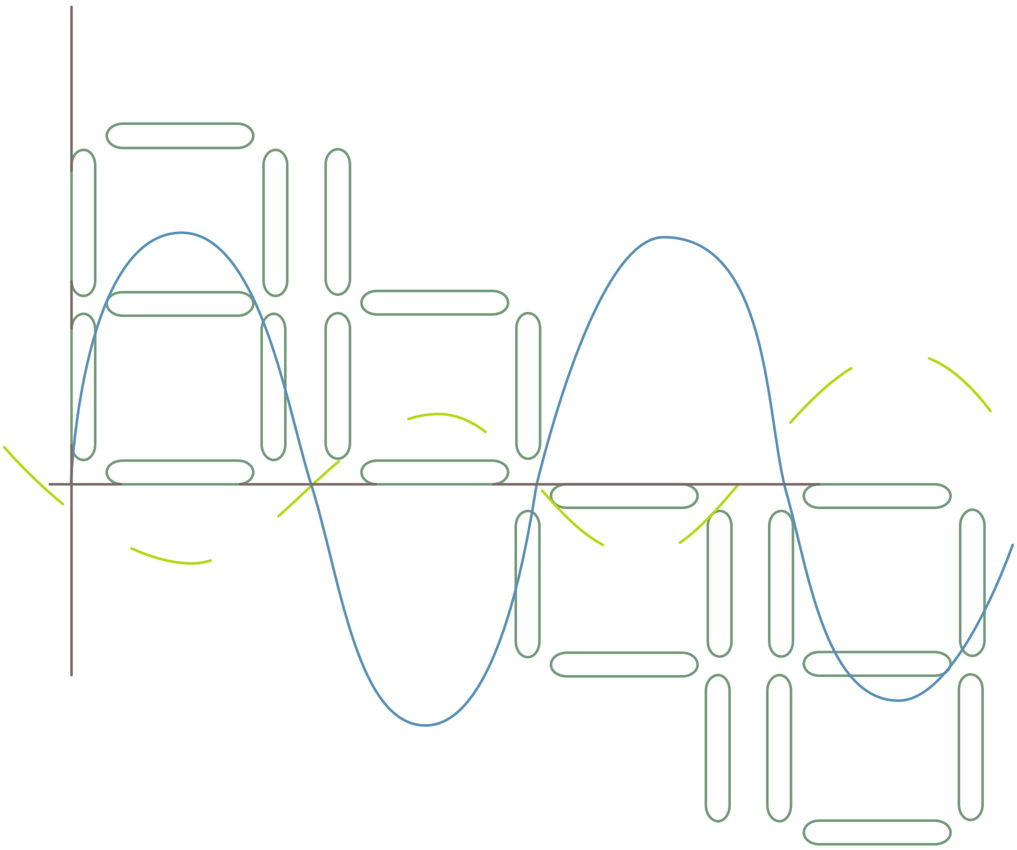
Report 32

GRDC Report Series

Detection of change in world-wide hydrological time series of maximum annual flow



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Detection of change in world-wide hydrological time series of maximum annual flow

by a team of experts under the leadership of
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Global Runoff Data Centre

GRDC operates under the auspices of the World Meteorological Organization (WMO) with the support of the Federal Republic of Germany within the Federal Institute of Hydrology (BfG)

Global Runoff Date Centre

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About the Global Runoff Data Centre (GRDC):

The GRDC is acting under the auspices of the World Meteorological Organization (WMO) and is supported by WMO Resolutions 21 (Cg XII, 1995) and 25 (Cg XIII, 1999). Its primary task is to maintain, extend and promote a global database on river discharge aimed at supporting international organisations and programmes by serving essential data and products to the international hydrological and climatological research and assessment community in their endeavour to better understand the earth system. The GRDC was established at the Federal Institute of Hydrology in 1988. The National Hydrological and Meteorological Services of the 187 member states of WMO are the principal data providers for GRDC.

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Contents

Abstract

The report presents results of a study on change detection in world-wide hydrological time series of maximum annual river flow. The study is limited to a subset of discharge time series held at the Global Runoff Data Centre (GRDC) in Koblenz, Germany (GRDC, 2003). Out of more than a thousand long time series made available by GRDC, a dataset consisting of 195 long series of daily mean flow records was selected, based on such criteria as length of series, topicality, lack of gaps and missing values, adequate geographic distribution, and priority to smaller catchments. The analysis of 195 long time series of annual maximum flows, stemming from the GRDC holdings does not support the hypothesis of general growth of flood flows. Even if 27 cases of strong, statistically significant increase have been identified by Mann-Kendall's test, there are 31 decreases as well, and most (137) time series do not show any significant changes. Some regional patterns have been observed. However, a caution is needed, that in case of strong natural variability, a weak trend, even if it exists, cannot be detected by statistical testing.

1. Introduction

Floods have been a major recent reason of concern in many areas of the world. It is ubiquitously felt that the media have been informing us more and more frequently about disastrous floods. Some people interpret this as a CNN-effect. In the past, before the globalization era, the timely information on far-away floods was missing. Now, no matter where a destructive flood occurs, it is regarded as a spectacular event, and news of recent inundations are promptly shown on the TV worldwide.

Notwithstanding the observation that the availability of information grows in the global village, it is also clear that indeed the flood risk (understood as the probability of extreme event multiplied by a measure of adverse consequences) is on the rise. The costs of extreme weather events have exhibited a rapid upward trend in recent decades and yearly economic losses from large events have increased ten-fold between the 1950s and 1990s, in inflation-adjusted dollars (IPCC, 2001a). The flood losses have soared globally to tens of billions of US$ in material damage and thousands of flood fatalities a year.

According to the global data of the Red Cross for the time period 1971-1995, floods killed, in an average year, over 12 700 humans, affected 60 million people and rendered 3.2 million homeless. Berz (2001) examined temporal variability of great flood disasters (understood as events where international or inter-regional assistance is necessary). Based on his data, one could state that the number of great flood disasters has grown considerably worldwide in the last decades. In the nine years 1990-1998 it was higher than in the three-and-half earlier decades 1950-1985, together (Kundzewicz, 2003).

Since 1990, there have been over 30 floods worldwide, in each of which material losses exceeded one billion US$ and/or the number of fatalities was greater than one thousand. The highest material flood losses, of the order of 30 billion US$, were recorded in China in the summer of 1998 (26.5 billion US$ in 1996), while the storm surge in Bangladesh during two days of April 1991 caused the highest number of fatalities (140 000).

In recent years, destructive deluges happened in many places, such as Mozambique, the Mekong drainage basin, Algeria, China, and several countries in Europe: Germany, Austria, Czech Republic, France, among others. See also the Global Active Archive of Large Flood Events at the Dartmouth Flood Observatory http://www.dartmouth.edu/~floods/archiveatlas

It is estimated that the material flood damage recorded in the European continent in 2002 has been higher than in any single year before. According to Munich Re (2003), the floods in August of 2002 alone caused damage at a level exceeding 15 billion Euro (therein 9.2 in Germany, and 3 each in Austria and in the Czech Republic). There were several other disastrous floods in 2002, e.g. in southern France (Rhone valley), in southern Russia, in northeastern and eastern India, Nepal and Bangladesh, and two floods in China. A flood in central and western China in June caused 3.1 billion USD losses and killed 500, while another one, in central and southern China in August, caused 1.7 billion USD damage and killed 250.

Detection of changes in long time series of hydrological data is an important scientific issue. It is necessary if we are to establish the true effect of climate change on our hydrological systems, and it is fundamental for planning of future water resources and flood protection. Flood protection systems have been designed and operated based on the assumption of stationarity of hydrological processes of river stage or discharge. Can hydrological processes be conceived as stationary? Is the past a key to the future? If this assumption is incorrect then the existing design procedures for embankments, dams, reservoirs, relief channels, polders, etc. have to be revised. Without revision, the flood protection systems can be over- or under-designed and either not serving their purpose adequately or being overly costly. Studies of trend detection are also of importance because of our need to understand the changes of the ”natural” world. The process of river flow has been directly influenced by changes caused by man (e. g. land-use changes: urbanisation, deforestation, changes in agricultural practices, and engineering works: drainage systems, dam construction, river regulation, etc.). Other changes may have been caused by man in an indirect way, e. g. through enhanced emissions of greenhouse gases resulting in the global warming and the related effects. However, also natural changes (e.g. in channel morphology, solar activity, ENSO cycle) can play a role. In view of the many dramatic recent floods, detection of trends in long time series of flood data is of paramount scientific and practical importance.

The present report summarizes results of the recent analysis of annual maximum floods. Literature review and general background borrows from such publications as: Kundzewicz & Robson (2004), Kundzewicz (2002), (2003), Kundzewicz *et al.* (2004).

2. Floods on the rise? - Review of literature on detection and attribution

The hypothesis that climate change will cause increases in frequency and severity of extreme hydrological events has resulted in growing recent interest in change detection in flow data. Yet, to date, there is little concrete evidence of climate-induced change for river flood records. There are problems with strong natural variability and with data availability and quality. The search for weak changes in time series of hydrological data, which are subject to strong natural variability, is a difficult task, and use of adequate data and of good quality methodology is essential.

Having observed that flood risk and vulnerability is likely to have grown in many areas, one is curious to understand the reasons for growth. Among possible mechanisms are changes in terrestrial systems, in socio-economic systems, and in climate.

Flood risk may have grown due to a range of land-use changes, which induce land-cover changes, hence changes of hydrological systems. Deforestation, urbanization, and reduction of wetlands empoverish the available water storage capacity in a catchment. Urbanization has adversely influenced flood hazard in many watersheds by increase in the portion of impervious area (roofs, yards, roads, pavements, parking lots, etc) and increase of the runoff coefficient. In result, higher peaks of runoff responses to intensive precipitation have been observed and the time-to-peak has decreased. As noted by Bronstert (1996), direct urbanization effects are particularly visible in small or middle size floods, which often constitute a substantial contribution to flood losses in a longer term. The urbanized area in West Germany more than doubled from 6% in 1950 to approximately 13% in 1995. Timing of river conveyance may also have been considerably altered by river regulation measures (channel straightening and shortening, construction of embankments), leading to either amplification or damping of flood peaks downstream.

Flood risk defined as integral over all water levels of the product of potential damage and associated occurrence probability may have grown due to considerable changes in socio-economic systems, such as economic development of flood-prone areas, with a general increase in population and wealth, which led to increasing exposure and exacerbated flood losses. Demographic growth, shortage of land, access to inexpensive transportation, attractiveness of floodplains, and unjustified belief in absolute safety of structural flood protection schemes (dikes, dams), cause the tendency of massive human encroaching into flood-prone areas, and investing in infrastructure there. Many wrong locational decisions have been taken, which cause the flood loss potential to increase. In the same time, much of the natural flood storage volume is lost, ecosystems are devastated and riparian wetlands destroyed.

Hope to overcome poverty drives poor people to migrate to informal (unauthorized) settlements in endangered, flood-prone, zones around mega-cities in developing countries. Such places are meant to be left uninhabited on purpose, since effective flood protection is not assured.

Humans have been driven to occupy unsafe areas, thereby increasing the loss potential. Growing wealth has been accumulated in flood-endangered areas. For instance, about 7% of the area of the conterminous United States is located in the 100-year flood zone and about 10% of population are living there. In Japan, half the total population and about 70% of the total assets are located on flood plains, which cover only about 10% of the land surface. Yet, the percentage of flood-prone area is much higher in Bangladesh. The 1998 flood inundated two thirds of the country's area.

An important factor influencing the flood hazard is a misconception of absolute flood protection provided by structural defences, designed according to a probabilistic principle (e.g. to withstand a 100-year flood). Even an over-dimensioned and perfectly maintained dike does not guarantee complete protection, as it can be overtopped or broken by a more extreme flood than the design flow, and the losses may considerably exceed those, which would have happened in a levee-free landscape.

Further, a short memory syndrome can be observed – in a flood-free time, societies and decision makers gradually keep forgetting about the investments necessary for flood-preparedness systems, so that the solidarity and dedication, plentiful during a deluge and immediately after it, may already fade away a few years after a disaster.

In many places flood risk is likely to grow, due to a combination of anthropogenic and climatic factors. Vulnerability to floods can be regarded as a function of exposure and adaptive capacity (cf., IPCC, 2001a), and all three entities have been increasing in many areas, where exposure grows faster than the adaptive capacity.

In addition to the changes specified above, also changes in climate are likely to play an important role in changing flood risk and vulnerability.

2.1 Changes in intense precipitation

According to IPCC (2001), a statistically significant increase in global land precipitation over the 20th century has been noted. Instrumental records of land surface precipitation continue to show an increase of 0.5 to 1 % per decade over much of mid- and high latitudes of the Northern Hemisphere (IPCC, 2001), particularly pronounced in autumn and winter (IPCC, 2001a), i.e. seasons when catchments' capacity to store precipitated water are limited.

The precipitation increase refers to both mean values and extremes, but in many areas the extremes in precipitation are likely to have changed more than the mean. This is particularly important, as changes in extremes may have greater impact than changes in average conditions. It is very likely (estimate of confidence: 90-99% chance) that in regions where the total precipitation has increased, there have been even more pronounced increases in heavy and extreme precipitation events. Moreover, increases in heavy and extreme precipitation have also been documented even in the regions where the total precipitation has remained constant or slightly decreased (number of days with precipitation decreasing stronger than the total precipitation volume).

It results directly from physics (Clausius-Clapeyron law) that the atmosphere's capacity to absorb moisture (and its absolute potential water content, pool of precipitable water, and thus potential for intensive precipitation) increases with temperature. This is a sufficient condition, *caeteris paribus*, for an increase in flood hazard. Increases in heavy precipitation events can arise from other causes, such as changes in thunderstorm activity and large-scale storm activity. Higher and more intense precipitation has been already observed, e.g. in the USA and in the UK (IPCC, 2001).

There are numerous studies restricted to a single drainage basin or a country, corroborating these findings. There is evidence that the frequency of extreme rainfall has increased in the UK (IPCC, 2001a) and a greater proportion of precipitation is currently falling in large events than in earlier decades (Osborn *et al.*, 2000).

Karl *et al.* (1995) noted that within the United States, the proportion of total precipitation contributed by extreme one-day events has increased significantly during the 20th century. The incidence of intensive precipitation events has steadily increased at the expense of moderate events.

Observations confirm that atmospheric moisture is increasing in many places. For example, growth at a rate of about 5% per decade was observed in the USA (Trenberth, 1998). Increased atmospheric moisture contents favours more intensive precipitation events thus increasing the risk of flooding.

As stated in IPCC (2001a), Australian annual mean rainfall has increased by a marginally significant amount over the last century. However, increases in heavy rainfalls have been observed over many parts of Australia in the 20th century (IPCC, 2001). After 1877, increases (some statistically significant) have been noted in mean rainfall for New Zealand´s west coast. This is partially explained by the increase in El Niño conditions over recent decades. There is some evidence of long-term variations in the Australasian region in storm frequency and tropical cyclones (IPCC, 2001a).

Information documenting the increase in the frequency of heavy precipitation events is compiled in Table 1. The area affected by most intense daily rainfall is growing. Although the trends are by no means uniform, about 20% of the stations analyzed worldwide show statistically significant increase of both the proportion of total annual daily precipitation within the upper five percentile and the maximum consecutive 5-day precipitation totals. The number of stations reflecting a locally significant increase in the proportion of total annual precipitation occurring in the upper five percentiles of daily precipitation totals outweighs the number of stations with significantly decreasing trends by more than 3 to 1 (IPCC, 2001).

In their studies of *Grosswetterlagen* (synoptic-scale weather patterns), Bárdossy & Caspary (1990) noted a rise of frequency and persistence (measured by the time intervals of occurrence) of some "wet" patterns (in particular Wz, i.e. West cyclonic) in catchments in Southwest Germany during the fall. A similar tendency of precipitation was detected by Engel (1997), who compared climatological standard normals of precipitation over the intervals 1931-1960 and 1961-1990 in the Rhine basin up to Cologne, Germany. He found increased precipitation during the fall (November to January) and spring (March to June). The precipitation growth was also detected over the time period 1891-1990.

Table 1. Sample of observed changes in intense precipitation (after IPCC, 2001).

Location	Time period	Observation
Globally	1961-1990	A 4% increase in the annual maximum consecutive five-day precipitation total
Mid- and high latitudes of the Northern Hemisphere	Latter half of the 20th century	A 2 to 4% increase in the frequency of heavy precipitation
Many regions of Australia	1910-1995	A 10 to 45% increase in heavy rainfall, as defined by the 99th percentile of daily precipitation totals
Siberia	Summer season, 1936-1994	Increase in the frequency of heavy rainfall (above 25 mm) of 1.9% per decade (despite a statistically significant decrease in total precipitation of 1.3% per decade)

2.2 Changes in high river flow

Where data are available, changes in annual streamflow usually relate well to changes in total precipitation (IPCC, 2001). However, this does not directly translate to general changes in flood flows, even if there are a number of studies reporting that high flows have become more frequent (Table 2).

Globally, no uniform increasing trend in flood flow has been detected (cf. Mitosek, 1992). However, as stated by Robson & Chiew (2000), it is possible that changes are occurring but we do not yet have sufficient data for it to be detectable. In case of a weak trend, a series must be very long in order for the trend to be detected. Climate-related changes in flood frequency are complex, depending on the flood-generating mechanism. Flood magnitudes typically increase with warming if high flows result from heavy rainfall and decrease where they are generated by spring snowmelt (IPCC; 2001). Floods related to low-temperature effects (e.g. ice jams) have become less frequent in the warmer world (IPCC, 2001a).

Table 2. Sample of observed changes in high flows, reported in literature.

Location	Time period	Observation	Reference
Rhine at Cologne	1890-2000	Positive trend in annual maxima	Engel (1997)
Rivers in Southwest Germany	Last several decades	Increased frequency of occurrence of wet Wz (West cyclonic) atmospheric circulation in winter, resulting in high flows	Bárdossy & Caspary, 1990)
Four rivers in Germany	Long time series	Marked recent increase in the amplitude of floods. The 100-year-flood determined from the older data corresponds to much lower return periods (between 5 and 30-year-flood) for the more recent data.	Caspary (2000)
Rivers in Austria	1952-1991	Analysis of the full 40-year period results in detecting a positive trend in 66.3% of the cases with significant trend.	Nobilis & Lorenz (1997)
River Tay in Scotland	1978-1997	Number of flood-induced embankment failures on the in the time period 1988/9 to 1996/7 was nearly five times higher than in 1978/9-1987/8.	Gilvear & Black (1999)
Four rivers in Scotland	Last 30 years	General increase in river flow (including the maximum), being significantly stronger than the increase in rainfall over the same period.	Mansell (1997)
UK, ca. 600 streamgauges	Long time series (from 15 to over 100 years)	Significant non-stationarity in annual maxima and peak-over-threshold (POT) variables. More incidences of increased flooding than decreasing flooding, particularly in Scotland and in South East of England.	Robson & Reed (1996).
Upper Mississippi, Lower Missouri and Illinois rivers	Long series (up to nearly 120 years)	Past-to-present and present-to-past analysis of subsets of data (between 10 and 100 years of length) showed several significant, typically growing, trends.	Olsen *et al.* (1999)

There have been a plethora of studies of time series at a single stream gauge (cf. Table 2), reported in the literature. Several reports of significant changes detected in flow records at a single gauge encouraged researchers to extend the analysis into a truly spatial domain, to check whether or not a pattern observed at a single gauge has been reproduced in the neighbouring locations.

Yet, it would be a gross oversimplification to say that, based on studies reported in literature, in general, floods have exhibited growing trends worldwide. Only some series show a significant trend and out of those only some (yet, typically more than half) feature a positive trend, while others exhibit negative trends. The time series of flood data show a complex response (due to other, non-climatic factors), whose behaviour is not necessarily in tune with gross climate-related prognostications.

The finding in IPCC (2001a) is that the costs of extreme weather events have exhibited a rapid upward trend in recent decades and yearly economic losses from large events have increased ten-fold between 1950s and 1990s (in inflation-adjusted dollars). The insured portion of these losses has grown even stronger. Demographic and socio-economic trends are increasing society's exposure to floods and part of the observed upward trend in weather disaster losses is linked to socio-economic factors, such as increase in population, wealth, and developing settlements in vulnerable areas. As stated in IPCC (2001a), a part of losses is linked to climatic factors, such as the observed changes in precipitation and flooding events. However, even if precise attribution is complex, the growth in losses caused by non-weather related natural disasters has been far lower than of extreme weather-related events.

Major floods observed during the last decade in Southwest Germany occurred during the Wz (West cyclonic) pattern of atmospheric circulation in winter, whose increased frequency of occurrence was detected (Bárdossy & Caspary, 1990). Caspary (2000) analyzed time series of discharge in four rivers in Germany. After having smoothed the year-to-year oscillation of annual peak discharge, he found a marked recent increase in the amplitude of floods. He also compared floods of different recurrence intervals for two consecutive sub-periods. The 100-year-flood determined from the older data in the first sub-period corresponds to much lower return periods (between 5 and 30-year-flood) for the more recent data. Large flows are therefore becoming more frequent. However, no space-covering study placing these results in a truly regional perspective has been available yet.

Nobilis & Lorenz (1997) analyzed the flood trends in Austria. They considered different periods of observation (40 year-interval: 1952-1991 and parts thereof). Only in a portion of cases, a significant trend was detected. The quantitative results depended on the sub-period and the characteristics studied (whether annual maxima, or number of floods per year, or partial duration series). The portion of cases for which a significant trend was detected ranged from 4.3% to 31.5%. Among those cases where a significant trend was detected, there were more examples of positive trend (64.3%) than of negative trend (35.7%). Analysis of the full 40-year period results in detecting a positive trend in 66.3% of the cases with significant trend.

A comprehensive study of flood records has been conducted in the UK by Robson & Reed (1996). Using a data base consisting of ca. 600 stream gauges with long data series (from 15 to over 100 years), they presented a map of gauging stations in the UK exhibiting significant non-stationarity in annual maxima and peak-over-threshold (POT) variables. Figure 1, stemming from Robson & Reed (1996), shows a summary measure (trend gradient) plotted at the geographical location at each site, with type of trend and its intensity noted. Some regional features are visible in the results. There are more incidences of increased flooding than decreasing flooding, particularly in Scotland and in South East of England.

