# Chapter 9
# Human Impacts on Water Regime

**Ognjen Bonacci and Dijana Oskoruš**

**Abstract** River water regime is continuously in motion and in interaction with many natural and human-induced factors. Human interventions, especially over the last two centuries, caused the natural water regime in most rivers to become substantially and irreparably disturbed. River training, floodplain reduction by construction of levees, building of numerous hydrotechnical structures, especially dams and hydroelectric power plants, and other large structures along the Drava River, as well as in its catchment in Italy, Austria, Slovenia, Croatia, and Hungary, have greatly influenced its water regime. This section plays an important role because 167 km of the Drava River course represents the boundary between Croatia and Hungary. At the end of 19th century, major regulation works were executed along the whole Drava River course. The last massive intervention on the Drava River in Croatia and Hungary was carried out at the end of the 19th and the beginning of the 20th centuries. The changes in water regime along the lowland part of the Drava River from the boundary between Slovenia and Croatia to its confluence with the Danube River are examined in this chapter. The findings of hydromorphological and sediment transport regime analyses are also presented.

**Keywords** Human impact · Floods · River regulation · Floodplain
Suspended sediment · River hydromorphology

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## 9.1 Introduction

Many substantially different issues may be considered under the notion of ‘river water regime’, for instance: (1) hydrology, (2) hydrogeomorphology, (3) climate, (4) relief, (5) soil, (6) vegetation cover, (7) transport of sediment, (8) water temperature regime, (9) ice regime, (10) ecological characteristics, etc. All these issues are strongly interconnected. The fluctuations of a river water regime are caused by natural forces as well as human activities. Over the past two centuries, because of intensive and generally uncontrolled human interventions, rivers have suffered the single most intensive impact of all the world’s ecosystems. Competition for water between users is a serious problem in all parts of the Drava River basin, too.

Human activities which result in alteration of natural river water regimes and their floodplains and wetlands are (1) damming of rivers, (2) extracting of surface water from the river and groundwater connected with the river surface water, (3) floodplain reduction by construction of levees, (4) change of the catchment drainage patterns, (5) river regulation and channelization, (6) extraction of gravel and alluvial sands from the channel, and dredging (Erskine et al. 1985; Kondolf 1997). Alteration in natural flow regimes can be caused by directly modifying flows, altering seasonality and the frequency, duration, magnitude, timing, predictability and variability of flow events, altering surface and subsurface water levels and modifying the rate of rise or fall of water levels.

‘*River training*’ refers to the structural measures which are taken to improve a river and its banks. River training is an important component in the prevention and mitigation of floods.

Frequently the changes in river water regime are simultaneously stimulated by natural and human-induced causes. Due to this fact, it is challenging (in many cases impossible) to strictly define which of them plays a more important role in the changes of the actual river water regime. In relevant scientific analyses of human impact on river water regime the crucial problem is the fact that numerous global, regional and local human interventions instantaneously act in combination with natural forces in large rivers. Some consequences of human activities occur after a short time, whereas others present themselves much later, after several decades.

Considering human impacts on the Drava River water regime, it should be noted that the river has two markedly different sections. The natural water regime of the upstream river section, from the spring to the outlet of Dubrava hydroelectric power plant (HEPP) in Croatia, is considerably and completely altered by human interventions, especially by construction and operation of HEPPs, regulations of river course and substantial interventions on the adjacent catchment (urbanization, industrialization, intensive agricultural production, excessive pumping of groundwater, deforestation, etc.). In the upstream part of the Drava River, up to the confluence with the Mura River, 22 hydroelectric power plants have been built; 11 in Austria, 8 in Slovenia and 3 in Croatia.

The situation in the lower Drava River is completely different, citing the opinion of Schwarz (2007): “*The lower Drava and Mura Rivers along the border between*

*Croatia, Slovenia and Hungary represent one of the last remaining continuous riverine landscapes in Central Europe, with all typical natural river elements, such as large natural islands, gravel and sand banks, side channels, meanders, loam cliffs, oxbows and soft woods. Together with its main tributary, the Mura River, the Drava represents a unique 'river corridor' of about 380 km without dams*." In the following, it will be shown that this statement is only partially true.

