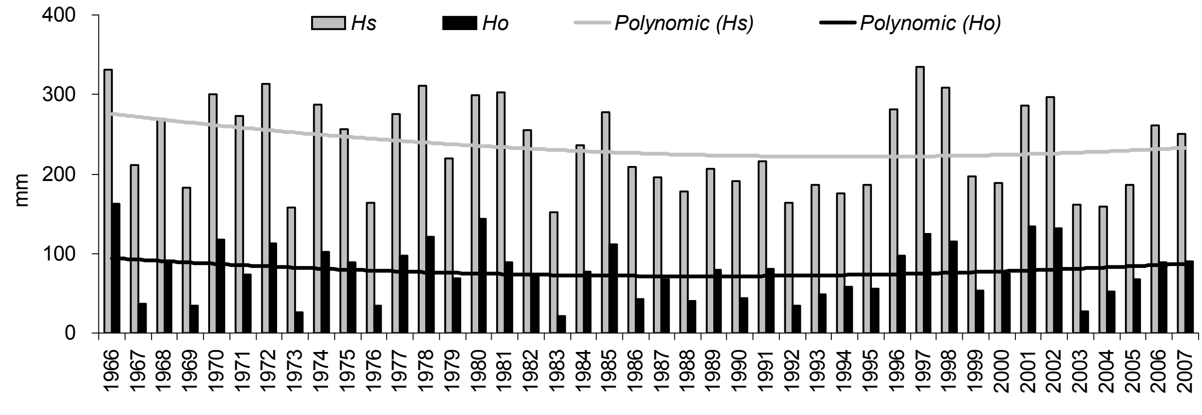

Figure 8. Highs of precipitation (*Hs*) and outflows (*Ho*) in the warm period; sub-watershed CE-B

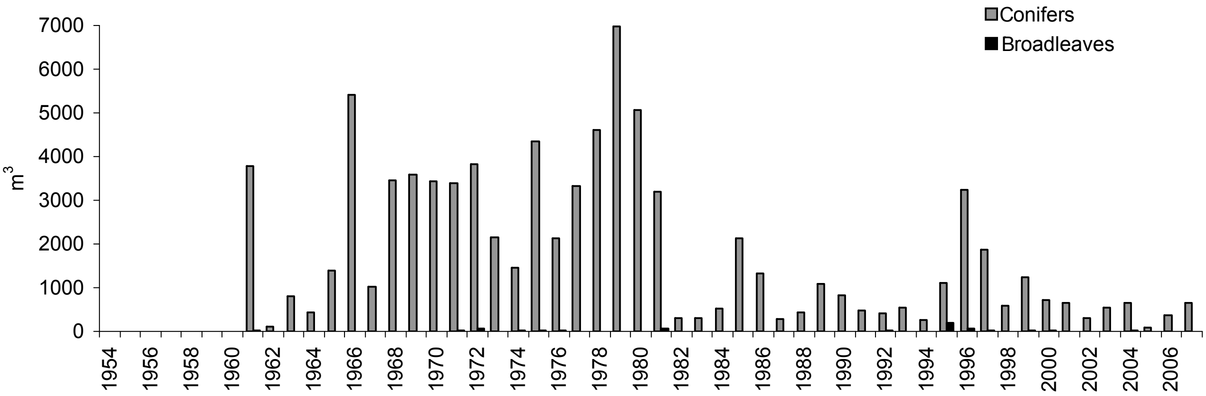

Figure 9. The volume of cutting from 1954 to 2007 on the CE watershead

only in the CE-A sub-watershed as manifested by a lower runoff in the warm period of the year since 1990 (Figures 3, 7). Table 1 shows the losses (not only the evaporation and transpiration in the watershed) and runoff coefficients (*R*, i.e. the outflow sum divided by the precipitation sum) in different periods.

In the first period, i.e. the period of intensive felling, the losses were the highest and the coefficients were the lowest. This fact does not correlate with the evaluation expressed by the double sum curve. Higher losses (evaporation, transpiration, and non-measured outflow) may have been caused by the stand felling and ground