Olsen *et al.* (1999) looked into the distribution of long series (up to nearly 120 years) of flow records in the Upper Mississippi, Lower Missouri and Illinois rivers and their relationship to climate indices. In many gauges, large and statistically significant upward trends were detected. Past-to-present and present-to-past analysis of subsets of data (between 10 and 100 years of length) showed several significant correlations (with significance level of 99% or better in many cases), typically corresponding to growing trends.

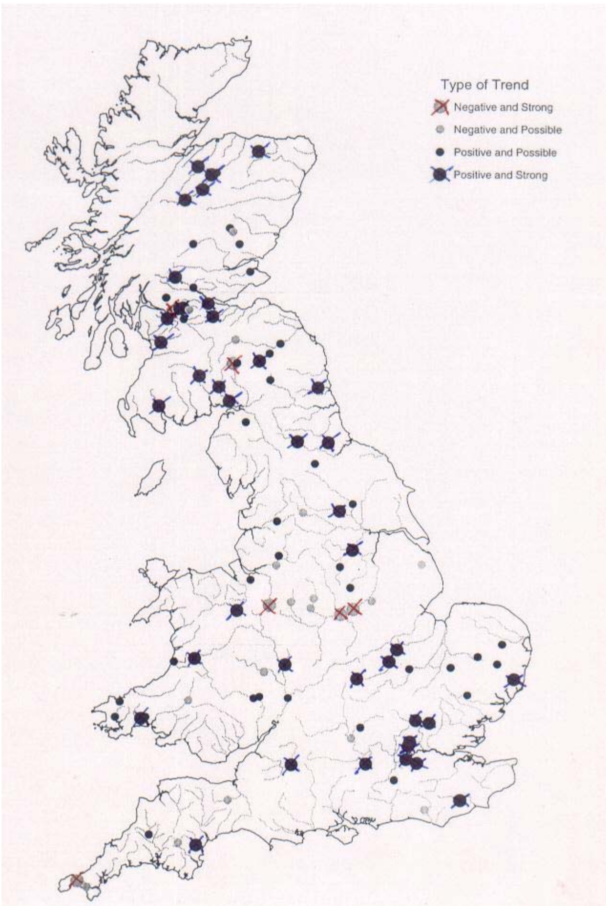

Fig 1. Summary measure (trend gradient) of high flows plotted at the geographical location, with type of trend and its intensity noted. Based on: Robson & Reed (1996)

Lins & Slack (1999) studied secular streamflow trends, using long series of daily data from 395 climate-sensitive stream gauging stations in the conterminous United States. When studying quantiles of discharge, they found that trends were least prevalent in the annual maximum (Q_{100}) category. For all, but the highest quantiles, streamflow has increased across broad areas of the US. These results were summarized as "getting wetter, but less extreme" (Lins & Slack, 1999).

In order to evaluate interdecadal streamflow variability Lins & Slack (1999) calculated quantile trends for 30-, 40-, 50-, 60-, 70-, and 80-year periods, all ending in 1993.

The principal results of Lins & Slack (1999) are summarized in Table 3 and Fig. 2. Table 3 shows the aggregate statistics illustrating changes of selected quantiles of streamflow. Figure 2 presents results of spatial studies of change in flow data, showing trends in percentiles of annual daily discharge.

Table 3. Aggregate statistics illustrating changes of selected quantiles of streamflow (based on results of Lins & Slack, 1999).

	Years of record					
	30	40	50	60	70	80
Beginning year	1964	1954	1944	1934	1924	1914
No. of stations tested	395	395	395	193	70	34
Annual minimum (daily mean) discharge						
No. of significant trends **(% of total)**	112 **(28%)**	177 **(45%)**	163 **(41%)**	85 **(44%)**	34 **(49%)**	13 **(28%)**
No. with increasing trend	74	145	127	76	32	10
Annual 30th percentile of daily discharge						
No. of significant trends **(% of total)**	109 **(28%)**	160 **(41%)**	135 **(34%)**	81 **(42%)**	28 **(40%)**	9 **(26%)**
No. with increasing trend	76	148	125	79	27	8
Annual 70th percentile of daily discharge						
No. of significant trends **(% of total)**	59 **(15%)**	130 **(33%)**	64 **(16%)**	58 **(30%)**	19 **(27%)**	9 **(18%)**
No. with increasing trend	55	124	61	58	19	6
Annual maximum (daily mean) discharge						
No. of significant trends **(% of total)**	37 **(9%)**	53 **(13%)**	35 **(9%)**	20 **(10%)**	9 **(13%)**	4 **(12%)**
No. with increasing trend	12	31	14	11	5	2

Since as many as 395 stations with at least 50-year series (1944-1993) were available, Lins & Slack analyzed not only 50-year records, but also 40-year (1954-1993) and 30-year (1964-1993) for all the stations. It can be observed that the trend in annual maxima is very sensitive to the choice of studied interval.

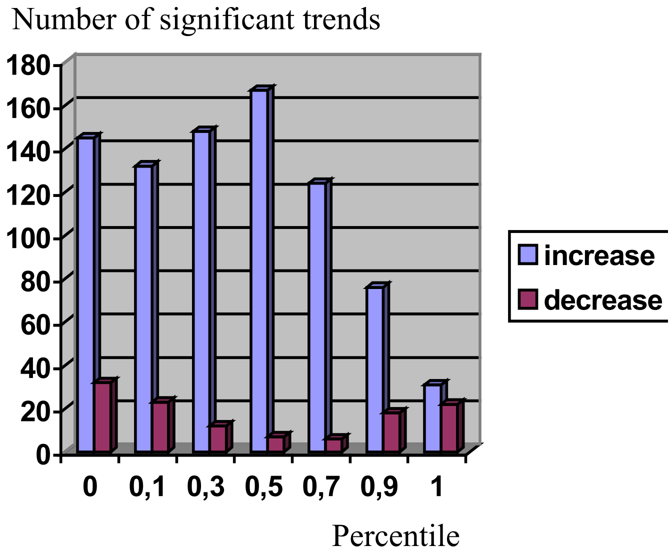

Fig 2. Presentation of results of change detection by Lins & Slack (1999) for 40-year-period (1954-1993) 395 stations, with 177 significant trends (significance level 0.05) detected. Notation used on x-axis, the numbers correspond to percentiles (0 stands for annual minimum, 0. 1 for 10th percentile, etc).

As shown in Fig. 2 and in Table 3, for 40-year interval, 1954-1993, 58.49% of all statistically significant trends in annual maximum flows were increasing trends, and relatively many (53 series, i.e. 13% of all records showed significant trends. However, results were quite different both for 30-year interval (1964-1993) and for 50-year interval (1944-1993). In both these cases, less series (9%) showed significant trend and the number of significant increasing trends was lower than the number of significant decreasing trends. For 30-year data, increase has occurred only in 32.4% of records with significant trends, while for 50-year data in 40% of records (decrease – in 67.6% and 60% respectively).

Pielke & Downton (2000) studied the rates of change in flood characteristics and socio-economic indicators in the USA in the time period from 1932 to 1997. They found that the total annual flood damage, adjusted for inflation, has grown in the average with the rate of 2.92% per year, that is more strongly than population (+1.26%) and tangible wealth per capita, in inflation-adjusted dollars (+1.85%) but less strongly than the net stock of fixed reproducible tangible wealth (+3.13%). They also found significant correlations of flood damage measures with several precipitation indices.

Zhang *et al.* (2001) analyzed trends in Canadian streamflow computed for the past 30-50 years for the 249 stations from the Canadian Reference Hydrometric Basin Network. They found that annual mean streamflow has generally decreased, with significant decreases detected in the southern part of the country. Significant negative trends are observed across much of southern Canada for annual maximum flow. The number of decreases noted is higher than the number of increases.

Chiew & McMahon (1993) stated that with the current data set, there is no clear evidence to suggest that the greenhouse signal is impacting on Australian streamflow. They showed that the detectability of change in the mean depends more on interannual variability and less on the length of data available. As the interannual variability of Australian streams is high, being twice as high as that in the Northern Hemisphere, the detection threshold is also high. If scenarios predicted by GCMs could be reached, then significant trends would be detected. Chiew & McMahon (1993) analyzed percentage changes in the means required in the future data set of 25 and 50 years to be considered as statistically different from the historic mean. They studied relationships between the historic data length, length of future data (since the trend commences), percentage change (strength of the trend), and coefficient of variation. For high values of the variation coefficient, long data records are needed to detect an existing trend; e. g., for $C_v = 1.48$; 76 to 88 years.

The links between flood-risk growth and climate variability and change have found extensive coverage in the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC, 2001, 2001a, Kundzewicz & Schellnhuber, 2003). In (IPCC, 2001a), floods have been ubiquitously identified on short lists of key regional concerns.

There are several factors influencing the process of river flow, so it is difficult to attribute the causes quantitatively. The longest existing Polish flow record of the river Warta, in Poznań, where daily values are available since 1822, has been subject to analyses of variability and change (e.g., Graczyk *et al*., 2002). Figure 3 shows the annual maximum flow, where a statistically significant decrease can be detected, whose origin is not likely to be attributed to climate.

Studying the complete time series does not give a persuading evidence as to the existence of a significant long-term trend in annual flow records. Therefore the search for a change can be performed at sub-sets of the complete record. Figure 4 presents fitting of linear regression to the annual minimum discharge data of the River Warta at Poznan (Poland), for 15 different

30-year intervals whose origins are shifted by one decade (1822–1851, 1832-1861,...,1962–1991). It can be seen that statistically significant increases and decreases been observed (growth in 11 cases and drop in 4 cases).

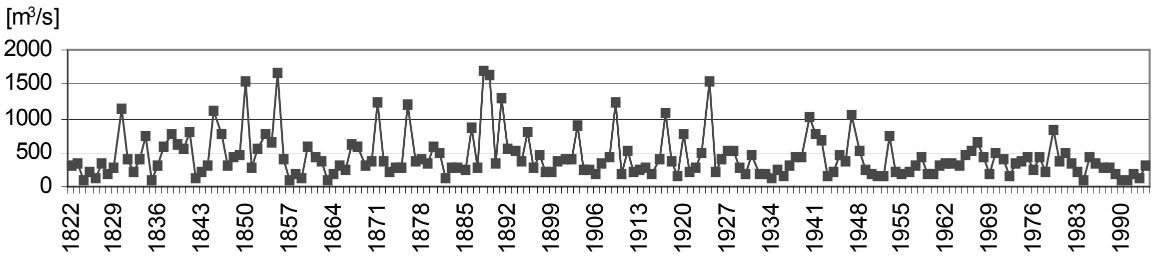

Fig. 3. Time series of annual maxima of flows of the river Warta in Poznań, 1822-1994.

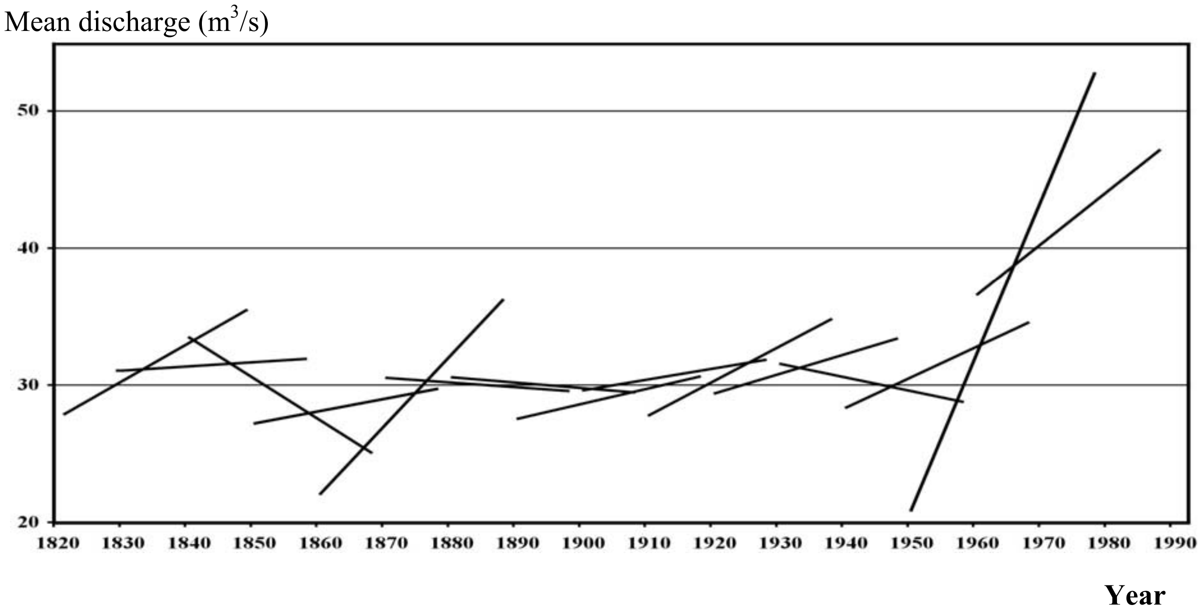

Fig. 4. Illustration of multi-decadal variability of minimum flow of the River Warta at Poznan – linear regression for 15 different 30-year intervals.

2.3 Changes in seasonality

An important change observed in flow data refers to seasonal characteristics (cf. Kundzewicz, 2002). River flow regimes, i. e. temporal distributions of flow, have considerably changed. It was reported from much of Europe that high flows come earlier in the year due to earlier snowmelt (sometimes in winter rather than spring) and less snow cover may reduce the severity of spring snowmelt floods. During warmer and wetter winters with less water storage in snow, increased flows are observed. It seems that, where the rivers freeze, milder winters lead generally to thinner ice cover and shorten persistence and reduce severity of ice jams.

Ice-jam floods are not a major problem anymore in much of Europe, where the rivers freeze less often in the warming climate (with industrial waste heat playing also a role in many locations). This finding has been corroborated by several authors, e.g. Mudelsee *et al.* (2003).

Beltaos & Prowse (2001) found that in Canada the trends in timing of freeze-up and breakup are consistent with concomitant changes in average temperature. Most stations show later freeze-up and earlier breakup. But, it is not only spring breakup but also winter thaws, which can lead to severe flood destruction, especially if a re-freeze follows soon. Increased incidence of mid-winter breakup events and higher freshet floods in certain parts of Canada could enhance the frequency and severity of ice jams. Destructive premature breakup, associated with rapid runoff (rapid melt and heavy rain) is a phenomenon of growing concern.

Krasovskaia & Gottschalk (2002) analysed river flow regimes in a changing climate. They discovered that changes in climate conditions influence regularity of seasonal flow pattern and dimensionality of flow regimes in Scandinavia.

2.4 Links with climatic variability

Studies of links between hydrological extremes and climatic variability (e.g., oscillations in the Ocean-Atmosphere system, such as the El Niño–Southern Oscillation (ENSO) or North-Atlantic Oscillation (NAO) lead to interesting findings. The warm phase of ENSO (i.e., El Niño) has been unusual since the mid 1970s, when compared with those of the previous 100 years, becoming relatively more frequent, persistent and intense. This change of El Niño properties has been linked with likelihood of intensive precipitation and floods in some areas, such as the Atlantic side of Central America, Northwest Peru, and Central-Western and Pampas regions of Argentina (IPCC, 2001a). However, even if there seems to exist a link between the frequency of extreme flood events and the anomalies of Ocean-Atmosphere variability, no clear connections for the magnitude of extreme floods have been detected (IPCC, 2001a).

3. Detection of change in annual maximum flow

3. 1 Data

As stated by Kundzewicz & Robson (2004) data are the backbone of any attempt to detect trend or other change in hydrological data. Hence results the importance of properly preparing and understanding the data, and the necessity of using accurate and meaningful data. Data should be quality-controlled *before* commencing an analysis of change. Examples of problems linked to the data that can cause apparent change in a data series are:

- Typographical errors;
- Instruments malfunctioning (zero-drift, bias);
- Change in measurement techniques, instrumentation, or instrument location;
- Change in accuracy of data, or changes of data units;
- Changes in data conversions (e.g. altered rating equations).

A great deal of uncertainty results from the need of extrapolation of rating curve (stage-discharge relationship) to high values, where no direct flow measurements exist. Missing values and gaps are further complicating factors. It is difficult to give a general advice as to how to deal with them: whether or not to fill missing values and gaps, and if so, in what way?

Selection of which stations to use in a study is also important (cf. Kundzewicz & Robson, 2004). For example, the issue of detecting a climate change signature in river flow data is very complex because the process of river flow is the integrated result of several factors, such as precipitation inputs, catchments storage and evaporation losses but also the river training measures taken over time and the morphological processes changing the river conveyance (Pinter *et al*., 2003, 2001). Furthermore, climate change signals may be overshadowed by strong natural background variability. These factors mean that particular care is needed in selecting data and sites for use in studying climate change. In order to study climate change signature in river flow records, data should ideally be taken from pristine / baseline rivers and should be of high quality and extend over a long period. Where pristine sites are not available, it may be possible to eliminate other influences or reconstruct natural flows, or using conceptual flow naturalization. Hence, catchments featuring strong changes in land-use and land-cover change (e.g. deforestation, urbanization), river regulation (e.g. dikes or dams) are not appropriate. Detailed suggestions as to how to select a network of stations for climate change detection are given in Pilon (2000). However, since GRDC metadata only cover very basic features of the gauging stations our ability of rational selection was severely constrained.

The study is limited to a subset of data holdings of Global Runoff Data Centre in Koblenz, Germany (GRDC, 2003). Out of more than a thousand long time series made available by GRDC, a dataset consisting of 195 long series of daily mean flow records was selected for use in this study. They have been subject to some quality control both in GRDC and within this study. Regional distribution of data, following the official WMO division into regions, is presented in Table 4. Unfortunately, the coverage is not uniform with many stations in three regions (North America, Australia and the Pacific, and Europe) and few stations in other three (Africa, Asia, and South America).

Table 4. Number of stations in regions.

Region	**Number of stations**
Africa	4
Asia	8
South America	3
North America	70
Australia and the Pacific	40
Europe	70
TOTAL	**195**

The choice of stations has been made based on the following criteria:

- Availability of long series (the longer the better); at least 40 years of data (few exceptions in areas with scarce data).
- Topicality (records ending as recently as possible – ideally, but rarely, in 2002, preferably at least in late 1990s, few exceptions, e.g. 1986 in the areas with scarce data).
- No such gaps admitted in the records, which could contaminate the series of annual maxima. Whether or not to fill missing values and gaps in data, and if so, in what way, is a complex issue, but in the present study they were not filled. If there are gaps, data are only conditionally useful for studies of annual maxima (in case of clear flood seasonality, if gaps occur in a non-flood season, they can be ignored (e.g., gaps in

autumn in a catchment subject to snowmelt flooding). Problems arise if data gaps result from destruction of a gauge. Consequence of such a gap is that high flow are missed.

- Geographic distribution (avoiding many neighbouring stations).
- Priority – smaller catchments (more likely to be without strong anthropogenic influence), especially in the developed countries.

It would be ideal if the datasets were available in common time intervals, e.g. 1953-2002. However, this turned out to be totally unrealistic.

Even weakening the conditions specified above, it was not possible to find many long time series of complete data in Africa, Asia, and South America. Hence, as shown in Table 4, only 4, 8, and 3 stations were selected, respectively, in these regions.

3.2 Methodology

Introduction to methodology given in this report follows Kundzewicz & Robson (2004). Change in a series can occur in numerous ways: e.g. gradually (a *trend*), abruptly (a *step-change*) or in a more complex form and may affect the mean, median, variance, autocorrelation or almost any other aspect of the data. In the present study, the daily flow data serve to identify annual maximum flow values for every station. The obtained time series of annual maximum flow were subject to testing for a presence of change. Further work in the Project will include a complementary study of partial duration series (peak over threshold, POT).

3.2.1 Hypothesis testing

In order to carry out a statistical test, it is necessary to define the null and alternative hypotheses; which describe what the test is investigating. To test for a significant change in the annual maximum flow of a series, the null hypothesis (H_0) is that there is no change, and the alternative hypothesis (H_1) is that the annual maximum flow is changing, i.e. either increasing or decreasing over time. In carrying out a statistical test one starts by assuming that the null hypothesis is true, and then checks whether the observed data are consistent with this hypothesis. The null hypothesis is rejected if the data are not consistent with H_0. To compare between the null and the alternative hypotheses a test statistic is selected and then its significance is evaluated, based on the available evidence. The test statistic is simply a numerical value that is calculated from the data series of annual maximum flows subject to testing.

The *significance level* (SL) measures whether the test statistic is very different from the range of values that would typically occur under the null hypothesis. Thus a 95% significance level would be interpreted as strong evidence against the null hypothesis – with a 1 in 20 chance of that conclusion being wrong. That is, there is a 5% (i.e. 100% - 95%) probability that we incorrectly rejected the hypothesis and detected a trend when none is present (5% probability of the type I error). Another type of error (type II error) occurs when the null hypothesis is incorrectly accepted when in fact the alternative hypothesis is true (i.e. we fail to detect a trend when one is present). A test that has low type II error probability is said to be powerful and more powerful tests are to be preferred.

3.2.2 Assumptions

In carrying out a statistical test it is always necessary to consider assumptions. Many standard tests require some or all of the following assumptions (cf. Kundzewicz & Robson, 2004):

A specified form of distribution (e. g. assuming that the data are normally distributed)
This assumption is violated if the data do not follow the specified distribution.

Constancy of the distribution (i.e. all data points have an identical distribution)
This assumption is violated if there are seasonal variations or any other cycles in the data, or if there is an alteration over time in the variance or any other feature of the data that is not allowed for in the test.

Independence
This assumption is violated if there is *autocorrelation* (correlation from one time value to the next: also referred to as *serial correlation* or *temporal correlation*).

Whether it is appropriate to use the classical test procedure, will depend on the assumptions that can be made about the data. This can be summarised as follows:

Case 1: Data are normally distributed and independent. However, this is an unlikely scenario for hydrological data.
Case 2: Data are non-normal, but are independent and non-seasonal. In this case, any of the basic distribution-free tests are suitable.
Case 3. Data are non-normal, and are not independent or are seasonal. In this case, the data do not meet the assumptions for any of the basic tests and it is necessary to use a resampling method to evaluate significance levels.

The situation analysed in the present study is represented by the Case 2 above. Extremes, such as series of annual maxima, generally have a positively skewed distribution. Each series was tested for independence between the annual maxima (and were largely found to be independent, see Section 3.3). The seasonal variation in flow is removed by the use of annual maxima rather than a continuous daily series.