In the Drava River stretch in Croatia, the following three HEPPs were constructed: (1) Varaždin HEPP, (2) Čakovec HEPP, (3) Dubrava HEPP (Table 9.1; Fig. 9.1). All three mentioned barrages and their reservoirs are located upstream of the Drava-Mura confluence. Old meanders still exist only in the Drava River stretch

**Table 9.1** Basic data for three Croatian HEPPs

| HEPP | Varaždin | Čakovec | Dubrava |
|---|---|---|---|
| Start of operation | 1975 | 1982 | 1989 |
| Installed discharge ($m^3 s^{-1}$) | 450 | 500 | 500 |
| Reservoir volume ($10^6$ $m^3$) | 8.0 | 51.0 | 93.5 |
| Reservoir water surface ($km^2$) | 3.0 | 10.5 | 16.6 |

**Fig. 9.1** The Dubrava dam with the canal which provides water to the Dubrava HEPP power house and the old Drava channel

**Table 9.2** Main characteristics of five Croatian hydrological stations along the Drava River watercourse

| Station name | Datum plane H (m a.s.l.) | Distance from the mouth L (km) | Basin area A ($km^2$) | Mean discharge Q ($m^3\ s^{-1}$) |
|---|---|---|---|---|
| Varaždin | 166.06 | 288.5 | 15,616 | 347 |
| Botovo | 121.55 | 227 | 31,038 | 510 |
| Terezino Polje | 100.67 | 152 | 33,916 | 516 |
| Donji Miholjac | 88.57 | 80.5 | 37,142 | 537 |
| Osijek | 81.48 | 19 | 39,982 | 562 |

between the settlements of Botovo and Terezino Polje. The analyses have shown that they become natural retention areas during high water regime.

The total length of the three Croatian reservoirs is 23.4 km, of three canals is 29.9 km and of old Drava channels is 54.1 km.

In the old Drava reaches, downstream of the three reservoirs, during 90% of the year discharge varies between 10 and 12 $m^3\ s^{-1}$. The discharge called '*biological minimum*' is agreed between Croatian Waters Company and Croatian Electricity Company and amounts to 8 $m^3\ s^{-1}$. Under natural conditions, mean annual discharge was about 335 $m^3\ s^{-1}$. During high waters when discharges of the upstream Drava River exceed 500 $m^3\ s^{-1}$ (installed discharge of HEPPs) the discharges through the old Drava channel reach are higher. Two or three times per year, maximum discharges can reach 1,500 $m^3\ s^{-1}$ and higher. The discharge of 'biological minimum' is too low; hence, it does not meet the criteria to be considered *ecological flow* (EU 2015).

The lower part of the Drava River is influenced by human interventions, but they are significantly less noticeable than upstream, from the spring in Italy to Dubrava HEPP. Downstream of Dubrava HEPP until Donji Miholjac, some large meanders, oxbows, and river islands are preserved. Downstream of Donji Miholjac to the Drava mouth, most of the large meanders were cut-off, but braided river sections are preserved.

Due to the limited space of this chapter, only human impacts on hydromorphological and sediment transport of the lower part of the Drava River water regime will be discussed.

Table 9.2 presents the main characteristics of five Croatian hydrological stations along the lover Drava River, whose different data will be analysed in this chapter.

## 9.2 Hydromorphological Changes

Hydromorphology is a science dealing with physical characteristic of the riverine environment, which serve as habitats based on hydrologic-hydraulic and morphologic-sedimentological parameters, including the channels, banks and floodplain. River morphology is an important control on flow, which can substantially affect flood intensification or mitigation. When rivers flow on an alluvial plain, they often meander or braid, which is typical of the lower section of the Drava River.

Schwarz's (2007) preliminary evaluation of the whole Drava River channel (749 km) indicates that about 35% of all river stretches fall into class two or better (mostly along the lower stretches in Hungary and Croatia), whereas the remaining 65% belong to classes 3–5 (over 26% are completely modified). It should be noted that human activity affecting channel morphology and fluvial processes in the analysed river section is quite varied. Large, yet uncontrolled and therefore unknown, amounts of groundwater are being pumped from the analyzed river catchment section. Indirect influences, including land use and management, urbanisation, massive deforestation, elimination of marshes and wetlands, alter the river hydrological regime, sediment yield, environmental characteristics, and ecological equilibrium. A wide range of direct impacts, as, for example, embankments which disrupt channel-floodplain connectivity (see Chap. 14 in this volume), grade-control structures, channelization, meander cut-offs and stream rectification, installation of groynes, artificial bank stabilization, etc., influenced the river channel characteristics and its stability.