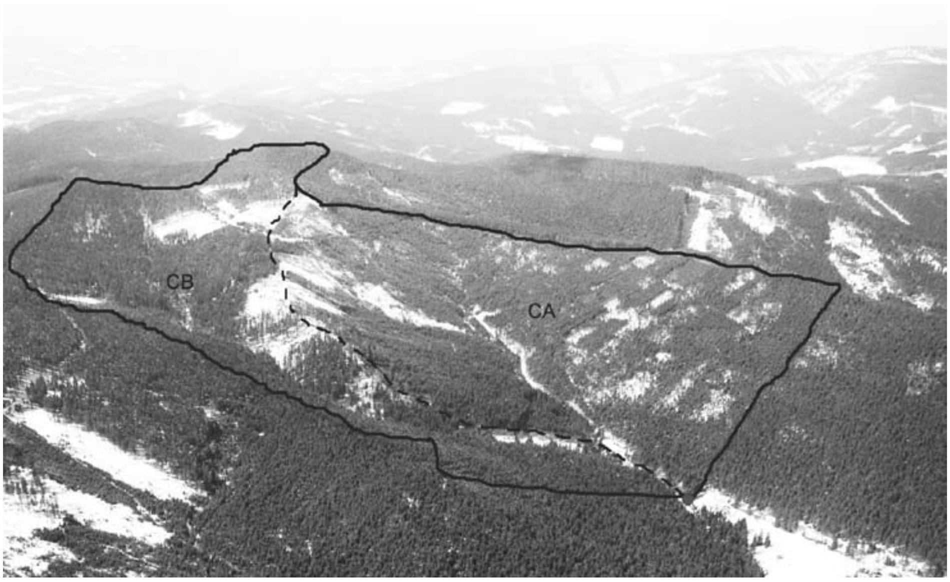

Figure 10. Aerial wiew of the whole area of the CE watershed with parts A and B

Table 1. Average values of losses and runoff coefficients *R* in individual periods in the course of the year

	CE		CE-A		CE-B	
	losses (mm)	*R*	losses (mm)	*R*	losses (mm)	*R*
Intensive felling (1966–1979)	540.9	0.54	212.0	0.62	324.2	0.40
Ongoing felling (1980–1993)	493.1	0.56	166.1	0.69	300.0	0.42
End of felling(1994–2007)	428.1	0.61	181.7	0.66	248.3	0.52
Whole period (1966–2007)	487.4	0.57	186.6	0.66	290.8	0.45

CE – watershed Červík; CE-A, CE-B – sub-watersheds

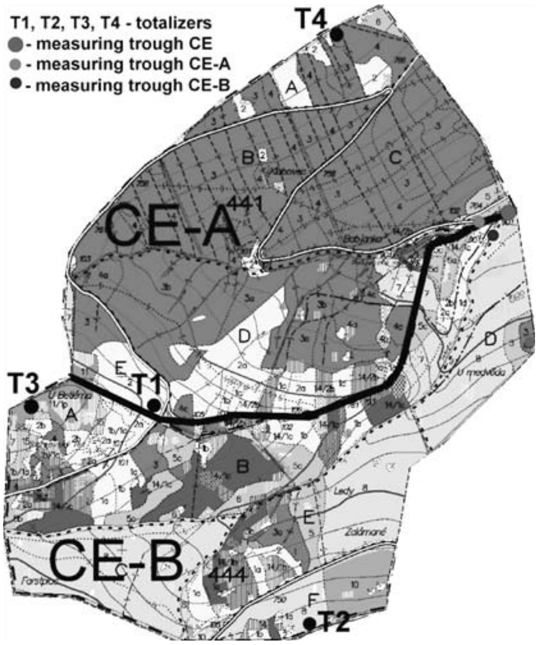

Figure 11. Stand map of the research watershed CE, with marked position of precipitation meters (totalizers) and measuring gutters

opening, but the transpiration by trees can have been also fast replaced by the transpiration by the ground vegetation. Average values are too rough here, so more detailed analysis should be completed, e.g. shorter periods must be analysed by statistical methods, mainly the flood waves or dry periods. Figures 7 and 8 present an example of the great variations in the precipitation and runoff sums in the warm and cold periods in the CE-A sub-watershed with both polynomic relations of natural origin. In recent years, increased runoff could be observed in the CE-B sub-watershed in the cold period (Figure 5) as well throughout the year. Whether this increase was caused by the hard winter in 2006, or if it is a trend caused by the increasing logging in the region, will be proved by measurings in the next periods.

CONCLUSIONS

The measuring of the precipitation – outflow (rainfall – runoff) process in the CE-A and CE-B sub-watersheds in the Beskydy Mts, has shown, that the annual effect of the forest logging on the water balance cannot be proved. More significant changes were measured in the intensively felled and immediately renewed CE-A sub-watershed. The changes were observed mainly in the warm period of the year. This result, however, should be verified by a long-term measuring, also in other small watersheds, under the given conditions. The results of this research in the CE watershed and its parts CE-A and CE-B are to be considered carefully; they cannot be recommended for being applied in the forest hydrological plans, either in the Beskydy Mts region, or in other regions, without a further verification.

To evaluate objectively the precipitation – outflow conditions in small, forested watersheds, long-term time series of the data measured are necessary, illustrating the local environmental conditions. Recent climatic misbalances, together with the negative effect of human activity on the precipitation-outflow conditions in the source mountain regions, need to be studied permanently. The important results of the forest hydrological research achieved in two small experimental watersheds cannot answer a lot of questions oc-

Figure 12. View of the limnigraph station on the CE watershed

Figure 13. View of the limnigraph station on the CE-A sub-watershed

Figure 14. View of the limnigraph station on the CE-B sub-watershed

curring in the forest management or assess the water sources occurring for a short time or in not measurable amounts.

With respect to the environment protection and benefit of the society, the forest hydrological research in the experimental watersheds of the Beskydy Mts should focus more on the shorter periods related to irregular distribution of huge or storming rainfalls causing floods.

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