The series of annual maxima were subject to two tests for independence: the median crossing test devised by Fisz (1963) and the turning point test (Kendall & Stuart, 1976). In both tests, the statistics is approximately normally distributed with mean and variance given analytically as function of the number of observations. The hypothesis that the sequence is generated by a random process is accepted if the value of the test statistics lies within the 95% confidence limits.

Due to the global coverage of the study, calendar years were used, since hydrological years start in different months in different areas.

If the assumptions made in a statistical test are not fulfilled by the data then test results can be meaningless, in the sense that estimates of significance level would be grossly incorrect. For example, data that is assumed to be independent when it is not, could result in a significance level of 95% when in reality it should only be 75% (insignificant case).

3.2.3 The Mann-Kendall test for trend

In this paper, the focus will be on a particular distribution-free method, the Mann-Kendall test, which is frequently applied to detect trends. This testing approach is selected because it allows the investigator to make minimal assumptions (constancy of distribution and independence) about the data. It is possible to avoid assumptions about the form of the distribution that the data derive from, e.g. there is no need to assume data are normally distributed.

The Mann-Kendall test belongs to a group of rank-based tests. Rank-based tests use the ranks of the data values (not the actual data values). A data point has rank r if it is the r^{th} largest value in a dataset. There are a number of widely used and useful rank-based tests. Most rank-based tests assume that data are independent and identically distributed. Rank based tests have the advantage that they are robust and usually simple to use. They are usually less powerful than a parametric approach. *The Mann-Kendall test* is a rank-based test, which is similar to *Spearman's rho* (same power and still based on ranks) but using a different measure of correlation, which has no parametric analogue. For details, see Kundzewicz & Robson (2000).

3.2.4 Significance level

When interpreting test results it is necessary to remember that no statistical test is perfect, even if all test assumptions are met. Assuming a 95% significance level means that an error will be made, on average, for 5% of the time.

If test results suggest that there is a significant change in a data series, then it is important to try to understand the cause. Although the investigator may be interested in detecting climate change, there may be many other possible explanations (Kundzewicz & Robson, 2004). Common causes of change include:

- Changes directly caused by man (urbanisation, reservoirs, drainage systems, water abstraction, land-use change, river training, river erosion etc);
- Natural catchment changes (e.g. natural changes in channel morphology);
- Climate variability;
- Climate change;
- Problems linked to data.

3.2.5 Climate variability and record length

It is very important to understand the difference between climate variability and change (cf. Kundzewicz & Robson, 2004), where the former is the natural variation in the climate from one period to the next, while the latter refers to a long-term alteration in the climate. Climate variability appears to have a very marked effect on many hydrological series. This has two important consequences:

- *Climate variability can cause apparent trend.* Climate variability can easily give rise to apparent trend when records are short – these are trends that would be expected to disappear once more data had been collected.
- *Climate variability obscures other changes.* Because climate variability is typically large, it can effectively obscure any underlying changes either due to climate change or to anthropogenic causes, such as urbanisation.

Data should consist of long time series of good quality records. Because of strong climate variability, records of 30 years or less are almost certainly too short for detection of climate change. It is suggested that *at least 50 years of record is necessary* for climate change detection (Kundzewicz & Robson, 2000), but even this may not be sufficient (cf. Chiew & McMahon, 1993). These demands, formulated for mean values, should be even stronger for extremes.

The best way to improve understanding of change is to gather as much information as possible. Examples include:

- Historical information about changes in the catchment, land-use change etc.
- Historical information about data collection methods etc.
- Data from nearby sites – if data from other nearby sites show similar patterns then the cause is probably widespread (e.g. linked to climate, or to extensive land-use change).
- Related variables – information on temperature and rainfall can help determine whether changes in flow can be explained by climatic factors
- Data that extend record lengths – a primary problem with many hydrological records is that they are too short. If related data can be obtained that extend to a longer period then this may be of assistance.

Unfortunately, this has not been possible in the present study.

3.2.6 Causes of change

Finding a significant change in time series of river flow data by statistical testing is not difficult if a change results from a major human intervention in the river regime, such as, for instance, dam construction. It is far more difficult to find a gradual change (e. g., related to climatic impacts) in the behaviour of the extremes of flow, amidst strong natural variability.

The very issue of detecting a climate change signature in river flow data is complex. There is considerable evidence that increasing concentrations of greenhouse gases in the atmosphere cause global temperature rise. This, in turn, enhances evapotranspiration and precipitation in most areas, thus likely accelerating the hydrological cycle. Also the water vapour (major greenhouse gas) content of the atmosphere increases, which in turn may change cloud patterns and reflection of radiation. The feedback mechanisms seem are not yet well understood in quantitative terms. Runoff is basically a difference between precipitation and evapotranspiration (whose annual means are increasing in most cases), so the net effect on their difference is not intuitively clear, also because this difference is redistributed in time and space by river basin transfer functions. In order to detect a weak, if any, climate change component, it is necessary to eliminate other influences. Using data from pristine / baseline river basins is recommended. In case of a strongly modified (e. g. dammed) river, conceptual re-naturalization, i.e. reconstruction of the natural flow could be used (e. g. by calculating the flow, which would have occurred in the absence of an existing reservoir). However, re-naturalization, would involve complex modeling, which is not easily feasible in large catchments with many feedbacks between climate and anthropogenic change.

3.2.7 Complexity of the issue

Apart from the inherent complexity of the issue of detecting a greenhouse component in flow records, there are serious problems with the data with which to work, and also with the methodology to detect changes.

But, even if the data are perfect, it is worthwhile to re-state a tautology: extreme (hence rare) events are rare. They do not happen frequently, so even having a very long time series of instrumental records one deals with a small sample of truly extreme floods, of most destructive power.

In order to detect rigorously a weak greenhouse signal in a noisy, and highly variable, hydrological record, one needs an appropriate advanced methodology. Are trustworthy methodological tools available? The existing methods are based on three types of assumption commonly made when carrying out statistical tests: the form of the distribution, the constancy of it and the independence.

Radziejewski *et al.* (1998) compared performance of different tests for generated data contaminated by artificially introduced, and fully controlled, trends. All methods considered could detect stronger changes, in form of a gradual trend or abrupt jump, yet they could not detect weaker changes. The results of detection for short-lasting change (analogous to climate variability effects) were different for different tests. Beyond the "strength" of the trend or step-change, duration of occurrence of a trend is important (cf. Pittock, 1980, Chiew & McMahon, 1993). It is unlikely to detect a trend that has not continued for a long time – the run-up phase must be appropriately long.

3.3 Results and discussion

3.3.1 Independence between annual maxima

The two tests for independence; the median crossing test devised by Fisz (1963) and the turning point test (Kendall & Stuart, 1976), showed that non-randomness was indicated in very few series of annual maxima. These series were excluded from the classical Mann-Kendall analysis. Using classical Mann-Kendall test for non-random (dependent) data could result in incorrect estimation of the significant level (cf. Kundzewicz & Robson, 2000). An appropriate value could be obtained by using resampling technique. Yet, since the number of non-random series was small, it was decided to ignore them, rather than using two different techniques.

Due to the global coverage of the study, calendar years were used, since hydrological years start in different months in different areas.

3.3.2 Trends in annual maximum river flows

The analysis of 195 long time series of annual maximum flows, stemming from the GRDC holdings does not support the hypothesis of growth of flood flows. Even if 27 cases of strong, statistically significant increase have been identified, there are 31 decreases as well, and most (137) time series do not show any significant changes.

In Appendix A, the time series of annual maximum flow for 195 stations analyzed in this study are presented. For each station, the following information is given: GRDC station number, geographic coordinates, catchment area, time period of data (year of beginning and end of the time series), results of the Mann-Kendall's test (value of test statistic and significance level) and maximum flow value ever observed. All time series of annual maxima are also presented for the possibility of visual inspection. Regression line is given for illustration of a least-squares fit; direction parameter in the regression equation indicates the direction of changes (positive for increase and negative for decrease). The variance of the data series that is explained by the regression line, r^2, is also given. Identification of regions (first digit of the GRDC station number) is in accordance with WMO region numbering scheme (1 – Africa, 2 – Asia, 3 – South America, 4 – North America, 5 – Australia and the Pacific, 6 – Europe).

Appendix B, organized after WMO regions, contains a set of two maps and a diagram for each region, visualizing the results. The first map for each region shows the direction and significance of changes – circles with black fill denote increase and hatched circles – decrease. Only large circles represent statistically significant trends (90% level).

The second series of maps for each region illustrates the year of occurrence of the highest maximum flow. This is important in order to check whether indeed the number of maxima observed since 1990s is higher than in other decades. Finally, visualization of the duration of the series and specification of the year of occurrence of the maximum flow value is offered in a diagram for each region.

Indeed, is several cases, the highest flow was observed after 1990. In some series, listed in Table 5, generally decreasing trend was observed, but the highest flow stems from 1990s.

However, occurrence of one single, very high flow is largely random. For example, in a number of cases compiled in Table 6, the highest value in a long time series was more than twice as high as the second highest annual maximum flow.

Table 5. Time series of maximum annual flow showing decreases, with highest value observed after 1990.

No.	River, station, country	Area (km^2)	Year of highest flow
2964122	Chao Phraya, Khai Chira Prawat, (TH)	110569	1995
2964130	Chao Phraya, Wat Pho Ngam (Ban Re Rai), (TH)	120639	1995
6731300	Etna, Etna, (NO)	557	1995
6731410	Atna, Atnasjo, (NO)	465	1995
6731570	Klara, Nybergsund, (NO)	4410	1995

Table 6. Occurrences of extreme annual maximum flows, being considerably higher than a second highest annual maximum flow.

No.	River, station, country	Highest annual maximum flow (m^3/s) (year of occurrence in asterisks)	Second highest annual maximum flow (year of occurrence in asterisks)
4103630	Chena River, Fairbanks, (US)	1809 (1967)	456 (1960)
4103650	Salcha River, Near Salchaket, (US)	2635 (1967)	879 (1986)
4121120	Cannonball River, Breien, (US)	1767 (1959)	851 (1997)
4122100	Elkhorn River, Waterloo, (US)	2626 (1944)	1246 (1952)
4122650	Missouri, Nebraska, (US)	10 920 (1952)	5796 (1944)
4125026	Neosho River, Near Parsons, (US)	10 248 (1951)	2517 (1986)
4148300	Pee Dee, Pee Dee (US)	6076 (1945)	2797 (1979)
5302320	Moorabool River, Batesford, (AU)	316 (1995)	163 (1978)
6142100	Morava, Moravicany, (CZ)	567 (1974)	247 (1941)
6338130	Ems, Rheine Unterschleuse Up, (DE)	920 (1946)	472 (1960)

Hence, analysis of annual maximum flows only is loaded with high random component, as the time series of annual maxima conveys information on some extremes only. Advantages of this approach are as follows: it is a straightforward and well established concept. Disadvantages are: it is not unlikely that there are more days with high flow or even more than one high flow event in any one year (e.g. 1997 Odra/Oder, 1998 Yangtze, 2002 Danube floods). On the other hand, in some years no extreme flows occur at all, hence elements of the time series of annual maximum flow may contain as well values that are not really high. Hence analyzing quantiles or all peaks above a particular threshold is advisable, as foreseen in a further stage of the Project.

The techniques of partial duration series (PDS), called also peaks-over-threshold (POT), lend themselves well to applications.

Africa, Asia and South America

For these three continents, the dataset consisting of long time series fulfilling all the conditions specified in 3.1 is very small.

For Africa, among four long time series of annual maxima, three show statistically significant (over 90%) changes, therein two decreases (1134100: Niger, Koulikoro, ML, and 1734600: Sota, Couberi, BJ), and one increase (1160510: Groot-Vis, Brandt Legte Piggot's Bridge, ZA).

Table 7. Significant changes in Africa.

Significant increases			
Station No.	River, station, country	Data period	Significance level
1160510	Groot -Vis, Brandt Legte Piggot's Bridge, (ZA)	1943-2000	98.71
Significant decreases			
Station No.	River, station, country	Data period	Significance level
1134100	Niger, Koulikoro, (ML)	1907-1987	90.14
1734600	Sota, Couberi, (BJ)	1954-1986	99.97

For Asia, among eight stations, three statistically significant changes (all decreases) were found – 2964122: Chao Phraya, Khai Chira Prawat, TH; 2964130: Chao Phraya, Wat Pho Ngam (Ban Re Rai), TH and 2903430: Lena, Stolb, RU) but two of them were highly significant (level above 99%)

Table 8. Significant changes in Asia.

Significant decreases			
Station No.	River, station, country	Data period	Significance level
2964122	Chao Phraya, Khai Chira Prawat, (TH)	1956-1999	99.97
2964130	Chao Phraya, Wat Pho Ngam (Ban Re Rai), (TH)	1950-1999	99.64
2903430	Lena, Stolb, (RU)	1951-1994	92.51

None of the South American stations analyzed showed a significant trend in annual maxima.

North America

Out of 70 time series, 26 show statistically significant changes (14 increases and 12 decreases). Table 9 presents stations where significant changes (at the level of 90%) have been observed.

Table 9. Significant changes in North America.

Significant increases			
Station No.	River, station, country	Data period	Significance level
4113300	Red River of the North, Grand Forks, (US)	1904-1999	99.9
4115310	Kettle River, Near Ferry, (US)	1929-1999	95.91
4119080	St. Croix River, St. Croix Falls, (US)	1910-1999	98.97
4119285	Raccoon River, Van Meter, (US)	1916-1999	92.69
4119322	Spoon River, Seville, (US)	1915-1999	95.96
4119650	Mississippi, Clinton, (US)	1900-1999	90.29
4121160	White River, Near Oacoma, (US)	1929-1999	91.68
4122100	Elkhorn River, Waterloo, (US)	1929-1999	99.95
4123111	Little Wabash River, Carmi, (US)	1940-1999	98.80
4123278	New River, Near Galax, (US)	1931-1999	99.18
4147410	Branch River, Forestdale, (US)	1941-1999	97.10
4147440	Pawcatuck River, Westerly, (US)	1941-1999	92.15
4147540	Saddle River, Lodi, (US)	1924-1999	99.99
4148051	James, Cartersville, (US)	1900-1999	92.36

Significant decreases			
Station No.	River, station, country	Data period	Significance level
4103630	Chena, River, Fairbanks, (US)	1947-1999	99.34
4103650	Salcha River, Near Salchaket, (US)	1949-1999	98.79
4116300	Clearwater River, Spalding, (US)	1926-1999	99.66
4123150	Hiwassee River, Above Murphy (US)	1898-2000	99.99
4123351	Allegheny River, Eldred, (US)	1940-1999	92.16
4150503	Brazos River, Seymour, (US)	1924-1999	99.85
4152550	Green, Green River, (US)	1906-1999	99.99
4207180	Nechako, Isle Pierre, (CA)	1951-1996	90.99
4207380	Fraser River, Red Pass, (CA)	1956-1996	97.46
4207800	Thompson, Near Spences Bridge(CA)	1952-1996	97.85
4214210	Beaver River, Cold Lake Reserve, (CA)	1956-1996	99.95
4215150	Barnes Creek, Near Needles, (CA)	1951-1996	94.30

Australia and the Pacific

Five time series of annual maximum flow showed significant decreases, while in one case (5171200: East Branch off Nf Wailua, Near Lihue, US), a significant increase was observed.

Table 10. Significant changes in Australia and the Pacific

Significant increases			
Station No.	River, station, country	Data period	Significance level
5171200	5171200: East Branch of Nf Wailua, Near Lihue, (US)	1920-1995	93.47

Significant decreases			
Station No.	River, station, country	Data period	Significance level
5202227	Suggan Buggan River, Suggan Buggan, (AU)	1958-2001	94.53
5204105	Murrumbidgee River, Mittagang Crossing, (AU)	1927-2000	99.48
5302250	Thomson River, Cooper Creek, (AU)	1956-2001	99.34
5606100	Blackwood River, Darradup, (AU)	1955-1998	90.28
5606130	Murray River (South West Au), Baden Powell Wtr Sp, (AU)	1953-2000	96.24
5171200	5171200: East Branch Of Nf Wailua, Near Lihue, (US)	1920-1995	93.47

Europe

European data consist of time series collected at 70 stations, therein 17 in Germany, 15 in Norway, 13 in the United Kingdom, 12 in Finland, 5 in Sweden, 2 in both - Czech Republic and Romania.

As intuitively expected, it is not uncommon that gauges located not far from each other (at different rivers) behave in a different way (for example station No. 6609400 – Avon, Evesham (GB), coordinates: 52.06 N and 1.56W and station No. 6609500 – Severn, Bewdley (GB), coordinates: 52.37 N and 2.32 W).

Out of 70 time series, 20 show statistically significant changes (11 increases and 9 decreases). Table 8 presents stations where significant changes (at the level of 90%) have been observed.

Table 8. Significant changes in Europe.

Significant increases			
Station No.	River, station, country	Data period	Significance level
6335100	Rhine River, Kaub, (DE)	1931-2002	97.52
6335125	Kinzig, Schwaibach, (DE)	1921-2000	98.71
6335350	Lahn, Leun (Neu), (DE)	1936-2001	91.58
6607650	Thames, Kingston, (GB)	1883-2000	93.38
6608200	Teifi, Glan Teifi, (GB)	1960-2000	91.83
6609400	Avon, Evesham, (GB)	1937-1999	92.57
6731165	Gaular, Viksvatn, (NO)	1903-2000	98.68
6731200	Vosso, Bulken, (NO)	1892-2000	99.3
6731610	Fusta, Fustvatn, (NO)	1909-2000	90.95
6854600	Iijoki, Raasakka (Near The Mouth), (FI)	1911-2001	98.6
6855500	Karjaanjoki, Lohjanjarvi-Peltokoski, (FI)	1938-2001	98.38

Significant decreases			
Station No.	River, station, country	Data period	Significance level
6335301	Main, Schweinfurt, (DE)	1845 to 2000	99.51
6335500	Main, Wuerzburg, (DE)	1824 to 2001	99.35
6337400	Weser, Hann.-Muenden, (DE)	1831 to 2000	99.96
6545200	Krka, Podbocje, (SI)	1933 to 1999	94.92
6609500	Severn, Bewdley, (GB)	1922 to 2001	96.46
6731160	Nausta, Nausta, (NO)	1909 to 2000	95.94
6731280	Austena, Austena, (NO)	1925 to 2000	97.0
6731300	Etna, Etna, (NO)	1920 to 2000	99.2
6731455	Otta, Lalm, (NO)	1914 to 2000	92.93

The lengths of data series are not the same, yet 69 datasets started before 1960 and one in 1960. Hence, it is interesting to examine the number of occurrences of the highest maximum annual flow in particular decades. It turns out that from 1990 to 2000, as many as 17 occurrences of highest maximum annual flow were noted (some records extend into early 2000s, in one case – up to 2002). Less occurrences of highest annual maximum flows have been noted in earlier decades (11 in 1980-1989, 7 in 1970-1979, and only 4 in 1960-1969). In seven cases, the highest maximum annual flow occurred in 1950s, and in 25 cases, before 1950 (in several cases of long time series – in 19th century.

4. Concluding remarks

Destructive floods observed in the last decade all over the world have led to record high material damage. The immediate question emerges, as to the extent in which this sensible rise of flood hazard and vulnerability can be documented in analysis of time series of hydrological variables (river flow) and whether it can be linked to climate variability and change.

Several projections for the future show likelihood of increase in intense precipitation and flood hazard in the warmer climate. There has been no conclusive and general proof as to how climate change affects flood behaviour, in the light of data observed so far. Several studies support the hypothesis that severe floods are becoming more frequent, while other publications report contradictory evidence, where a non-stationary behaviour of flood series could not be detected or when the finding was: “wetter but less extreme”. There is a discontinuity between some observations made so far, where increase in flood maxima is not evident (e.g. Mudelsee *et al*., 2003) and model-based projections for the future, which show increase.

In further stages of this project, it would be adviceable to extend the analysis of annual maxima by using percentiles of flows, or peak-over-threshold method (with possibly several thresholds).

The inherent uncertainty in analysis of any set of global maxima stems from the fact that accuracy of measuring extreme flows is problematic (rating curves needed, gauges destroyed, observers evacuated, yet – indirect determination of the highest stage is often possible).

It would be useful to attempt to describe deterministically the reasons for atypical behaviour of some series (as compared to their spatial neighbourhood). Here, influence of a local event (e.g., flood resulting from a very high-intensity local storm, reservoirs, polders, flood control) could play an important role.

A closer look into particularities of individual stations concerned would be needed to discriminate driving factors. Since this information is not available in the GRDC holdings, there is a need to augment the collected data by accommodating more detailed metadata with more information about a station, including history of river development for navigation and energy generation. Analysis should also differentiate the flood generation mechanisms (snowmelt *vs* rainfall). In the present study, all floods treated as one category, due to lack of information on the causative factor.

A regional change in timing of floods has been observed in many areas, with increasing late autumn and winter floods. Less ice-jam-related floods have been observed in Europe. Mudelsee *et al*. (2003) demonstrated clear decrease in ice-jam floods at the Elbe and the Oder. This has been a robust result (IPCC, 2001a).

It is difficult to disentangle the climatic component in the flood data subject to strong natural variability and influenced by man-made environmental changes: river training, barrage construction, urbanization, deforestation, human occupying hazardous areas, reduction in storage capacity and increase in runoff coefficient.

As stated in IPCC (2001), Technical Summary, “ the analysis of extreme events in both observations and coupled models is underdeveloped” and “the changes in frequency of extreme events cannot be generally attributed to the human influence on global climate.”