In the natural state, approximately 250 years ago, the lowland part of the Drava River was full of meanders, which resulted from the natural river erosion and deposition processes (Mantuáno 1973, 1976; Bognar 1995, 2008; Biondić 1999). The predominant intervention in this part of the Drava River regulation and channelization was cutting off meanders. Due to the cutoffs, both the length and sinuosity of the lowland part of the Drava River strongly decreased, and the lengths of straight sections and the river's slope strongly increased. Figure 9.2 shows the changes in the longitude of the Drava River section between the mouth of the Mura River and the confluence with the Danube River over the 1784–1990 period. After 1990, there have not been any significant interventions. The length of the analyzed river section was decreased by 120.8 km or 34.3%. These interventions in morphological system substantially, severely, and unpredictably changed the natural dynamics of the lower Drava River with strong influences on its ecological properties. The precise consequences of these human interventions have not been studied and explained until now, because adequate complex and continuous monitoring was missing.

The best documented human influence on the Drava River hydromorphological regime is in the river section from the city of Osijek to the confluence with the Danube River. Figure 9.3 presents the changes in the Drava channel from 1796 to 2000. The shortening of the Drava River and the reduction of wetland area on the left bank is evident. In 1796, Osijek was 33 km away from the Drava mouth, whereas in 1898 the distance was only 20 km. During the period between 1880 and 1898, major river regulation works were implemented to improve navigation conditions. Two of the largest meanders were cut off; the river course was significantly shortened and straightened by 13 km. The natural Drava River delta disappeared, as well as the part of the floodplain (Biondić 1999). During the 20th

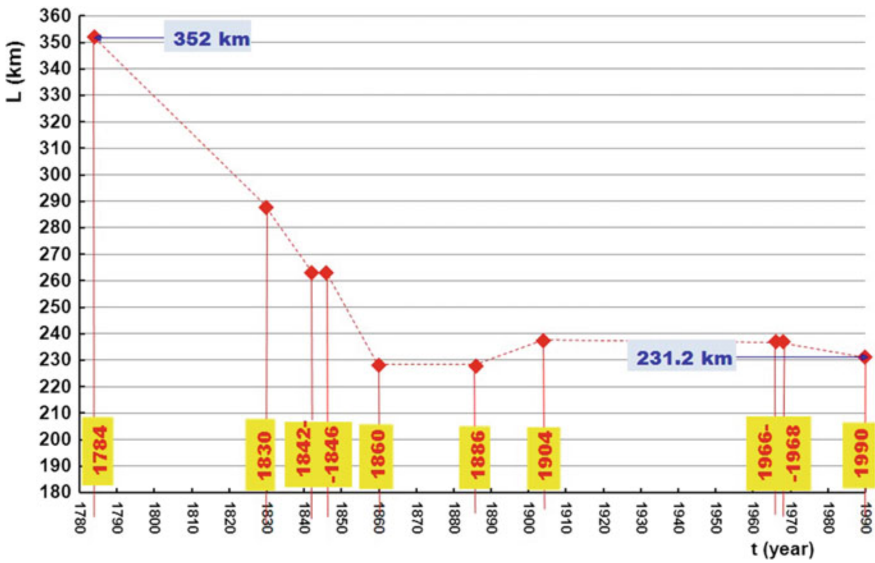


**Fig. 9.2** Changes in the length of the Drava River section between the mouth of the Mura River and the confluence the Danube River, 1784–1990 (modified after Bognar 1995, 2008; Biondić 1999)

century, some interventions were also performed. On the left bank, existing dykes were heightened and connected to a dyke along the right Danube River bank. In that way, the area primarily used for flood retention was significantly reduced and replaced by agricultural fields with a land drainage system.