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Appendix A

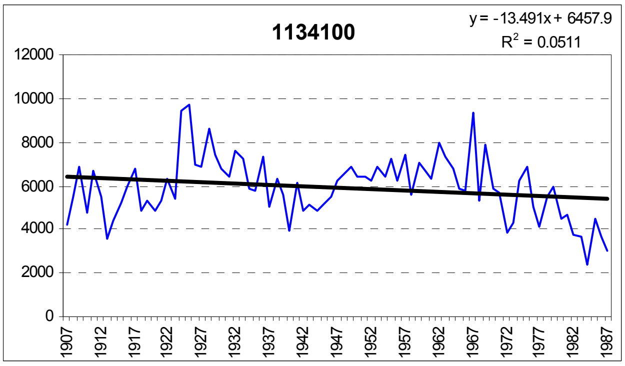
Region Nr 1 - Africa

1134100: Niger, Koulikoro (ML)
12.87 φ N, 7.55 λ W
Area: 120000 km^2

Data from 1907 to 1987 (81 years)

Mann-Kendall's test:
Test statistic: -1.65193
Significance level: 90.14%

Max: 9670 m^3/s in 1925

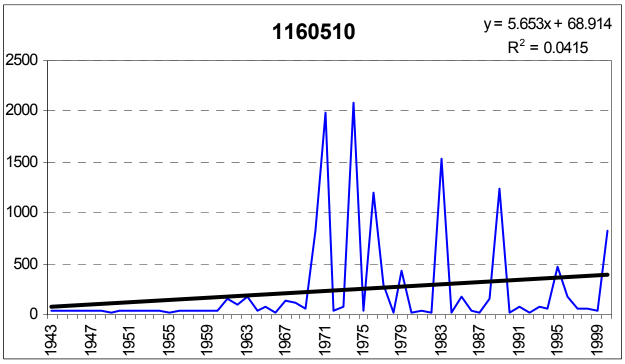


1160510: Groot-Vis, Brandt Legte Piggot's Bridge (ZA)
33.1 φ S, 26.45 λ E
Area: 23067 km^2

Data from 1943 to 2000 (58 years)

Mann-Kendall's test:
Test statistic: 2.4874
Significance level: 98.71%

Max: 2085 m^3/s in 1974

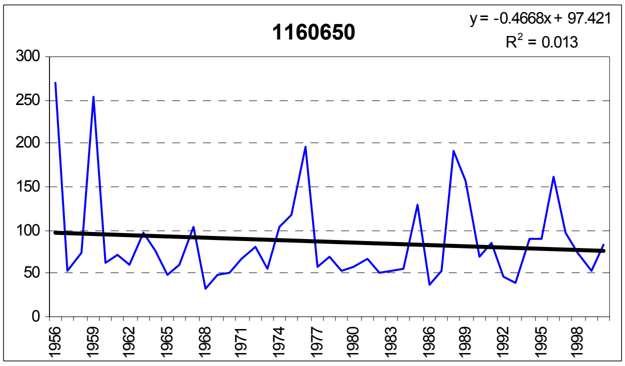


1160650: Mtamvuna, Gundrift (ZA)
30.73 φ S, 29.83 λ E
Area: 715 km^2

Data from 1956 to 2000 (45 years)

Mann-Kendall's test:
Test statistic: 0.039133
Significance level: 3.12%

Max: 271 m^3/s in 1956

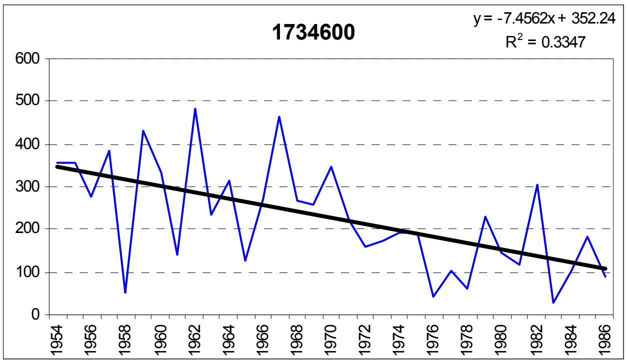


1734600: Sota, Couberi (BJ)
11.75 φ N, 3.33 λ E
Area: 13410 km^2

Data from 1954 to 1986 (33 years)

Mann-Kendall's test:
Test statistic: -3.64162
Significance level: 99.97%

Max: 484 m^3/s in 1962



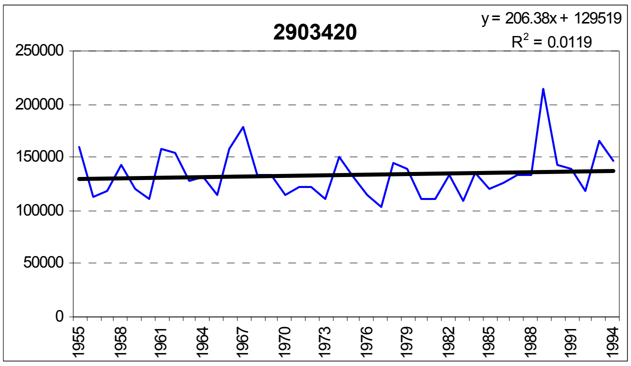
Region Nr 2 - Asia

2903420: Lena, Kyusyur (Kusur) (RU)
70.7 φ N, 127.65 λ E
Area: 2430000 km^2

Data from 1955 to 1994 (40 years)

Mann-Kendall's test:
Test statistic: 0.513017
Significance level: 39.20%

Max: 215000 m^3/s in 1989

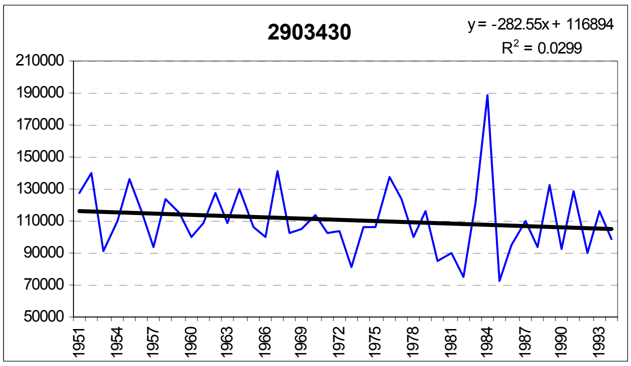


2903430: Lena, Stolb (RU)
72.37 φ N, 126.8 λ E
Area: 2460000 km^2

Data from 1951 to 1994 (44 years)

Mann-Kendall's test:
Test statistic: -1.78114
Significance level: 92.51%

Max: 189000 m^3/s in 1984

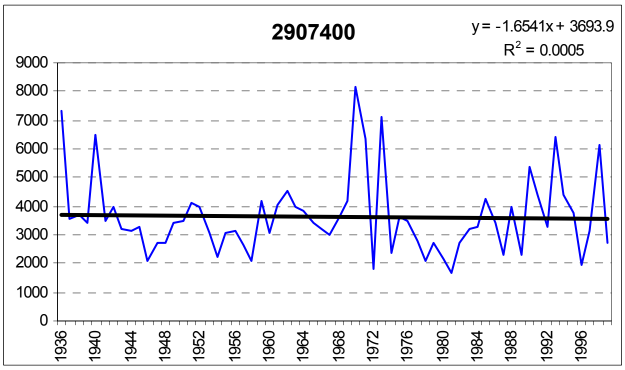


2907400: Selenga, Mostovoy (RU)
52.03 φ N, 107.48 λ E
Area: 440200 km^2

Data from 1936 to 1999 (64 years)

Mann-Kendall's test:
Test statistic: -0.370817
Significance level: 28.92%

Max: 8160 m^3/s in 1970

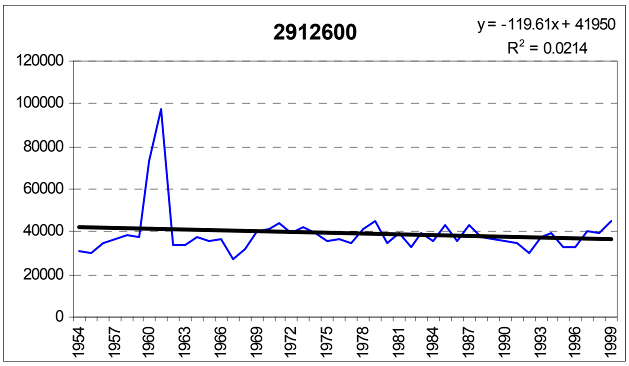


2912600: Ob, Salekhard (RU)
66.57 φ N, 66.53 λ E
Area: 2949998 km^2

Data from 1954 to 1999 (46 years)

Mann-Kendall's test:
Test statistic: 0.568267
Significance level: 43.1%

Max: 97200 m^3/s in 1961

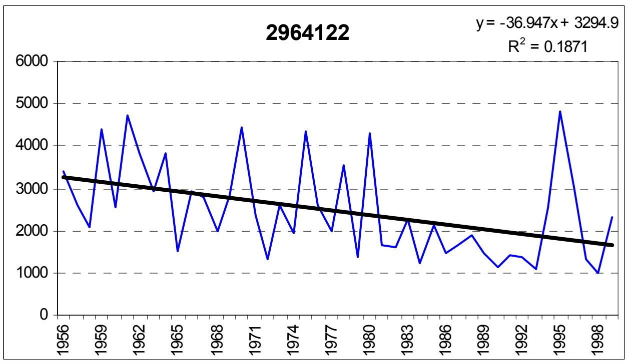


2964122: Chao Phraya, Khai Chira Prawat (TH)
15.67 φ N, 100.67 λ E
Area: 110569 km^2

Data from 1956 to 1999 (44 years)

Mann-Kendall's test:
Test statistic: -3.62091
Significance level: 99.97%

Max: 4820 m^3/s in 1995



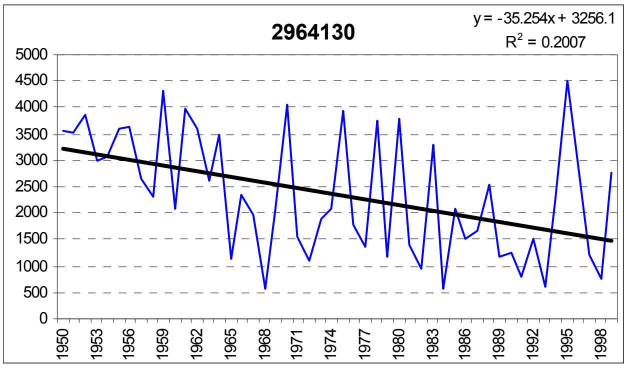
Region Nr 2 – Asia cont.

2964130: Chao Phraya, Wat Pho Ngam (Ban Re Rai) (TH)
15.17 φ N, 100.19 λ E
Area: 120693 km^2

Data from 1950 to 1999 (50 years)

Mann-Kendall's test:
Test statistic: -2.91528
Significance level: 99.64%

Max: 4501 m^3/s in 1995

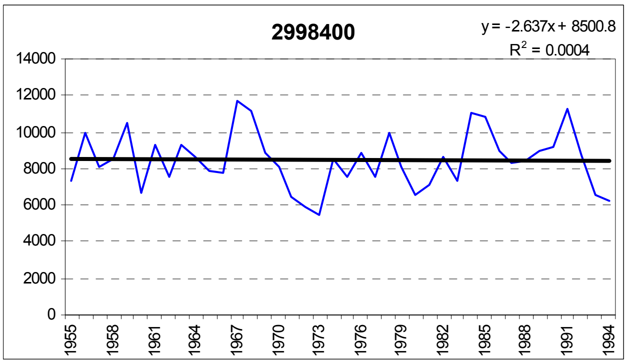


2998400: Indigirka, Vorontsovo (RU)
69.58 φ N, 147.35 λ E
Area: 305000 km^2

Data from 1955 to 1994 (40 years)

Mann-Kendall's test:
Test statistic: -0.0349555
Significance level: 2.78%

Max: 11700 m^3/s in 1967

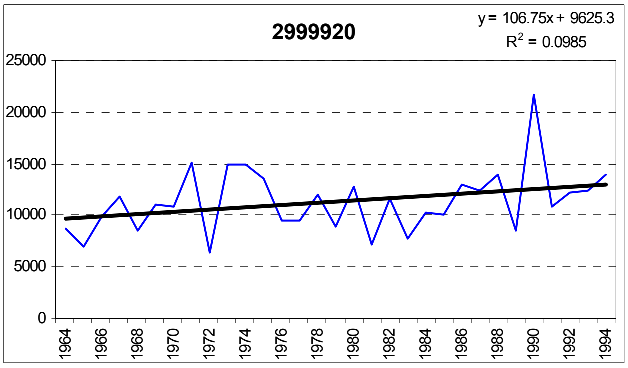


2999920: Olenek, Sukhana (RU)
68.62 φ N, 118.33 λ E
Area: 127000 km^2

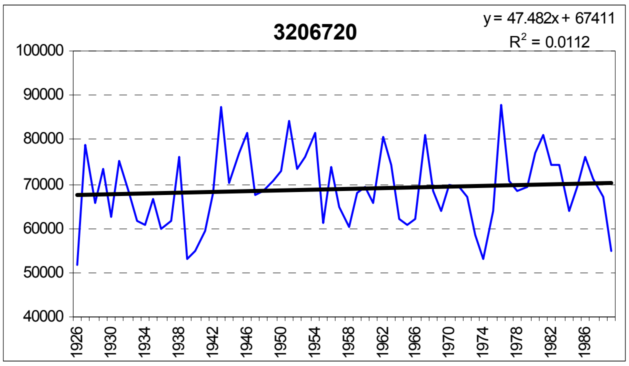
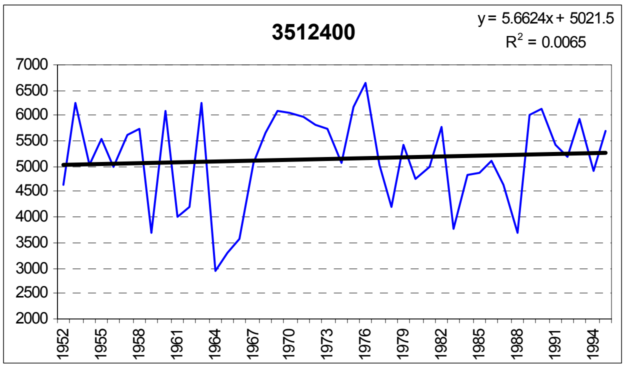
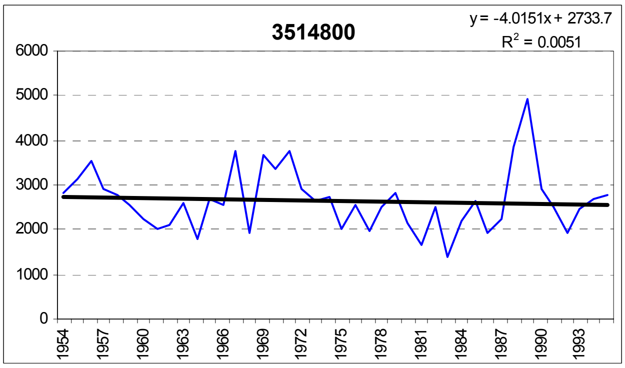
Data from 1964 to 1994 (31 years)

Mann-Kendall's test:
Test statistic: 1.59836
Significance level: 89.0%

Max: 21700 m^3/s in 1990



Region Nr 3 – South America

3206720: Orinoco, Puente Angostura (VE) 8.15 φ N, 63.6 λ W Area: 836000 km^2 Data from 1926 to 1989 (64 years) Mann-Kendall's test: Test statistic: 0.956028 Significance level: 66.9% Max: 87860 m^3/s in 1976	
3512400: Maroni, Langa Tabiki (GF) 4.98 φ N, 54.43 λ W Area: 60930 km^2 Data from 1952 to 1995 (44 years) Mann-Kendall's test: Test statistic: 0.1922 Significance level: 15.24% Max: 6640 m^3/s in 1976	
3514800: Oyapock, Maripa (GF) 3.82 φ N, 51.88 λ W Area: 25120 km^2 Data from 1954 to 1995 (42 years) Mann-Kendall's test: Test statistic: -1.09496 Significance level: 72.64% Max: 4920 m^3/s in 1989	

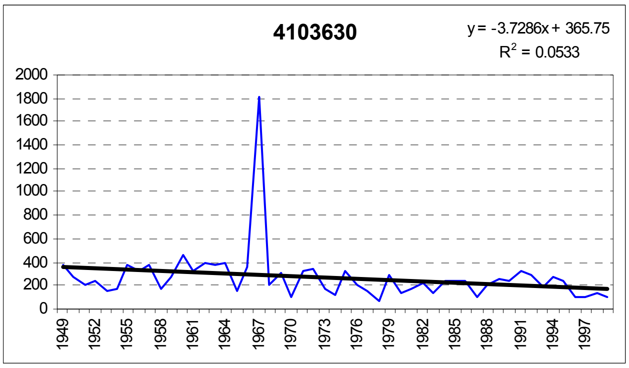
Region Nr 4 – North America

4103630: Chena River, Fairbanks (US)
64.85 φ N, 147.70 λ W
Area: 5167 km^2

Data from 1947 to 1999 (53 years)

Mann-Kendall's test:
Test statistic: -2.72094
Significance level: 99.34%

Max: 1809 m^3/s in 1967

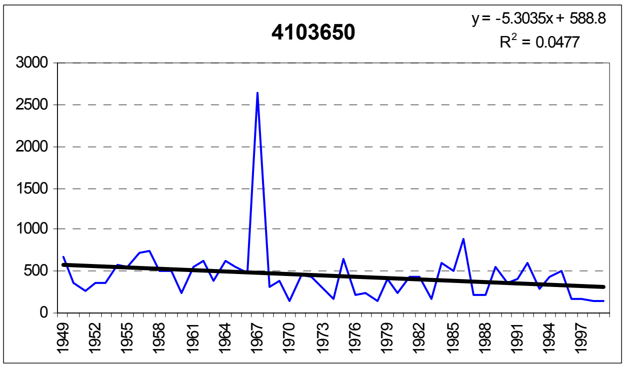


4103650: Salcha River, Near Salchaket (US)
64.47 φ N, 146.92 λ W
Area: 5620 km^2

Data from 1949 to 1999 (51 years)

Mann-Kendall's test:
Test statistic: -2.50993
Significance level: 98.79%

Max: 2635 m^3/s in 1967

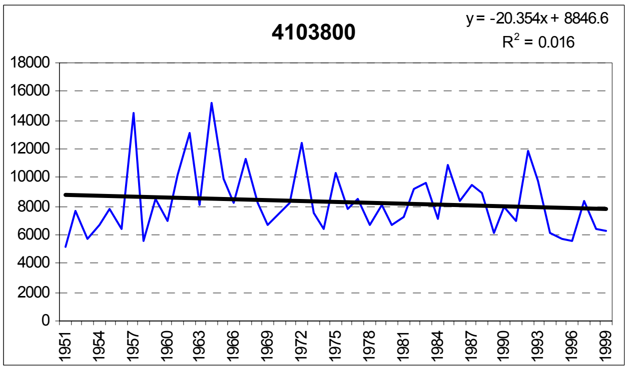


4103800: Yukon, Eagle (US)
64.79 φ N, 141.20 λ W
Area: 293965 km^2

Data from 1951 to 1999 (49 years)

Mann-Kendall's test:
Test statistic: -0.525869
Significance level: 40.10%

Max: 15260 m^3/s in 1964

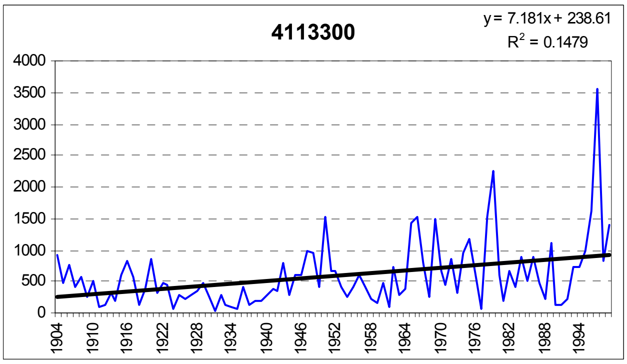


4113300: Red River Of The North, Grand Forks (US)
47.93 φ N, 97.03 λ W
Area: 77959 km^2

Data from 1904 to 1999 (96 years)

Mann-Kendall's test:
Test statistic: 3.31726
Significance level: 99.90%

Max: 3556 m^3/s in 1997

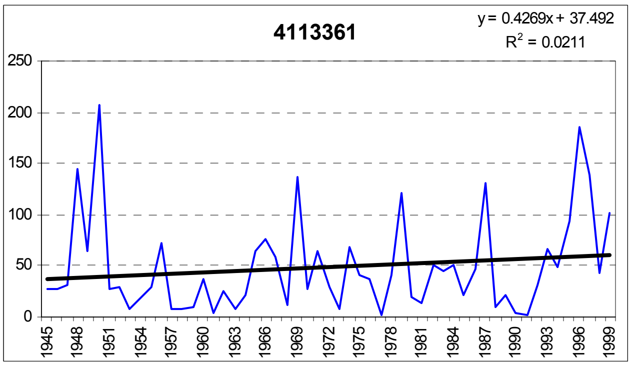


4113361: Sheyenne River, Near Cooperstown (US)
47.43 φ N, 98.02 λ W
Area: 16757 km^2

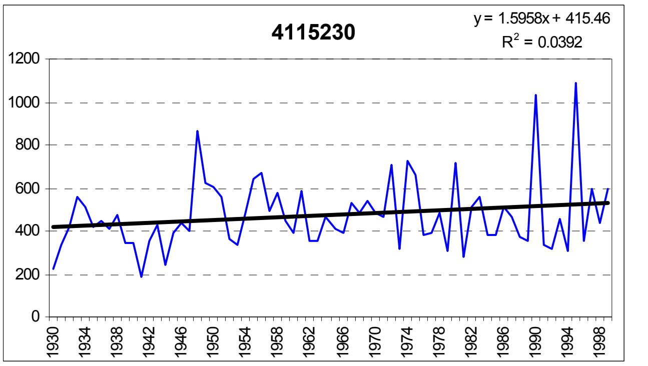
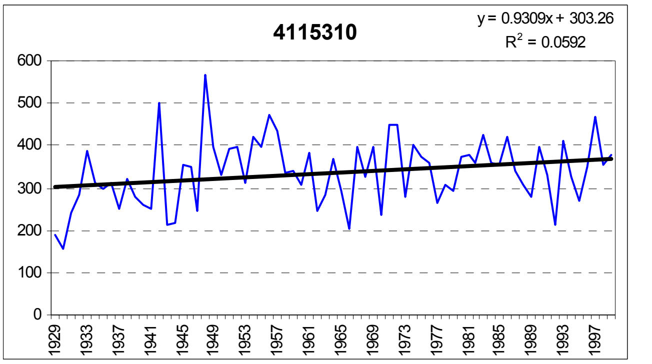
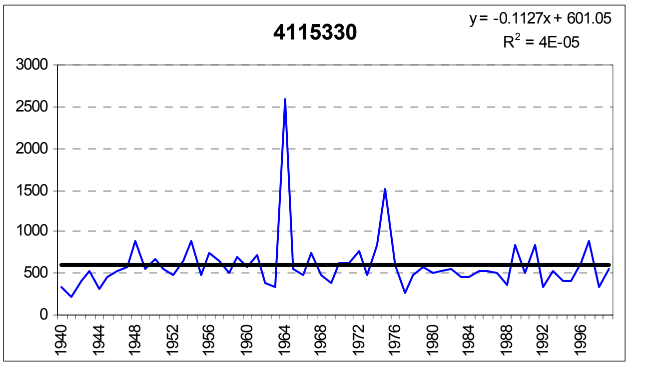
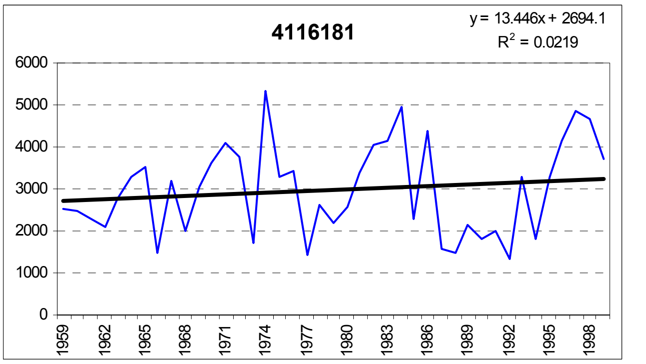
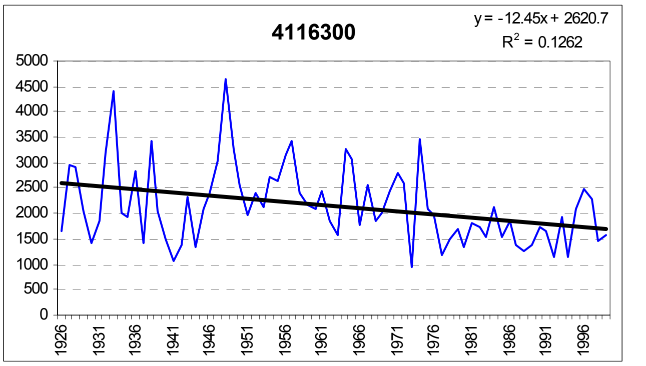
Data from 1945 to 1999 (55 years)

Mann-Kendall's test:
Test statistic: 1.27778
Significance level: 79.86%

Max: 207 m^3/s in 1950



Region Nr 4 – North America cont.