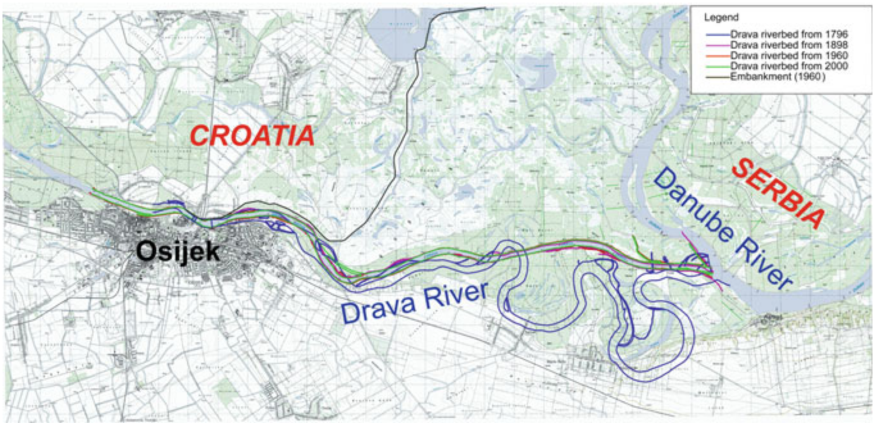


**Fig. 9.3** Map of the Drava River channels around the city of Osijek between 1796 and 2000 (modified after Dadić et al. 2015)

From the engineering and ecological point of view, the following three zones of river environments play the most important role: (1) channel, (2) river banks and riparian zone, (3) floodplain. The floodplain represents the aquatic/terrestrial transition zone, i.e., an ecotone. During high water, the floodplain is incorporated into the surface flow system. The extremely important function of the floodplain is to retain high water during floods, protecting thus downstream areas along the river from flooding (Bonacci 2016). During the period of low water, significant amount of groundwater, which feeds baseflow, is stored underground. Schwarz (2007) indicates that the overall floodplain loss for the entire area of Drava and Mura Rivers can be assessed to about 75% with large regional differences.

Fast rising and falling of discharges and water levels, caused by the development of Dubrava HEPP, resulted in the erosion of the banks and channel in the downstream section of the Drava River. Daily water-level fluctuations amount to 150 cm, but do not pose a risk to the stability of river morphology. However, they represent a great risk to environmental and ecological processes.

Figure 9.4 presents eight Drava riverbed cross-sections measured at the Terezino Polje gauging station from 1st July 1977 to 13th March 2014. It is discernible that the morphology of this profile has changed rather rapidly over a short time. It should be emphasized that a similar situation is typical for all other hydrological profiles controlled by the Croatian Meteorological and Hydrological Service. At the Terezino Polje profile, and virtually along the entire lower Drava River section downstream of the last Croatian HEPP, Dubrava, there is a simultaneous process of riverbed deepening and general bottom erosion (Bonacci et al. 1992; Bonacci and

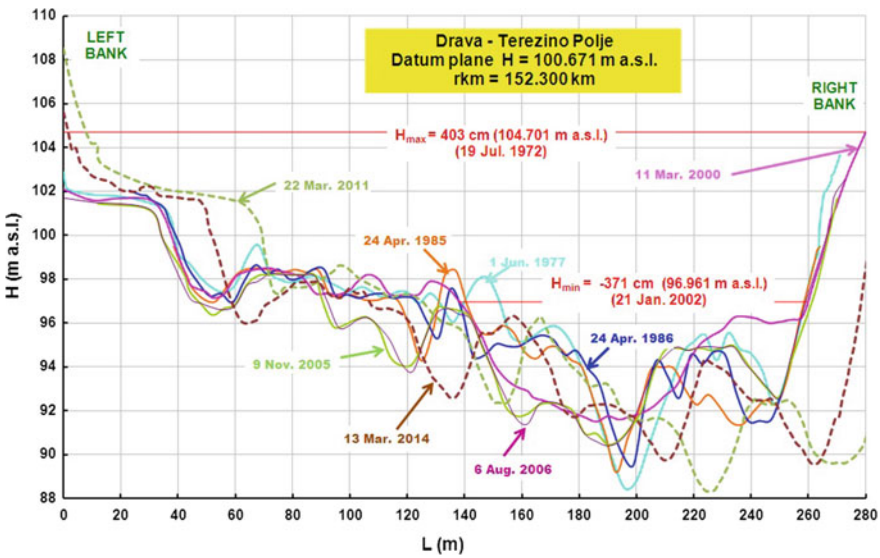


**Fig. 9.4** Eight Drava riverbed cross-sections measured at the Terezino Polje hydrological station from 1 July 1977 to 13 March 2014