4115230: Wenatchee River, Peshastin (US) 47.58 φ N, 120.61 λ W Area: 2590 km^2 Data from 1930 to 1999 (70 years) Mann-Kendall's test: Test statistic: 0.806186 Significance level: 57.98% Max: 1089 m^3/s in 1995	
4115310: Kettle River, Near Ferry (US) 48.98 φ N, 118.76 λ W Area: 5750 km^2 Data from 1929 to 1999 (71 years) Mann-Kendall's test: Test statistic: 2.04553 Significance level: 95.91% Max: 568 m^3/s in 1948	
4115330: Middle Fork Flathead River, Near West Glacier (US) 48.50 φ N, 114.01 λ W Area: 2921 km^2 Data from 1940 to 1999 (60 years) Mann-Kendall's test. Test statistic: -0.108436 Significance level: 8.63% Max: 2596 m^3/s in 1964	
4116181: Snake River, Near Anatone (US) 46.10 φ N, 116.98 λ W Area: 240766 km^2 Data from 1959 to 1999 (41 years) Mann-Kendall's test: Test statistic: 0.92129 Significance level: 64.31% Max: 5348 m^3/s in 1974	
4116300: Clearwater River, Spalding (US) 46.44 φ N, 116.82 λ W Area: 24786 km^2 Data from 1926 to 1999 (74 years) Mann-Kendall's test: Test statistic: -2.9355 Significance level: 99.66% Max: 4648 m^3/s in 1948	

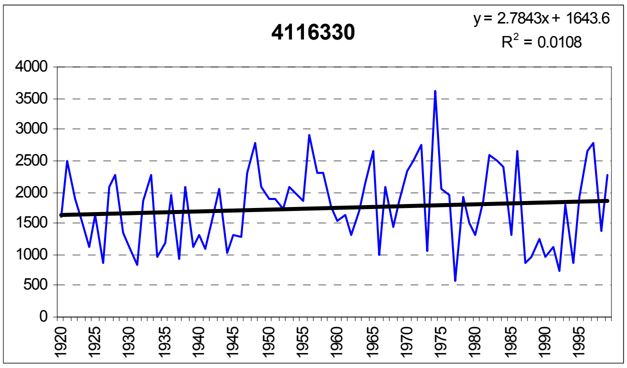
Region Nr 4 – North America cont.

4116330: Salmon River, White Bird (US)
45.75 φ N, 116.32 λ W
Area: 35094 km^2

Data from 1920 to 1999 (80 years)

Mann-Kendall's test:
Test statistic: 0.955605
Significance level: 66.7%

Max: 3612 m^3/s in 1974

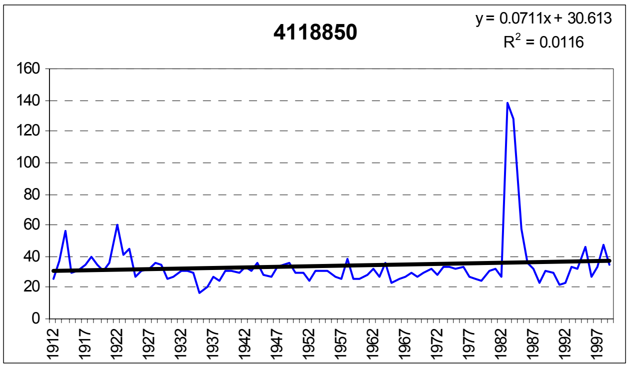


4118850: Sevier River, Juab (US)
39.37 φ N, 112.04 λ W
Area: 13377 km^2

Data from 1912 to 1999 (88 years)

Mann-Kendall's test:
Test statistic: -0.540757
Significance level: 41.13%

Max: 138 m^3/s in 1983

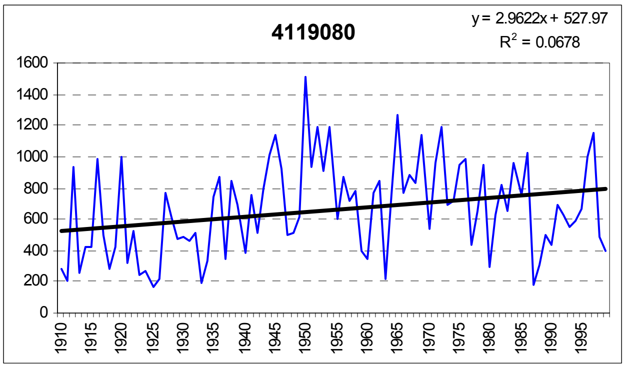


4119080: St. Croix River, St. Croix Falls (US)
45.40 φ N, 92.64 λ W
Area: 16161 km^2

Data from 1910 to 1999 (90 years)

Mann-Kendall's test:
Test statistic: 2.5688
Significance level: 98.97%

Max: 1509 m^3/s in 1950

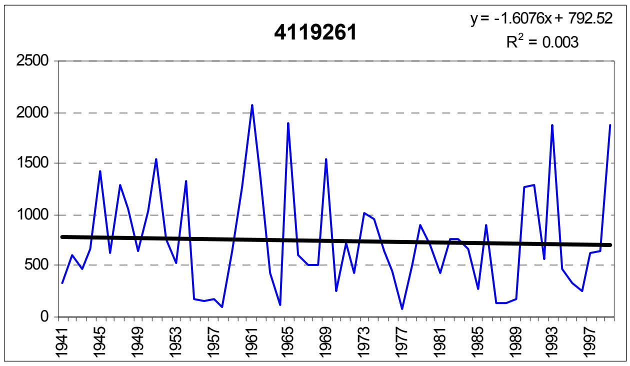


4119261: Cedar River, Waterloo (US)
42.49 φ N, 92.33 λ W
Area: 13328 km^2

Data from 1941 to 1999 (59 years)

Mann-Kendall's test:
Test statistic: -0.614778
Significance level: 46.12%

Max: 2072 m^3/s in 1961

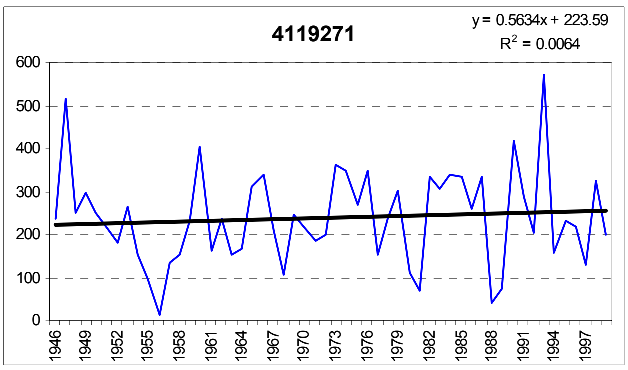


4119271: South Skunk River, Near Oskaloosa (US)
41.36 φ N, 92.66 λ W
Area: 4235 km^2

Data from 1946 to 1999 (54 years)

Mann-Kendall's test:
Test statistic: 0.522272
Significance level: 39.85%

Max: 571 m^3/s in 1993



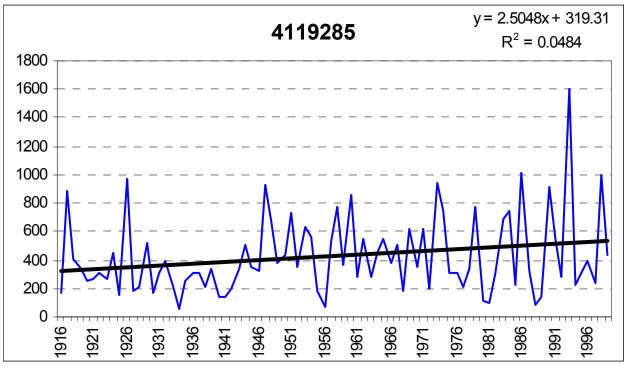
Region Nr 4 – North America cont.

4119285: Raccoon River, Van Meter (US)
41.53 φ N, 93.94 λ W
Area: 8912 km^2

Data from 1916 to 1999 (84 years)

Mann-Kendall's test:
Test statistic: 1.79265
Significance level: 92.69%

Max: 1610 m^3/s in 1993

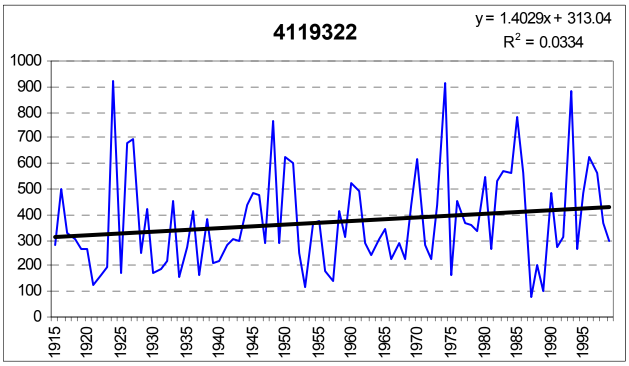


4119322: Spoon River, Seville (US)
40.49 φ N, 90.34 λ W
Area: 4237 km^2

Data from 1915 to 1999 (85 years)

Mann-Kendall's test:
Test statistic: 2.04971
Significance level: 95.96%

Max: 918 m^3/s in 1924

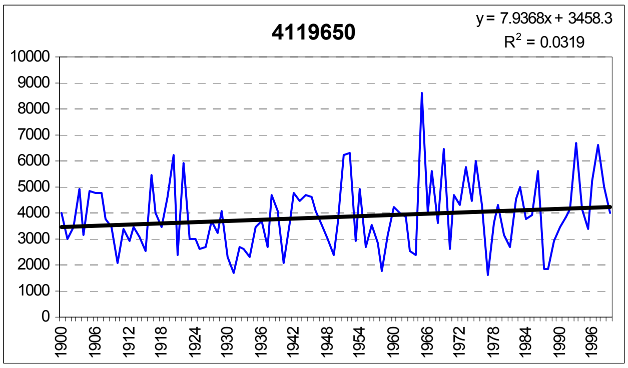


4119650: Mississippi,Clinton (US)
41.78 φ N, 90.25 λ W
Area: 221704 km^2

Data from 1900 to 1999 (100 years)

Mann-Kendall's test:
Test statistic: 1.65921
Significance level: 90.29%

Max: 8596 m^3/s in 1965

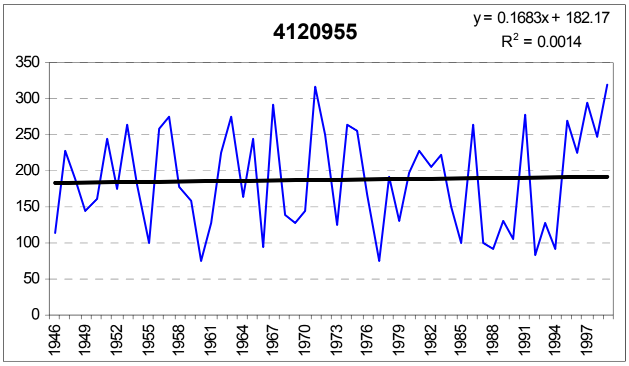


4120955: Wind River, Near Crowheart (US)
43.24 φ N, 109.01 λ W
Area: 4898 km^2

Data from 1946 to 1999 (54 years)

Mann-Kendall's test:
Test statistic: 0.164143
Significance level: 13.3%

Max: 319 m^3/s in 1999

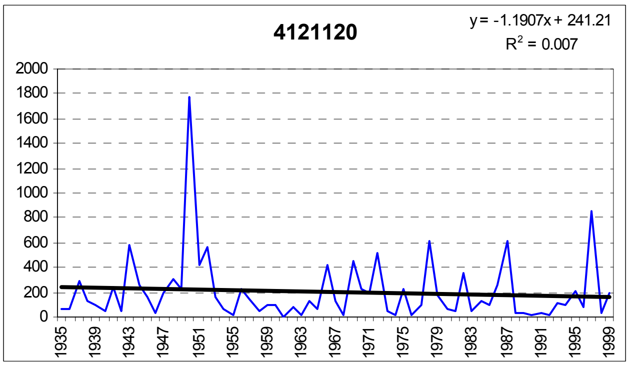


4121120: Cannonball River, Breien (US)
46.37 φ N, 100.93 λ W
Area: 10619 km^2

Data from 1935 to 1999 (65 years)

Mann-Kendall's test:
Test statistic: -1.17761
Significance level: 76.10%

Max: 1767 m^3/s in 1950



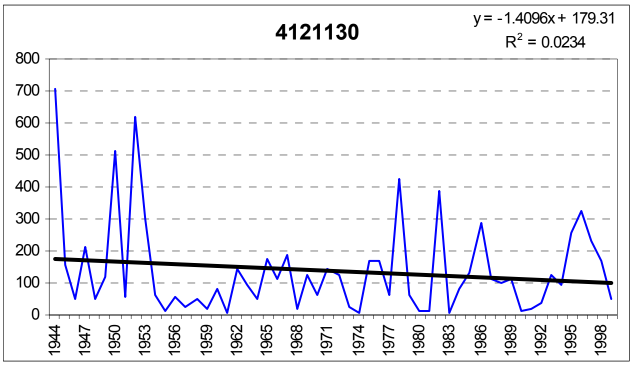
Region Nr 4 – North America cont.

4121130: Moreau River, Near Faith (US)
45.19 φ N, 102.15 λ W
Area: 6889 km^2

Data from 1944 to 1999 (56 years)

Mann-Kendall's test:
Test statistic: -0.0565459
Significance level: 4.50%

Max: 708 m^3/s in 1944

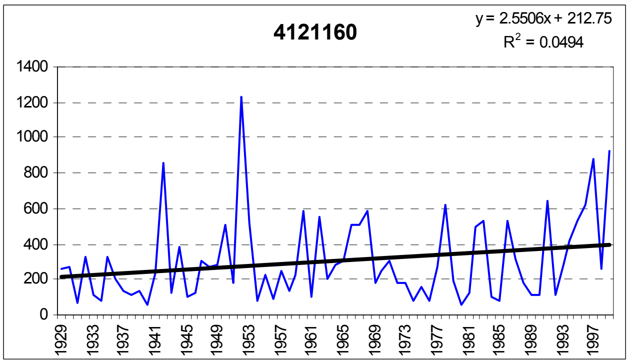


4121160: White River, Near Oacoma (US)
43.74 φ N, 99.55 λ W
Area: 26418 km^2

Data from 1929 to 1999 (71 years)

Mann-Kendall's test:
Test statistic: 1.73245
Significance level: 91.68%

Max: 1232 m^3/s in 1952

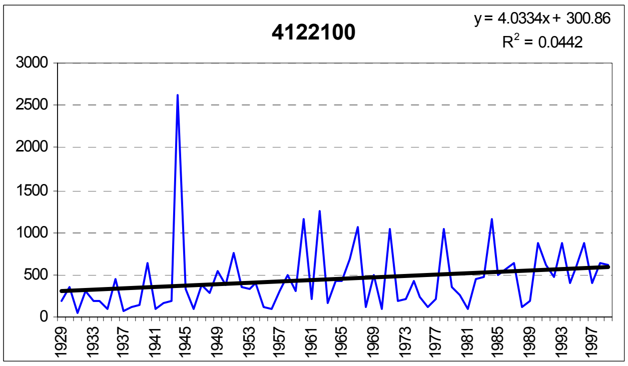


4122100: Elkhorn River, Waterloo (US)
41.29 φ N, 96.28 λ W
Area: 17871 km^2

Data from 1929 to 1999 (71 years)

Mann-Kendall's test:
Test statistic: 3.50454
Significance level: 99.95%

Max: 2626 m^3/s in 1944

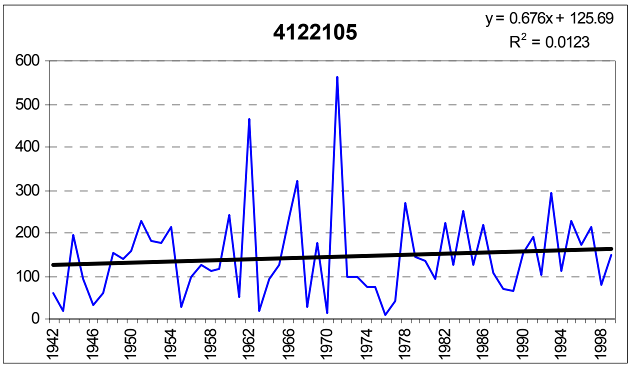


4122105: Logan Creek, Near Uehling (US)
41.71 φ N, 96.52 λ W
Area: 2668 km^2

Data from 1942 to 1999 (58 years)

Mann-Kendall's test:
Test statistic: 1.17395
Significance level: 75.95%

Max: 563 m^3/s in 1971

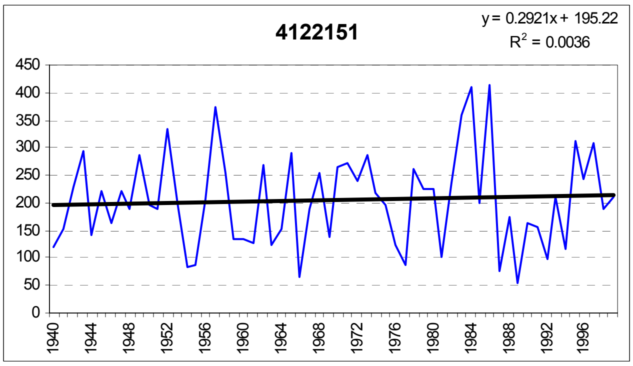


4122151: North Platte River, Above Seminoe Reservoire Nr Sinclair (US)
41.87 φ N, 107.05 λ W
Area: 10813 km^2

Data from 1940 to 1999 (60 years)

Mann-Kendall's test:
Test statistic: 0.325294
Significance level: 25.50%

Max: 414 m^3/s in 1986



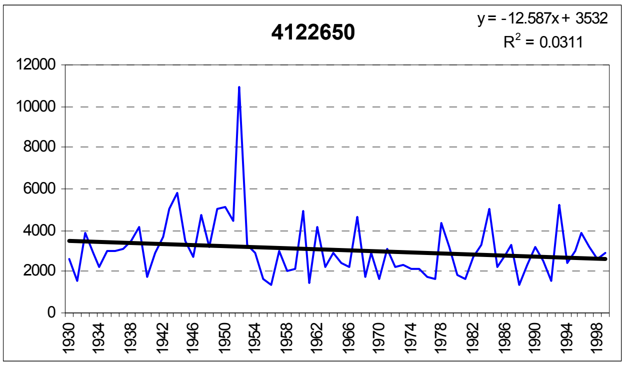
Region Nr 4 – North America cont.