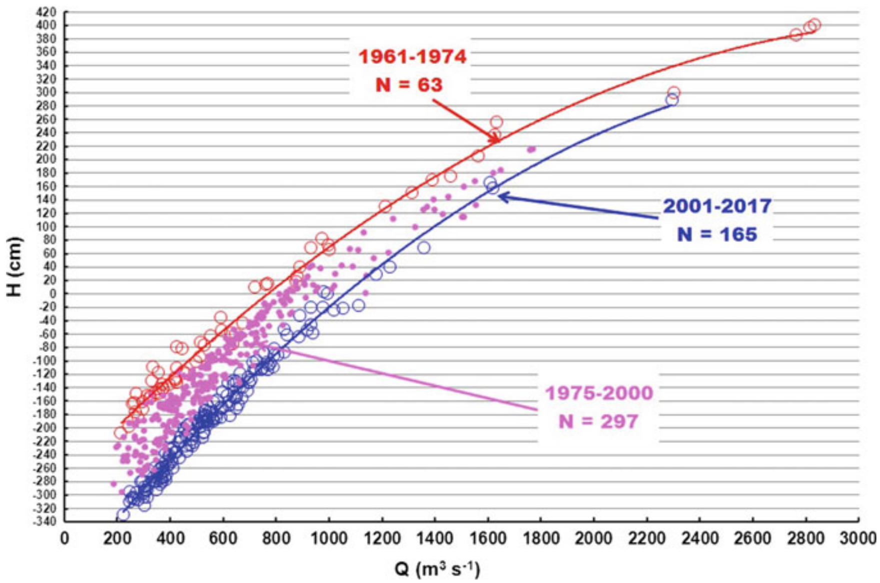


**Fig. 9.5** All (565) measured discharges at Terezino Polje in the period from 25 September 1961 to 8 March 2017 with two rating curves

Oskoruš 2010). Due to this fact, the rating curves of the Drava River along the analysed stretch are not stable—particularly in the low water period. Figure 9.5 shows 565 measured discharges at Terezino Polje in the period from 25th September 1961 to 8th March 2017. The minimum measured discharge was 187 $m^3 s^{-1}$ (on 15 February 1989) and the maximum discharge was 2,833 $m^3 s^{-1}$ (on 19 July 1972). The rating curve for the 1961–1974 period is highlighted in red and rating curve for 2001–2017 in dark blue. During the 1975–2000 period, changes in rating curves were very fast, especially for low flows.

From a hydrogeomorphological point of view, river mouths are particularly dynamic and unstable environments. The Drava–Mura confluence changes its place every year. About 40 years ago it was located 900 m higher upstream the Mura River than today. In the mouth area, there are two enormous meanders at the Drava River. In the case of the superior meander, the Drava River almost reaches the Mura River. The two rivers are only 50 m away from each other, but this distance has reduced rather rapidly during the recent years. In September 2013, a new confluence was formed about 200 m upstream of the old site (Fig. 9.6).

Kopački Rit is located at the confluence of the Drava with the Danube. It represents one of the most important and well-preserved natural wetlands in Europe, formed during Pleistocene and Holocene epochs. The Kopački Rit Nature Park was organized 45 years ago and it was protected by law in 1967 as a nationally valuable area. In 1993, Kopački Rit was declared a Ramsar Convention site and included into the list of internationally important wetlands (Tadić et al. 2014, 2016).

**Fig. 9.6** New Drava-Mura confluence formed in September 2013

Fluctuating water levels in the area create a wide variety of habitats and generate high biological diversity. Compared to the wetland area of about 37,000 ha in the 18th century, there is a substantial reduction of flood retention capacity along the left bank downstream to Osijek. Tadić et al. (2014) warned that regulation works have shortened the river channel and have increased the hydraulic gradient, which resulted in more intensive erosion. Water balance components change according to water quantity and flood intensity, which critically affect the valuable and vulnerable ecological system.

## 9.3 Sediment Regime

Sediment transport is critical to understanding river functioning. Analyses of suspended sediment load along the river course and its changes over time are of crucial importance to river water management and its environmental protection. Water and sediment inputs are fundamental drivers of river ecosystems, but river management tends to emphasize flow regime at the expense of sediment regime (Wohl et al. 2015). Dammed rivers are subject to changes in their flow, water-quality, and sediment regimes.

Changes of *suspended sediment* regime measured at three Croatian stations (Varaždin, Botovo and Donji Miholjac) located along the lower Drava River downstream of Croatian HEPP Dubrava will be discussed in this section.