4122650: Missouri, Nebraska (US)
40.68 φ N, 95.85 λ W
Area: 1072154 km^2

Data from 1930 to 1999 (70 years)

Mann-Kendall's test:
Test statistic: -1.25747
Significance level: 79.14%

Max: 10920 m^3/s in 1952

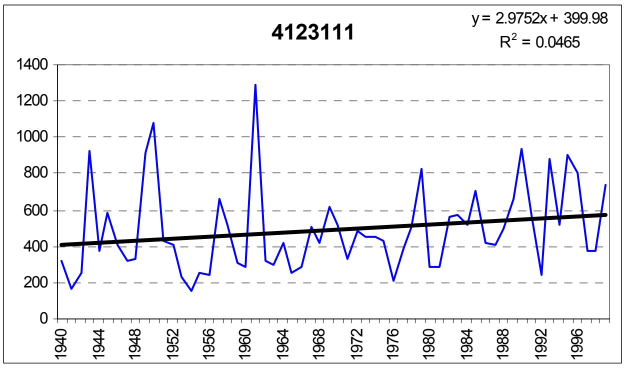


4123111: Little Wabash River, Carmi (US)
38.06 φ N, 88.16 λ W
Area: 8034 km^2

Data from 1940 to 1999 (60 years)

Mann-Kendall's test:
Test statistic: 2.51324
Significance level: 98.80%

Max: 1288 m^3/s in 1961

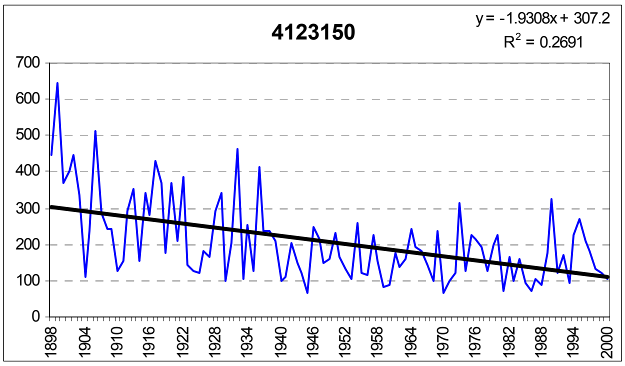


4123150: Hiwassee River, Above Murphy (US)
35.08 φ N, 84.00 λ W
Area: 469 km^2

Data from 1898 to 2000 (103 years)

Mann-Kendall's test:
Test statistic: -4.86435
Significance level: 99.99%

Max: 647 m^3/s in 1899

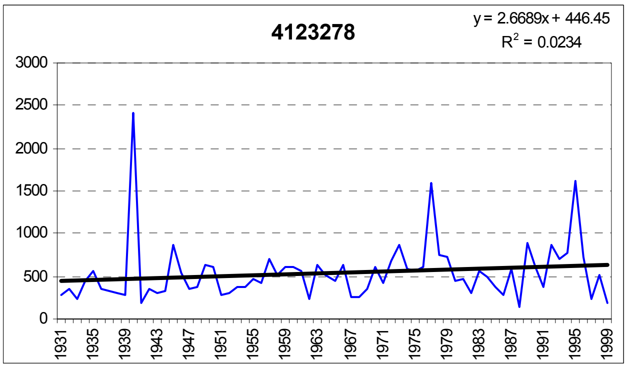


4123278: New River, Near Galax (US)
36.65 φ N, 80.98 λ W
Area: 2929 km^2

Data from 1931 to 1999 (69 years)

Mann-Kendall's test:
Test statistic: 2.64734
Significance level: 99.18%

Max: 2414 m^3/s in 1940

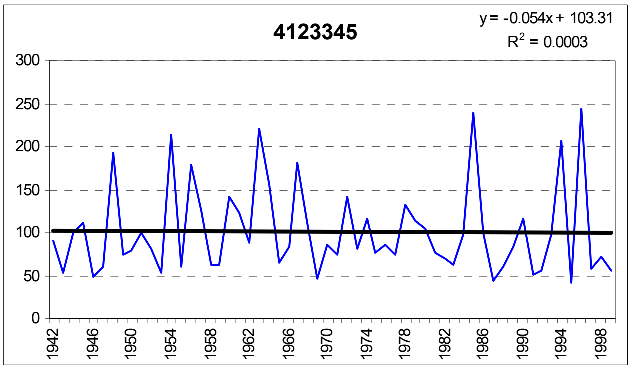


4123345: Youghiogheny River, Near Oakland (US)
39.42 φ N, 79.43 λ W
Area: 347 km^2

Data from 1942 to 1999 (58 years)

Mann-Kendall's test:
Test statistic: -0.74462
Significance level: 54.34%

Max: 245 m^3/s in 1996



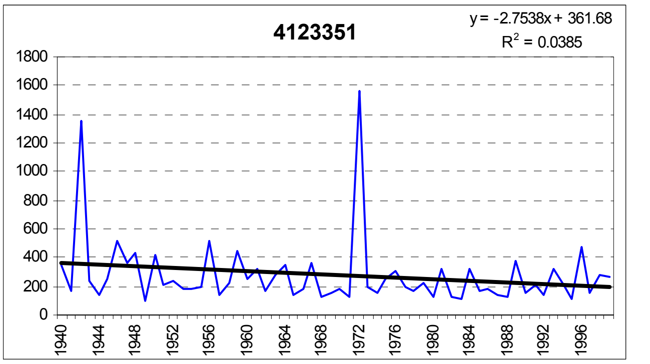
Region Nr 4 – North America cont.

4123351: Allegheny River, Eldred (US)
41.96 φ N, 78.39 λ W
Area: 1424 km^2

Data from 1940 to 1999 (60 years)

Mann-Kendall's test:
Test statistic: -1.76048
Significance level: 92.16%

Max: 1560 m^3/s in 1972

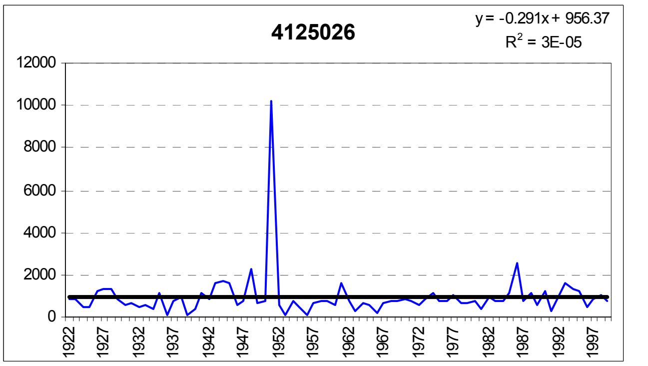


4125026: Neosho River, Near Parsons (US)
37.34 φ N, 95.11 λ W
Area: 12704 km^2

Data from 1922 to 1999 (78 years)

Mann-Kendall's test:
Test statistic: 1.13481
Significance level: 74.35%

Max: 10248 m^3/s in 1951

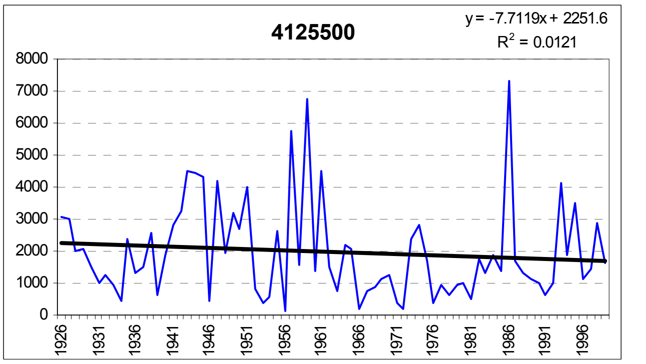


4125500: Arkansas, Tulsa (US)
36.14 φ N, 96.01 λ W
Area: 193253 km^2

Data from 1926 to 1999 (74 years)

Mann-Kendall's test:
Test statistic: -1.08272
Significance level: 72.10%

Max: 7308 m^3/s in 1986

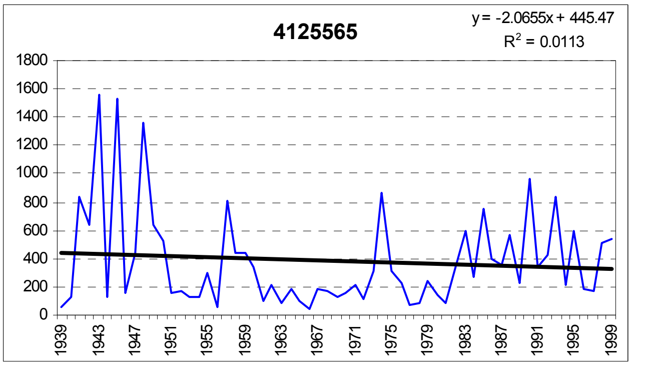


4125565: Deep Fork, Near Beggs (US)
35.68 φ N, 96.07 λ W
Area: 5227 km^2

Data from 1939 to 1999 (61 years)

Mann-Kendall's test:
Test statistic: 0.889928
Significance level: 62.64%

Max: 1557 m^3/s in 1943

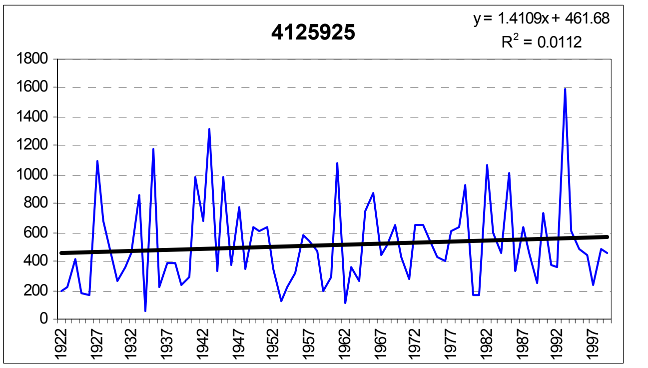


4125925: James River, Galena (US)
36.81 φ N, 93.46 λ W
Area: 2556 km^2

Data from 1922 to 1999 (78 years)

Mann-Kendall's test:
Test statistic: 1.2254
Significance level: 77.95%

Max: 1596 m^3/s in 1993



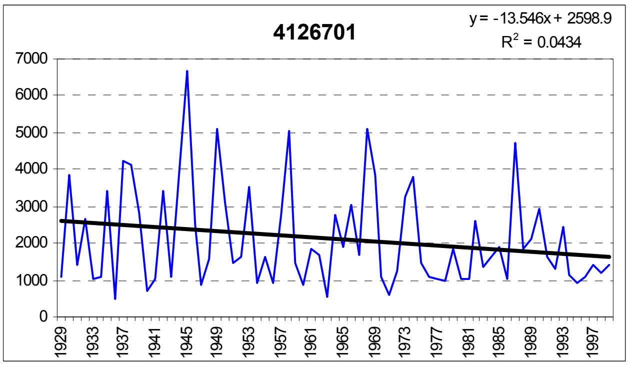
Region Nr 4 – North America cont.

4126701: Quachita, Camden (US)
33.59 φ N, 92.82 λ W
Area: 13874 km^2

Data from 1929 to 1999 (71 years)

Mann-Kendall's test:
Test statistic: -1.06226
Significance level: 71.18%

Max: 6664 m^3/s in 1945

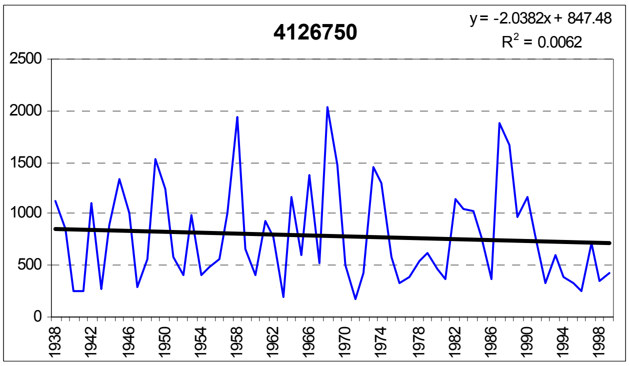


4126750: Saline River, Near Rye (US)
33.70 φ N, 92.02 λ W
Area: 5444 km^2

Data from 1938 to 1999 (62 years)

Mann-Kendall's test:
Test statistic: -0.710694
Significance level: 52.27%

Max: 2030 m^3/s in 1968

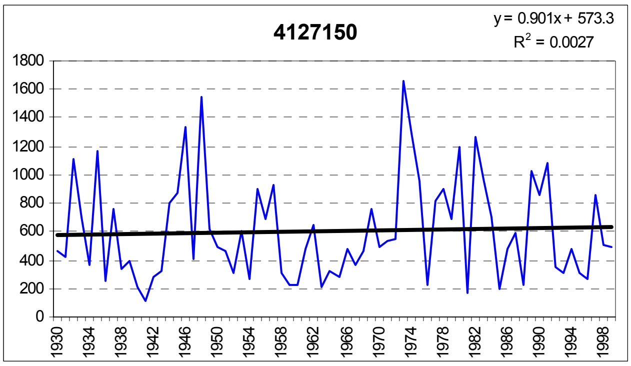


4127150: Hatchie River, Bolivar (US)
35.28 φ N, 88.98 λ W
Area: 3833 km^2

Data from 1930 to 1999 (70 years)

Mann-Kendall's test:
Test statistic: 0.659098
Significance level: 49.1%

Max: 1660 m^3/s in 1973

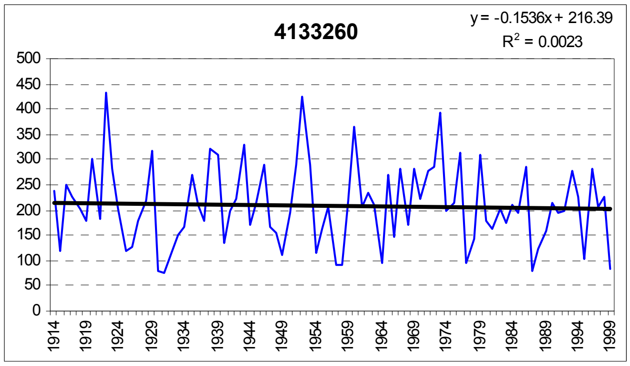


4133260: Wolf River, New (US)
44.39 φ N, 88.74 λ W
Area: 5853 km^2

Data from 1914 to 1999 (86 years)

Mann-Kendall's test:
Test statistic: -0.253643
Significance level: 20.2%

Max: 434 m^3/s in 1922

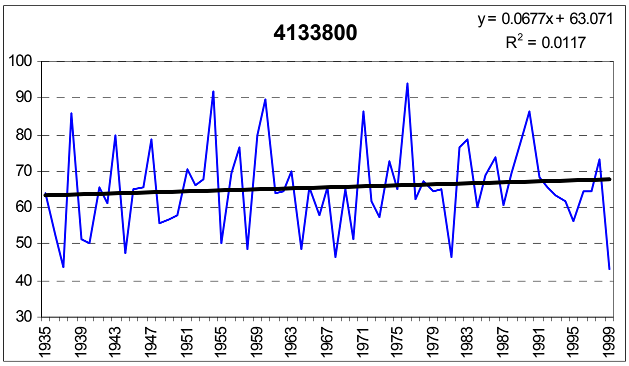


4133800: Manistee River, Near Sherman (US)
44.44 φ N, 85.70 λ W
Area: 2220 km^2

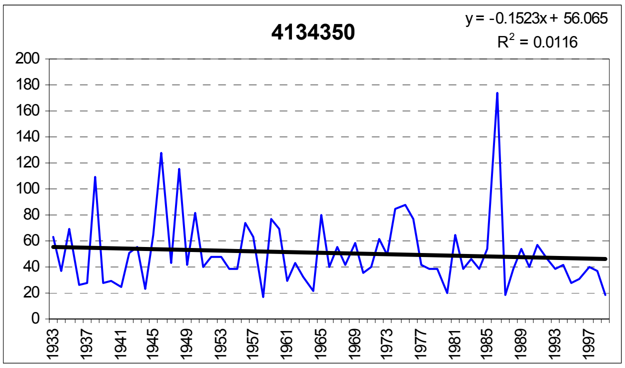
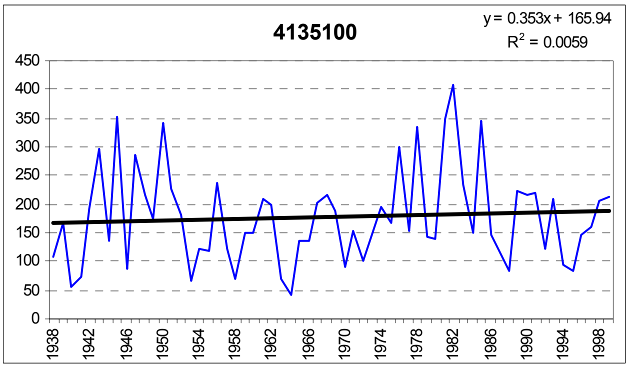
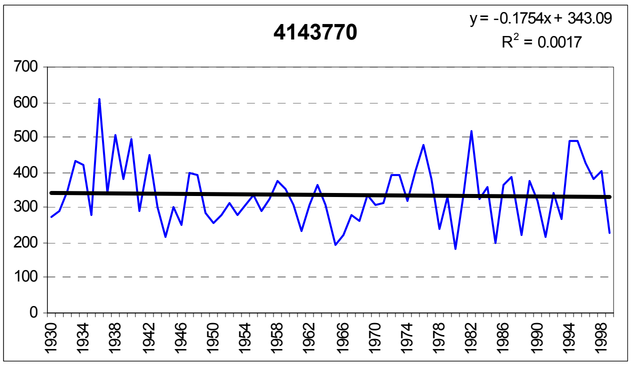
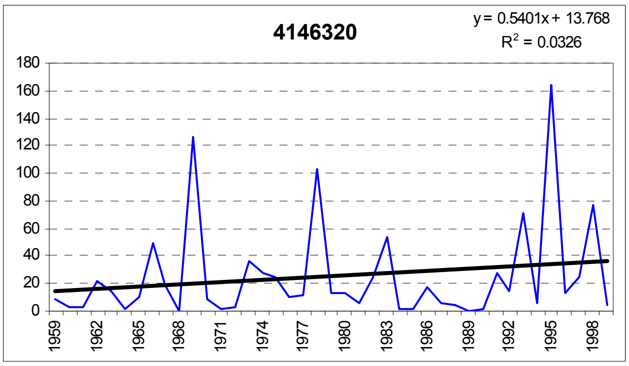
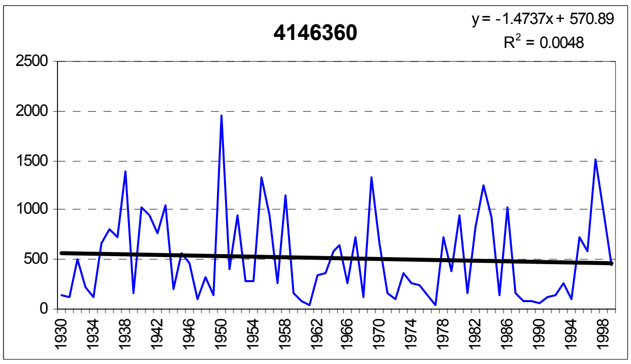
Data from 1935 to 1999 (65 years)

Mann-Kendall's test:
Test statistic: 0.923047
Significance level: 64.40%

Max: 94.1 m^3/s in 1976



Region Nr 4 – North America cont.

4134350: Chippewa River, Near Mount Pleasant (US) 43.63 φ N, 84.71 λ W Area: 1077 km^2 Data from 1933 to 1999 (67 years) Mann-Kendall's test: Test statistic: -1.1149 Significance level: 73.51% Max: 174 m^3/s in 1986	
4135100: River Raisin, Near Monroe (US) 41.96 φ N, 83.53 λ W Area: 2699 km^2 Data from 1938 to 1999 (62 years) Mann-Kendall's test: Test statistic: 0.813972 Significance level: 58.43% Max: 409 m^3/s in 1982	
4143770: Lamoille River, East Georgia (US) 44.68 φ N, 73.07 λ W Area: 1777 km^2 Data from 1930 to 1999 (70 years) Mann-Kendall's test: Test statistic: 0.425966 Significance level: 32.98% Max: 608 m^3/s in 1936	
4146320: San Lorenzo Creek, Bl Bitterwater Creek Near King City (US) 36.27 φ N, 121.07 λ W Area: 603 km^2 Data from 1959 to 1999 (41 years) Mann-Kendall's test: Test statistic: 0.831163 Significance level: 59.41% Max: 164 m^3/s in 1995	
4146360: San Joaquim, Vernalis (US) 37.67 φ N, 121.26 λ W Area: 35058 km^2 Data from 1930 to 1999 (70 years) Mann-Kendall's test: Test statistic: -0.806117 Significance level: 57.98% Max: 1960 m^3/s in 1950	

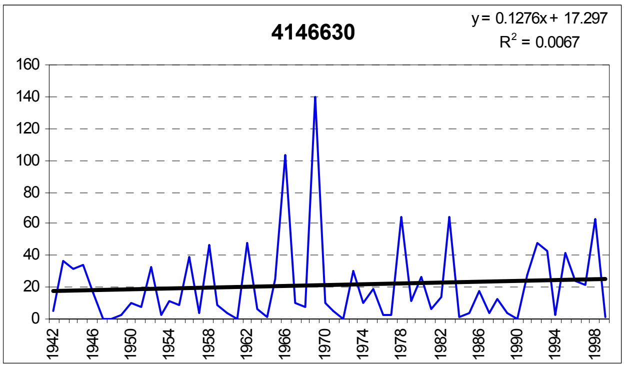
Region Nr 4 – North America cont.

4146630: Santa Cruz Creek, Near Santa Ynez (US)
34.60 φ N, 119.91 λ W
Area: 192 km^2

Data from 1942 to 1999 (58 years)

Mann-Kendall's test:
Test statistic: 0.66412
Significance level: 49.33%

Max: 140 m^3/s in 1969

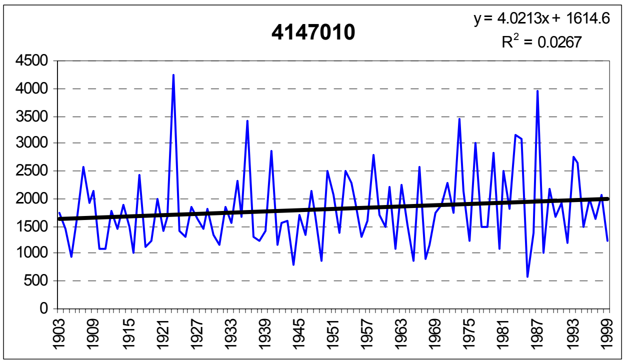


4147010: Penobscot, West Enfield (US)
45.24 φ N, 68.65 λ W
Area: 16633 km^2

Data from 1903 to 1999 (97 years)

Mann-Kendall's test:
Test statistic: 1.59577
Significance level: 88.94%

Max: 4256 m^3/s in 1923

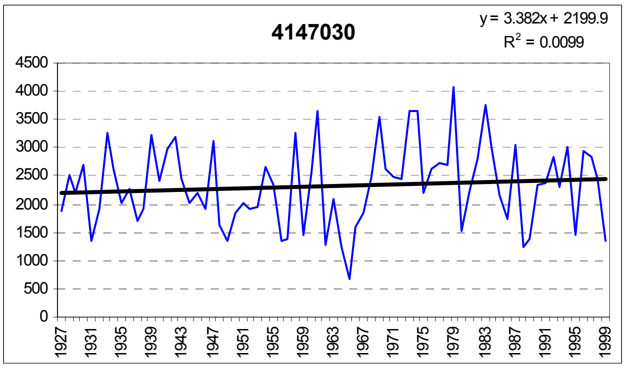


4147030: St. John River, Below Fish River, Fort Kent (US)
47.25 φ N, 68.59 λ W
Area: 14672 km^2

Data from 1927 to 1999 (73 years)

Mann-Kendall's test:
Test statistic: 0.852552
Significance level: 60.60%

Max: 4088 m^3/s in 1979

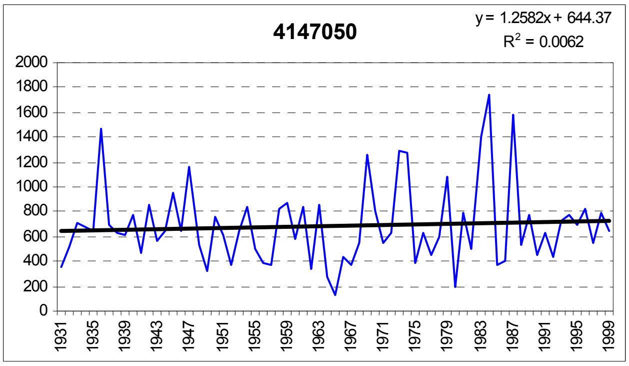


4147050: Kennebec River, Bingham (US)
45.05 φ N, 69.89 λ W
Area: 7032 km^2

Data from 1931 to 1999 (69 years)

Mann-Kendall's test:
Test statistic: 0.300436
Significance level: 23.61%

Max: 1736 m^3/s in 1984

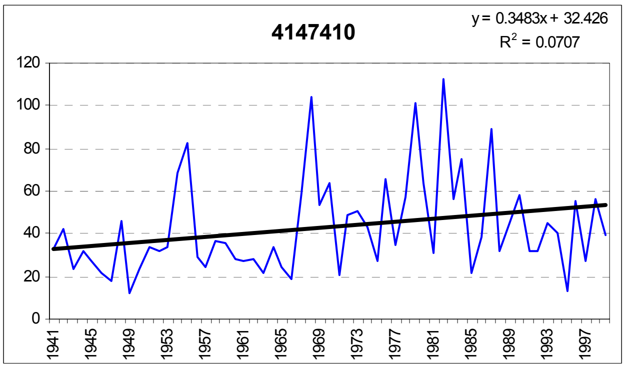


4147410: Branch River, Forestdale (US)
42.00 φ N, 71.56 λ W
Area: 236 km^2

Data from 1941 to 1999 (59 years)

Mann-Kendall's test:
Test statistic: 2.18433
Significance level: 97.10%

Max: 113 m^3/s in 1982



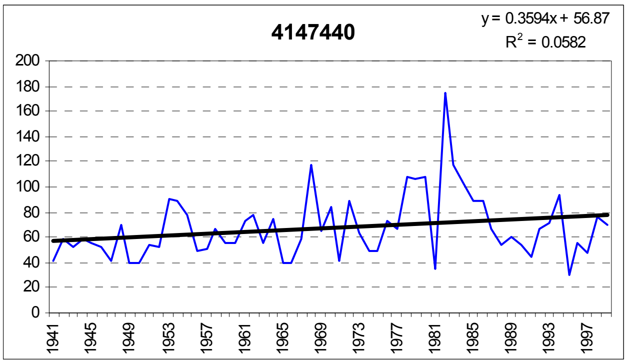
Region Nr 4 – North America cont.

4147440: Pawcatuck River, Westerly (US)
41.38 φ N, 71.83 λ W
Area: 764 km^2

Data from 1941 to 1999 (59 years)

Mann-Kendall's test:
Test statistic: 1.7595
Significance level: 92.15%

Max: 174 m^3/s in 1982

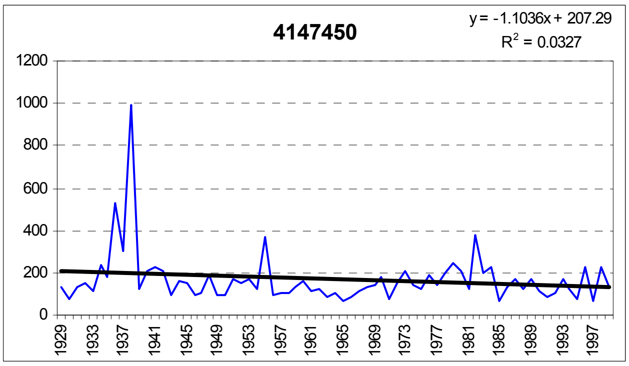


4147450: Shetucket River, Near Willimantic (US)
41.70 φ N, 72.18 λ W
Area: 1046 km^2

Data from 1929 to 1999 (71 years)

Mann-Kendall's test:
Test statistic: -0.521207
Significance level: 39.77%

Max: 994 m^3/s in 1938

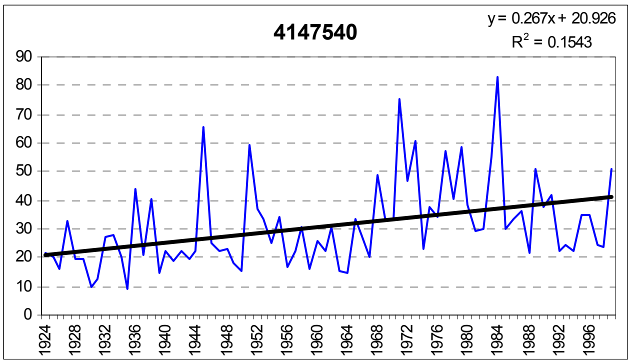


4147540: Saddle River, Lodi (US)
40.89 φ N, 74.08 λ W
Area: 141 km^2

Data from 1924 to 1999 (76 years)

Mann-Kendall's test:
Test statistic: 4.10857
Significance level: 99.99%

Max: 83.2 m^3/s in 1984

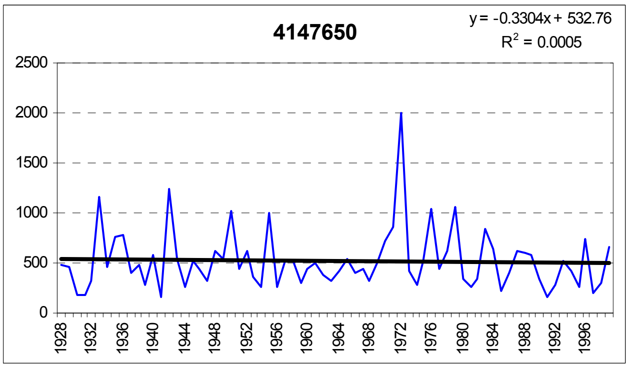


4147650: Schuylkill River, Pottstown (US)
40.24 φ N, 75.65 λ W
Area: 2971 km^2

Data from 1928 to 1999 (72 years)

Mann-Kendall's test:
Test statistic: -0.301435
Significance level: 23.69%

Max: 1994 m^3/s in 1972

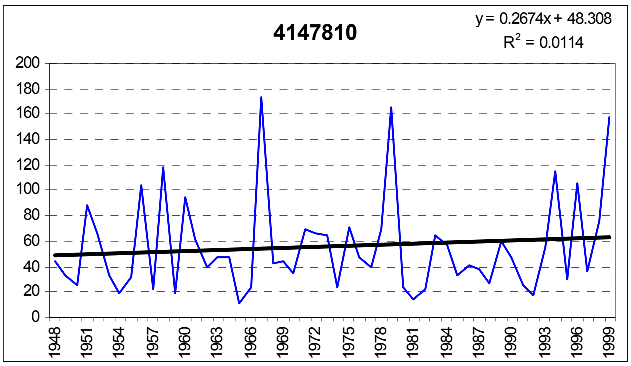


4147810: Choptank River, Near Greensboro (US)
39.00 φ N, 75.79 λ W
Area: 293 km^2

Data from 1948 to 1999 (52 years)

Mann-Kendall's test:
Test statistic: 0.591923
Significance level: 44.60%

Max: 172 m^3/s in 1967



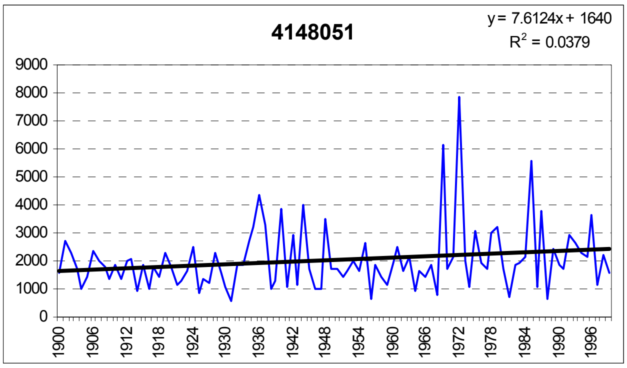
Region Nr 4 – North America cont.

4148051: James, Cartersville (US)
37.67 φ N, 78.09 λ W
Area: 16205 km^2

Data from 1900 to 1999 (100 years)

Mann-Kendall's test:
Test statistic: 1.77202
Significance level: 92.36%

Max: 7840 m^3/s in 1972

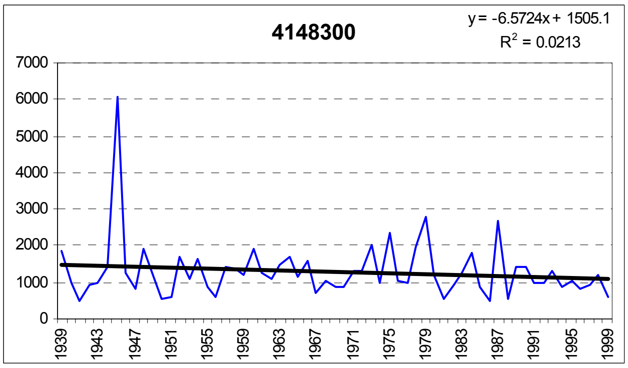


4148300: Pee Dee, Pee Dee (US)
34.20 φ N, 79.55 λ W
Area: 22870 km^2

Data from 1939 to 1999 (61 years)

Mann-Kendall's test:
Test statistic: -0.784118
Significance level: 56.70%

Max: 6076 m^3/s in 1945

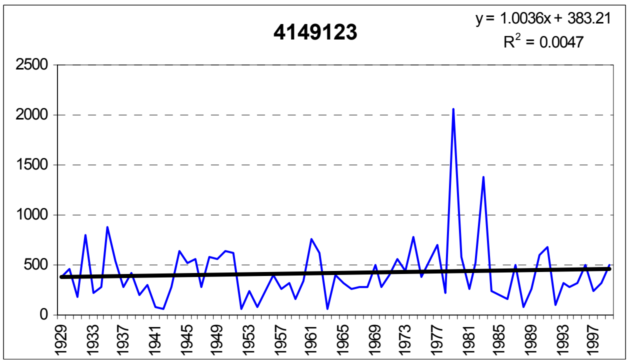


4149123: Pearl, Edinburg (US)
32.80 φ N, 89.34 λ W
Area: 2341 km^2

Data from 1929 to 1999 (71 years)

Mann-Kendall's test:
Test statistic: 0.18863
Significance level: 14.96%

Max: 2058 m^3/s in 1979

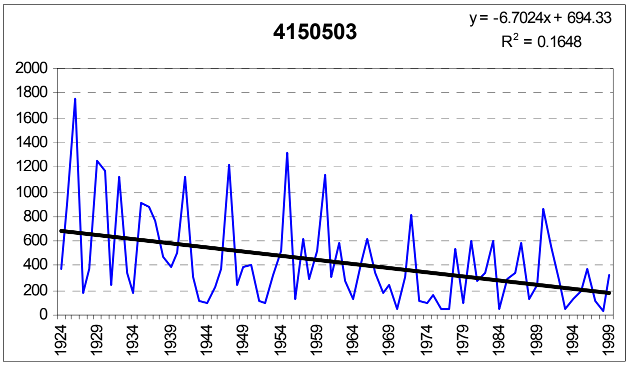


4150503: Brazos River, Seymour (US)
33.58 φ N, 99.27 λ W
Area: 40243 km^2

Data from 1924 to 1999 (76 years)

Mann-Kendall's test:
Test statistic: -3.19335
Significance level: 99.85%

Max: 1753 m^3/s in 1926

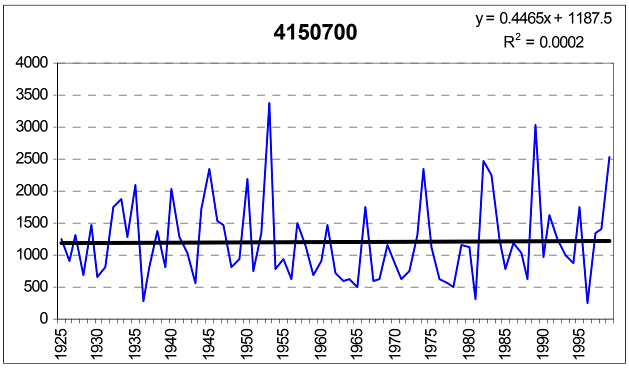


4150700: Sabine River, Near Ruliff (US)
30.30 φ N, 93.74 λ W
Area: 24162 km^2

Data from 1925 to 1999 (75 years)

Mann-Kendall's test:
Test statistic: -0.384245
Significance level: 29.92%

Max: 3360 m^3/s in 1953



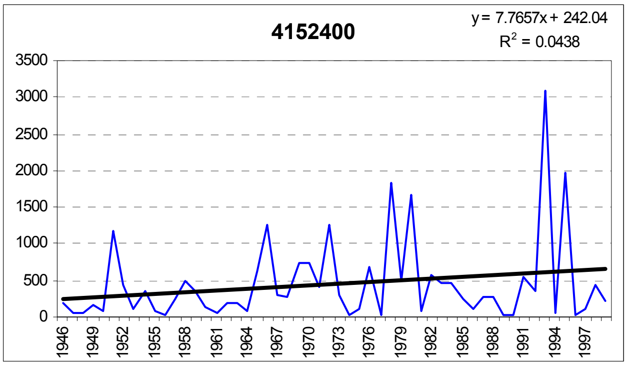
Region Nr 4 – North America cont.

4152400: Verde River, Below Tangle Creek (US)
34.07 φ N, 111.71 λ W
Area: 15208 km^2

Data from 1946 to 1999 (54 years)

Mann-Kendall's test:
Test statistic: 0.857946
Significance level: 60.90%

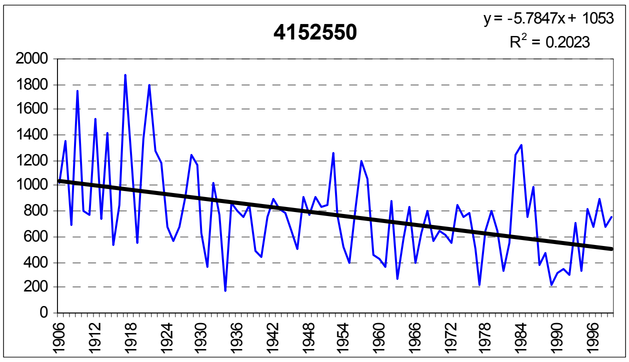
Max: 3080 m^3/s in 1993



4152550: Green, Green River (US)
38.99 φ N, 110.15 λ W
Area: 116161 km^2
0
Data from 1906 to 1999 (94 years)

Mann-Kendall's test:
Test statistic: -4.06404
Significance level: 99.99%

Max: 1868 m^3/s in 1917

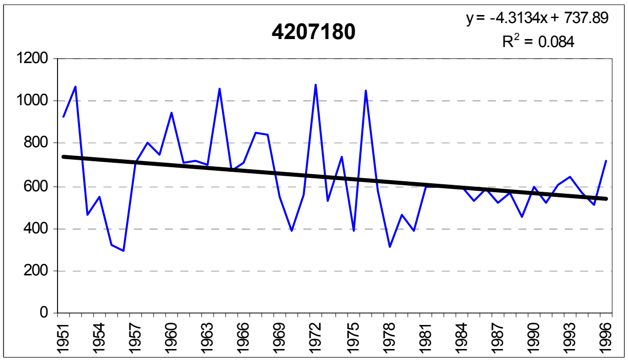


4207180: Nechako, Isle Pierre (CA)
53.96 φ N, 123.23 λ W
Area: 42500 km^2

Data from 1951 to 1996 (46 years)

Mann-Kendall's test:
Test statistic: -1.69495
Significance level: 90.99%

Max: 1080 m^3/s in 1972

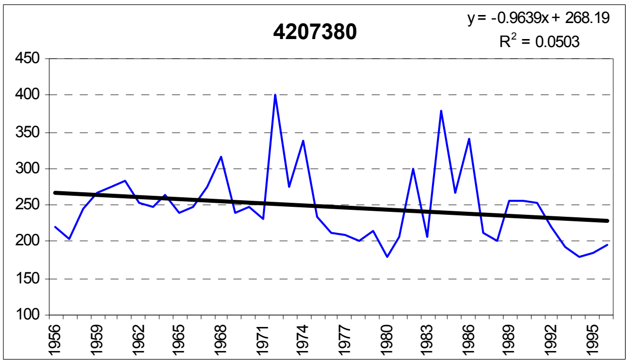


4207380: Fraser River, Red Pass (CA)
52.98 φ N, 119.00 λ W
Area: 1700 km^2

Data from 1956 to 1996 (41 years)

Mann-Kendall's test:
Test statistic: -2.23624
Significance level: 97.46%

Max: 402 m^3/s in 1972

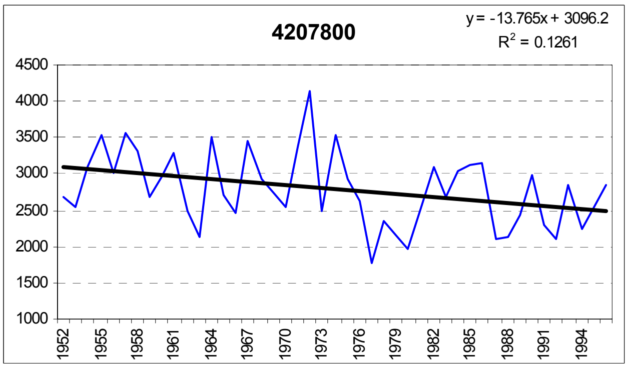


4207800: Thompson, Near Spences Bridge (CA)
50.36 φ N, 121.39 λ W
Area: 54900 km^2

Data from 1952 to 1996 (45 years)

Mann-Kendall's test:
Test statistic: -2.29962
Significance level: 97.85%

Max: 4130 m^3/s in 1972



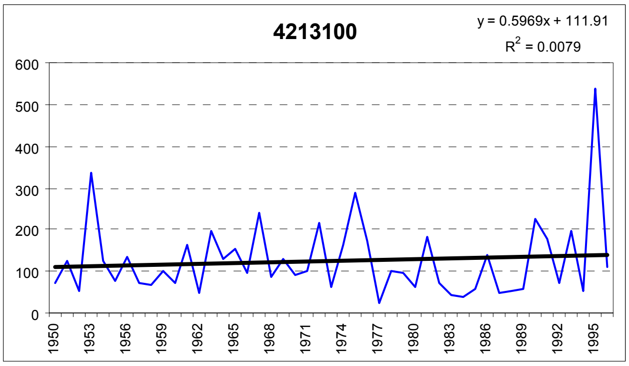
Region Nr 4 – North America cont.