Figure 9.7 shows the time series of annual suspended sediment load (G $10^3$t $y^{-1}$) measured at the Varaždin station for the period 1960–1981 (Bonacci and Oskoruš 2010). Owing to the construction of Čakovec HEPP in 1982, the measurement of suspended sediment in this profile was terminated. This station was located a few kilometres downstream of the Varaždin Reservoir dam. In the first subperiod (1960–1967), before the commencement of operation of the upstream Zlatoličje HEPP in Slovenia, the sediment load was 2.3 times higher than after its construction (1968–1974 subperiod). The Varaždin Reservoir caused a drop in suspended sediment in the third subperiod (1975–1981) by a further 2.4–5.5 times less than in the first (1960–1967).

The Botovo profile is located 68 km downstream of the Varaždin Reservoir dam, 48 km from the Čakovec dam and 28 km from the Dubrava dam. The construction of the Varaždin Reservoir caused a 17% decrease in the suspended sediment transport during the 1975–1981 subperiod (Fig. 9.8). The construction of the Čakovec Reservoir decreased the suspended sediment transport by 2.7 times compared to the first subperiod (1967–1974) and by 2.2 times compared to the second (1975–1981). The construction of the Dubrava Reservoir decreased the suspended sediment transport by 3.4 times compared to the first subperiod (1967–1974), by 2.8 times compared to the second (1975–1981) and by 1.3 times compared to the third (1982–1988).

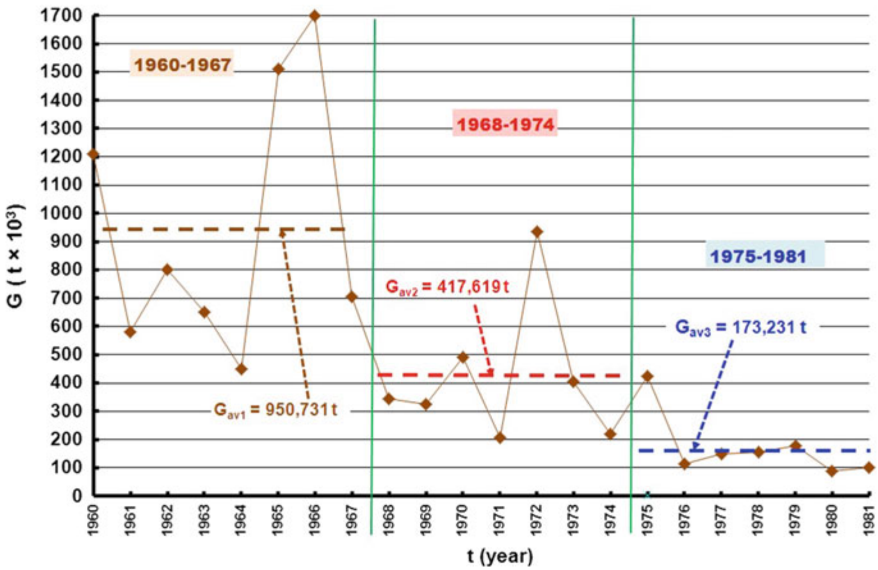


**Fig. 9.7** Annual suspended sediment load at Varaždin, 1960–1981

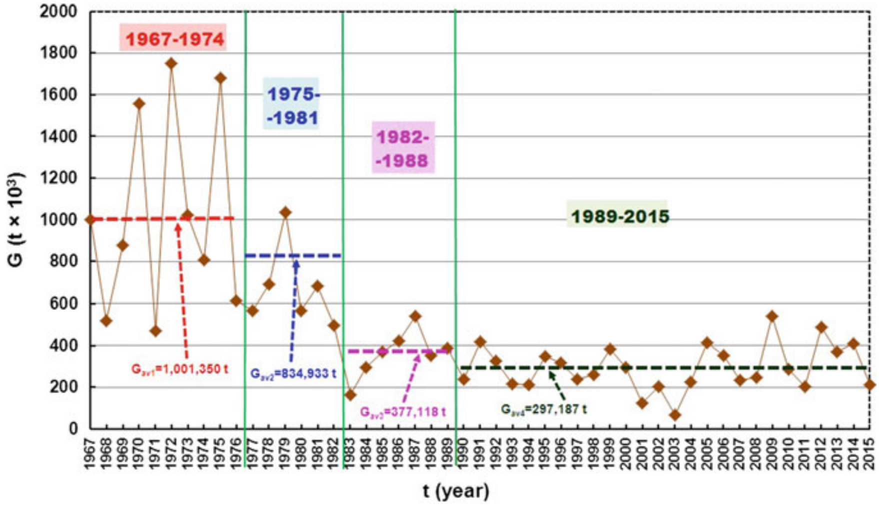


**Fig. 9.8** Annual suspended sediment load at Botovo, 1967–2015

The Donji Miholjac profile is located 218 km downstream of the Varaždin dam, 198 km from the Čakovec dam and 178 km from the Dubrava dam. The construction of the Varaždin Reservoir did not cause any change in suspended sediment transport in the 1968–1981 subperiod (Fig. 9.9). The establishment of the

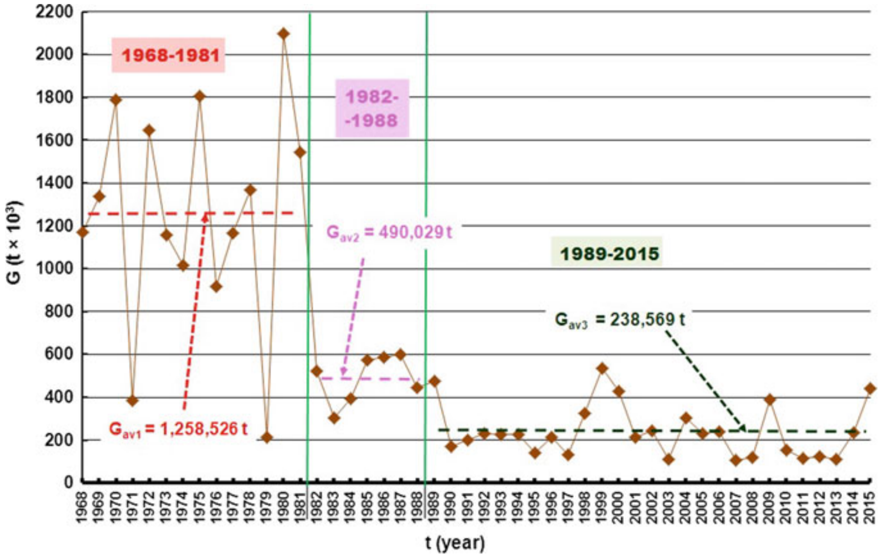


**Fig. 9.9** Annual suspended sediment load at Donji Miholjac, 1968–2015

Čakovec Reservoir decreased suspended sediment transport by 2.6 times compared to the previous subperiod (1968–1981). The construction of the Dubrava HEPP decreased it by 5.3 times compared to the first subperiod (1967–1981) and by 2.1 times compared to the second (1982–1988). Today, only about 19% of suspended sediment of the 1968–1981 interval flows through the Donji Miholjac profile.

It should be noted that only a small quantity of suspended sediment is stored in the three Croatian reservoirs. The cause of suspended sediment reduction downstream of the Dubrava Reservoir could be explained mostly by the exclusion of about 80 km of the Drava bed and the adjacent catchment from sediment production.

Large amounts of *gravel and sand* for civil engineering works were and still are *excavated* from the studied section of the Drava riverbed an in its neighboring area. These activities are not under adequate control, and despite major efforts, it was not possible to obtain official and reliable data on them. A rough estimate of the volume of official and more or less controlled excavated materials in Croatia and Hungary during the past decades is about 300.000 $m^3$ $y^{-1}$, but it could be much higher in some years. The assessment of illegal excavations is not possible.

## 9.4 Conclusions

The management of the Drava River water regime has to consider local, national, and international boundary conditions. Sustainable development is possible only through an integral planning and interdisciplinary management approach for the considered area. Regarding future human activities special attention should be attributed to the confluence of the Mura with the Drava, and the Drava with the Danube. These two locations are very important from the hydrogeomorphological point of view and their role in global environmental processes is inestimable.

Natural flow regime today presents a paradigm for river conservation and restoration. The ecological integrity of river ecosystems depends on their natural dynamic characteristics. Human activities substantially, frequently, and severely change the naturally balanced water and ecological regime. The alteration of the natural flow regimes of rivers and streams and their floodplains and wetlands is recognized as a major factor contributing to the loss of biological diversity and ecological function in aquatic ecosystems, including floodplains. The ichtyofauna composition of the Drava River in the area and downstream of three Croatian HEPPs is considerably and adversely affected (see Chap. 16). Hydroelectric development leads to an unnatural variability of the ichthyofauna.

A definite conclusion is that the water regime of the Drava River is substantially influenced by human activities even on the lower section. If we really wish to preserve this invaluable and extremely vulnerable landscape and environment, more efficient international cooperation and interdisciplinary efforts should be invested.

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