4213100: Oldman River, Near Waldron's Corner (CA)
49.80 φ N, 114.18 λ W
Area: 1450 km^2

Data from 1950 to 1996 (47 years)

Mann-Kendall's test:
Test statistic: -0.284308
Significance level: 22.38%

Max: 539 m^3/s in 1995

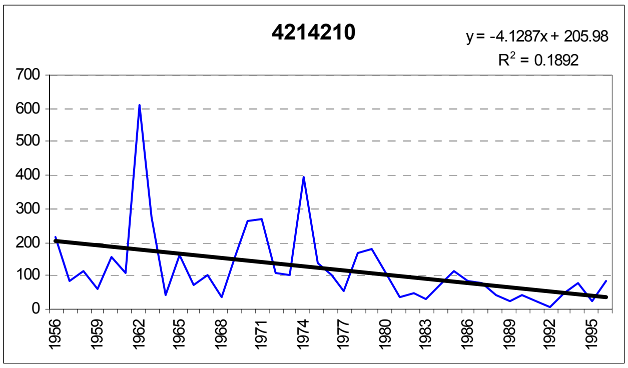


4214210: Beaver River, Cold Lake Reserve (CA)
54.35 φ N, 110.22 λ W
Area: 14500 km^2

Data from 1956 to 1996 (41 years)

Mann-Kendall's test:
Test statistic: -3.52683
Significance level: 99.95%

Max: 612 m^3/s in 1962

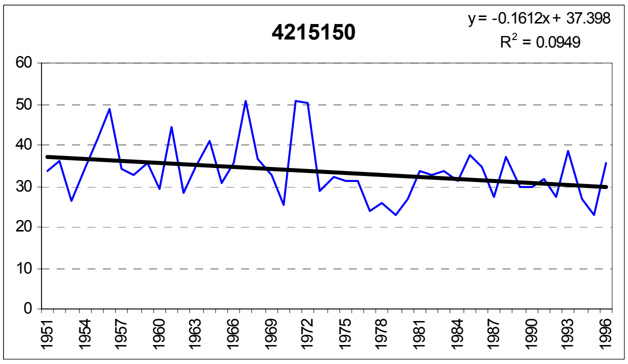


4215150: Barnes Creek, Near Needles (CA)
49.90 φ N, 118.12 λ W
Area: 201 km^2

Data from 1951 to 1996 (46 years)

Mann-Kendall's test:
Test statistic: -1.90361
Significance level: 94.30%

Max: 50.7 m^3/s in 1967

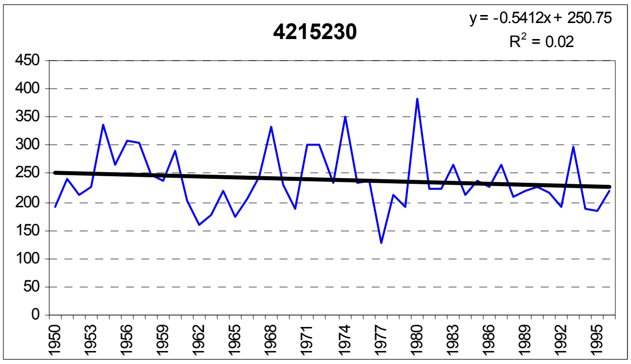


4215230: Salmo River, Near Salmo (CA)
49.07 φ N, 117.27 λ W
Area: 1230 km^2

Data from 1950 to 1996 (47 years)

Mann-Kendall's test:
Test statistic: -1.27527
Significance level: 79.77%

Max: 382 m^3/s in 1980

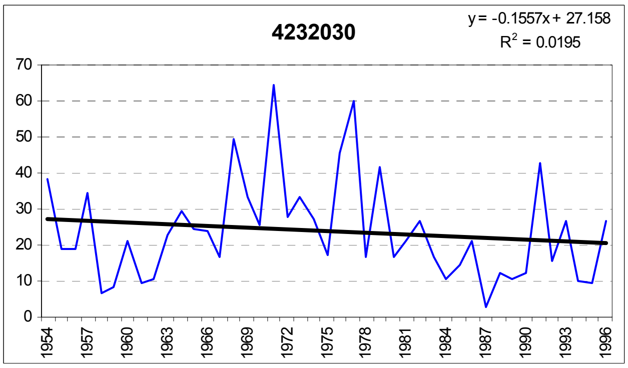


4232030: Neebing, Near Thunder Bay (CA)
48.38 φ N, 89.31 λ W
Area: 187 km^2

Data from 1954 to 1996 (43 years)

Mann-Kendall's test:
Test statistic: -1.19369
Significance level: 76.74%

Max: 64.6 m^3/s in 1971



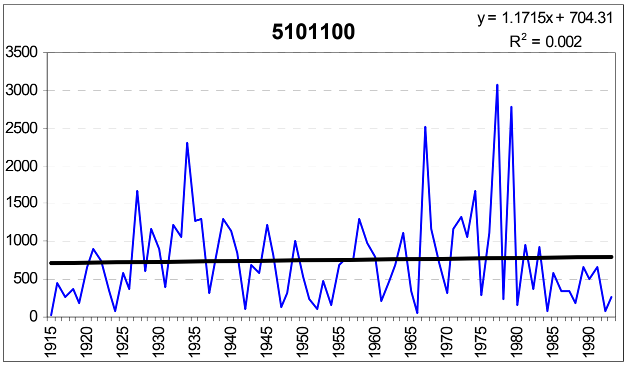
Region Nr 5 – Australia and the Pacific

5101100: Barron River, Myola (AU)
16.8 φ S, 145.61 λ E
Area: 1940 km^2

Data from 1915 to 1993 (79 years)

Mann-Kendall's test:
Test statistic: -0.186271
Significance level: 14.77%

Max: 3075 m^3/s in 1977

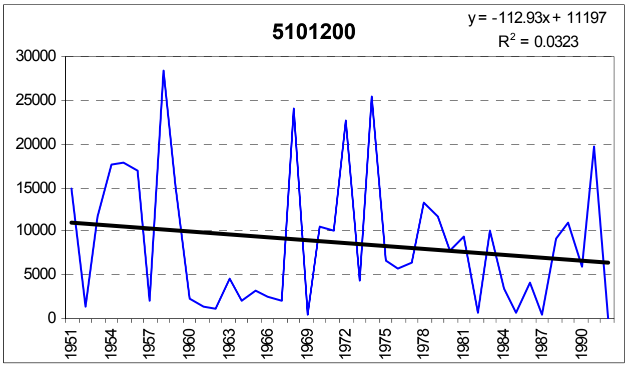


5101200: Burdekin, Clare (AU)
19.76 φ S, 147.24 λ E
Area: 129660 km^2

Data from 1951 to 1992 (42 years)

Mann-Kendall's test:
Test statistic: -0.899503
Significance level: 63.16%

Max: 28427 m^3/s in 1958

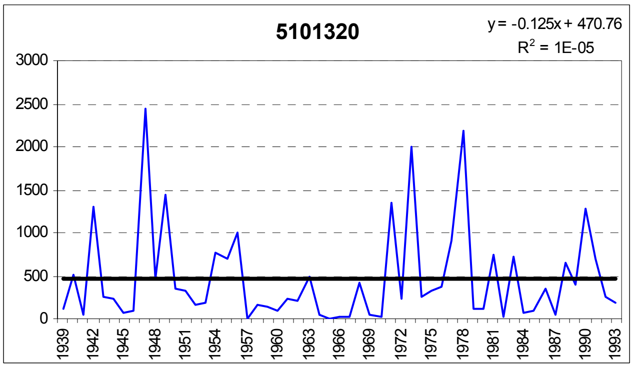


5101320: Calliope River, Castlehope (AU)
23.98 φ S, 151.09 λ E
Area: 1310 km^2

Data from 1939 to 1993 (55 years)

Mann-Kendall's test:
Test statistic: 0.130675
Significance level: 10.39%

Max: 2450 m^3/s in 1947

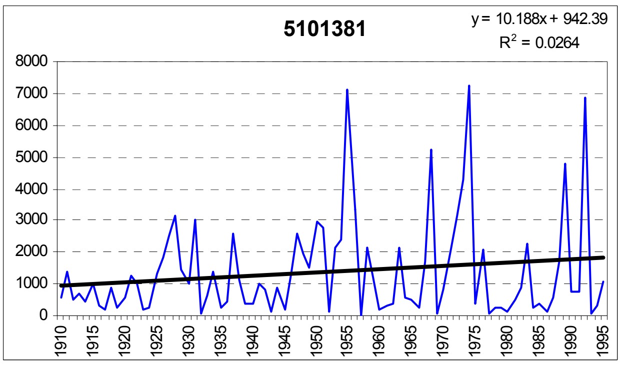


5101381: Mary River (Australia, Pacific), Miva (AU)
25.95 φ S, 152.5 λ E
Area: 4830 km^2

Data from 1910 to 1995 (86 years)

Mann-Kendall's test:
Test statistic: 0.384174
Significance level: 29.91%

Max: 7272 m^3/s in 1974

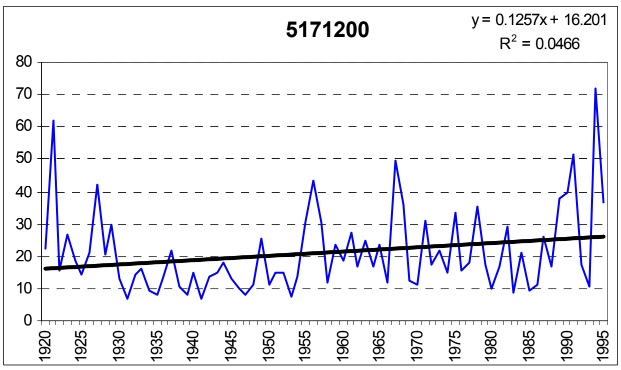


5171200: East Branch Of Nf Wailua, Near Lihue (US)
22.07 φ N, 159.42 λ W
Area: 16 km^2

Data from 1920 to 1995 (76 years)

Mann-Kendall's test:
Test statistic: 1.84338
Significance level: 93.47%

Max: 71.9 m^3/s in 1994



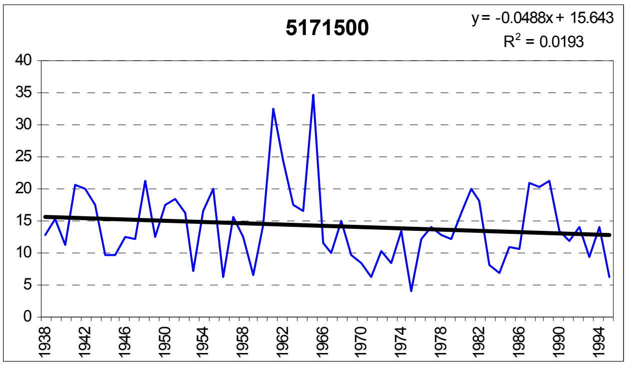
Region Nr 5 – Australia and the Pacific cont.

5171500: Halawa Stream, Near Halawa (US)
21.16 φ N, 156.76 λ W
Area: 12 km^2

Data from 1938 to 1995 (58 years)

Mann-Kendall's test:
Test statistic: -1.08677
Significance level: 72.28%

Max: 34.7 m^3/s in 1965

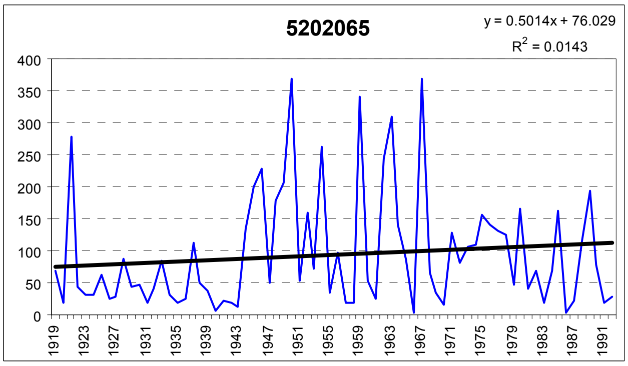


5202065: Styx River, Jeogla (AU)
30.59 φ S, 152.16 λ E
Area: 163 km^2

Data from 1919 to 1992 (74 years)

Mann-Kendall's test:
Test statistic: 1.1947
Significance level: 76.77%

Max: 370 m^3/s in 1967

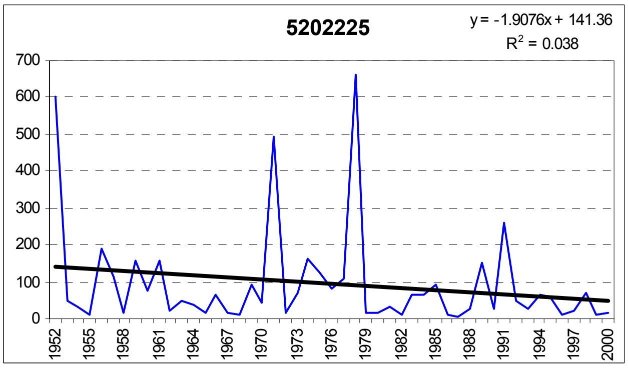


5202225: Delegate River, Quidong (AU)
36.91 φ S, 149.03 λ E Area: 1127 km^2

Data from 1952 to 2000 (49 years)

Mann-Kendall's test:
Test statistic: -1.51709
Significance level: 87.7%

Max: 663 m^3/s in 1978

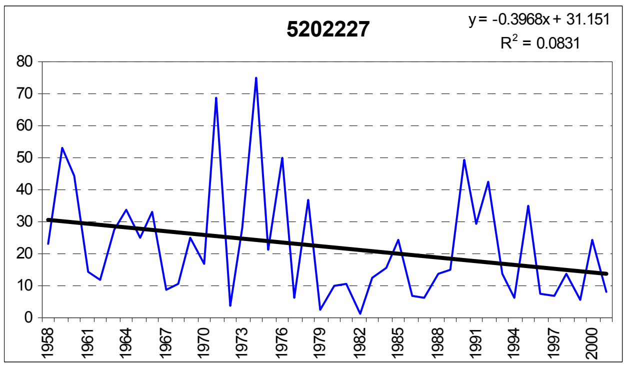


5202227: Suggan Buggan River, Suggan Buggan (AU)
36.95 φ S, 148.49 λ E
Area: 360 km^2

Data from 1958 to 2001 (44 years)

Mann-Kendall's test:
Test statistic: -1.92171
Significance level: 94.53%

Max: 75 m^3/s in 1974

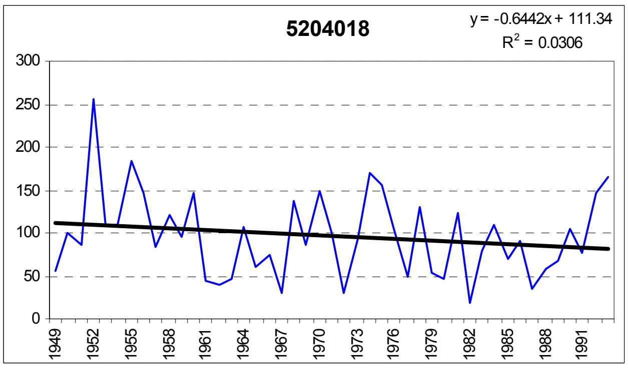


5204018: Murray, Biggara (AU)
36.32 φ S, 148.05 λ E
Area: 1165 km^2

Data from 1949 to 1993 (45 years)

Mann-Kendall's test:
Test statistic: -0.77284
Significance level: 56.3%

Max: 257 m^3/s in 1952



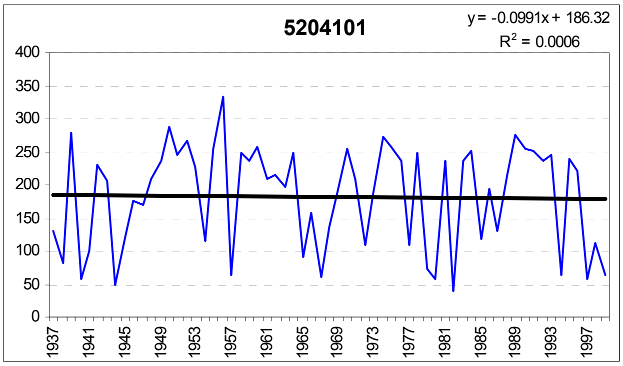
Region Nr 5 – Australia and the Pacific cont.

5204101: Murrumbidgee River, Maude Weir (AU)
34.48 φ S, 144.3 λ E
Area: 57700 km^2

Data from 1937 to 1999 (63 years)

Mann-Kendall's test:
Test statistic: -0.0177933
Significance level: 1.41%

Max: 334 m^3/s in 1956

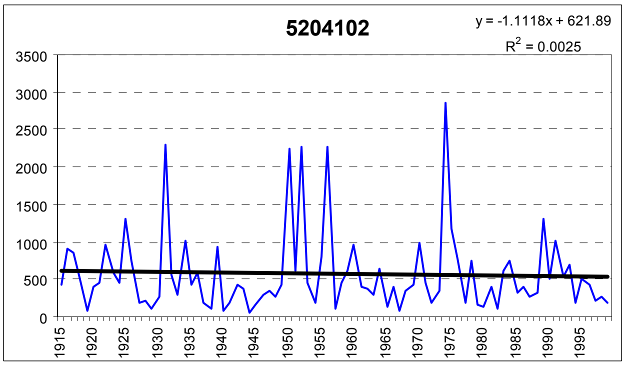


5204102: Murrumbidgee River, Narrandera (AU)
34.76 φ S, 146.55 λ E
Area: 34200 km^2

Data from 1915 to 1999 (85 years)

Mann-Kendall's test:
Test statistic: -0.508603
Significance level: 38.89%

Max: 2868 m^3/s in 1974

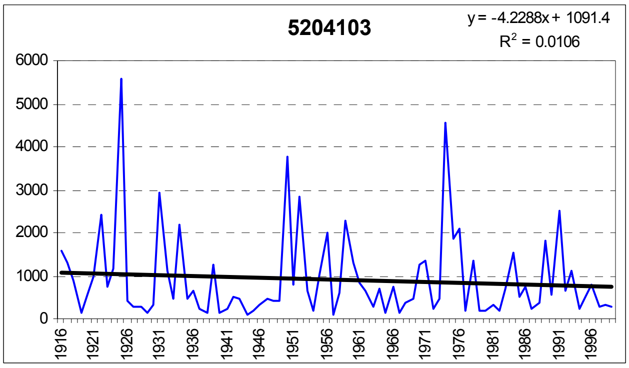


5204103: Murrumbidgee River, Gundagai (AU)
35.08 φ S, 148.11 λ E
Area: 21100 km^2

Data from 1916 to 1999 (84 years)

Mann-Kendall's test:
Test statistic: -0.479023
Significance level: 36.80%

Max: 5590 m^3/s in 1925

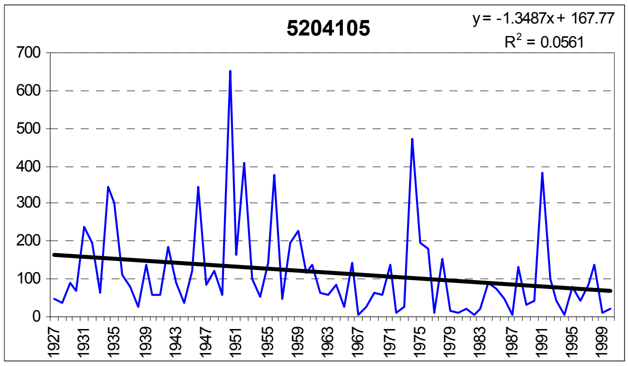


5204105: Murrumbidgee River, Mittagang Crossing (AU)
36.17 φ S, 149.09 λ E
Area: 1891 km^2

Data from 1927 to 2000 (74 years)

Mann-Kendall's test:
Test statistic: -2.79537
Significance level: 99.48%

Max: 653 m^3/s in 1950

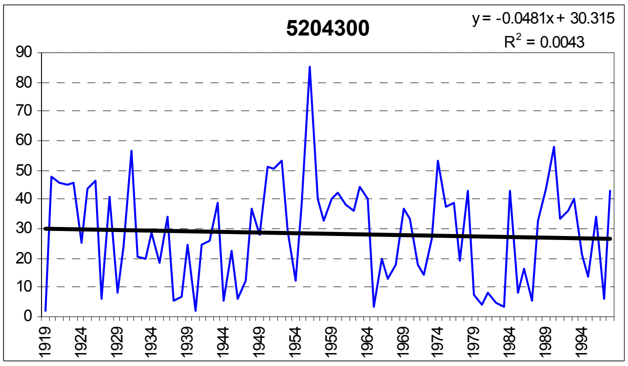


5204300: Lachlan River, Booligal (AU)
33.87 φ S, 144.88 λ E
Area: 55900 km^2

Data from 1919 to 1998 (80 years)

Mann-Kendall's test:
Test statistic: -0.710466
Significance level: 52.25%

Max: 85 m^3/s in 1956



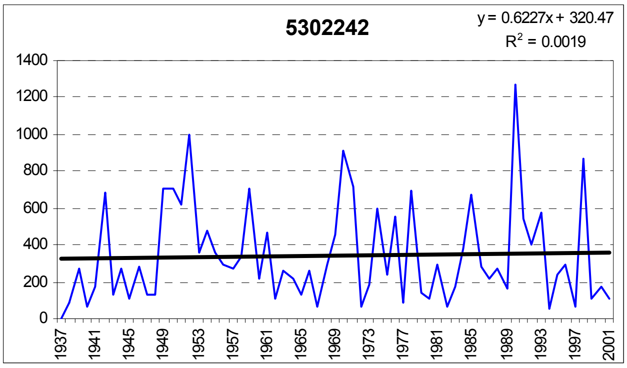
Region Nr 5 – Australia and the Pacific cont.

5302242: Mitchell River (Se Au), Glenaladale (AU)
37.77 φ S, 147.38 λ E
Area: 3903 km^2

Data from 1938 to 2001 (64 years)

Mann-Kendall's test:
Test statistic: 0.0113228
Significance level: 0.90%

Max: 1270 m^3/s in 1990

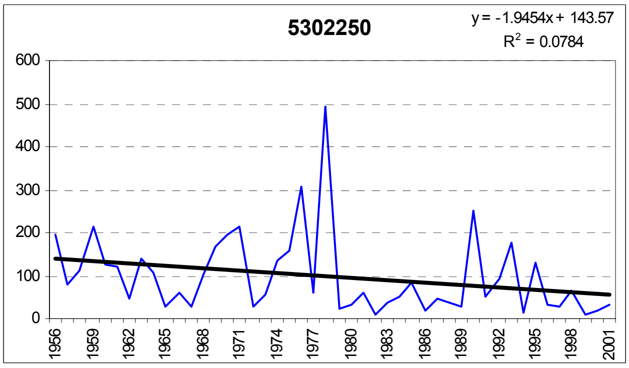


5302250: Thomson River, Cooper Creek (AU)
37.99 φ S, 146.43 λ E
Area: 906 km^2

Data from 1956 to 2001 (46 years)

Mann-Kendall's test:
Test statistic: -2.71736
Significance level: 99.34%

Max: 493 m^3/s in 1978

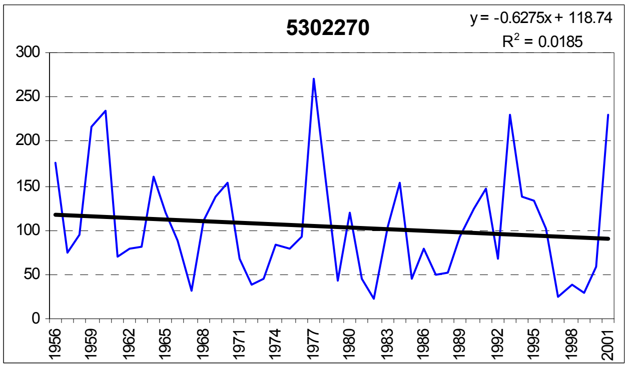


5302270: Tarwin River, Meeniyan (AU)
38.58 φ S, 145.99 λ E
Area: 1067 km^2

Data from 1956 to 2001 (46 years)

Mann-Kendall's test:
Test statistic: -1.0699
Significance level: 71.53%

Max: 271 m^3/s in 1977

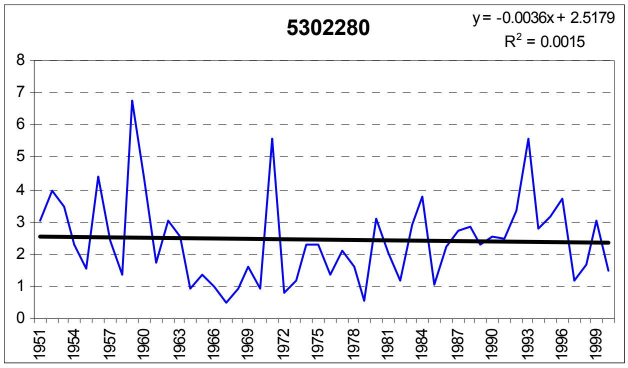


5302280: Bunyip River, Headworks (AU)
37.95 φ S, 145.74 λ E
Area: 41 km^2

Data from 1951 to 2000 (50 years)

Mann-Kendall's test:
Test statistic: 0.309572
Significance level: 24.31%

Max: 6.78 m^3/s in 1959

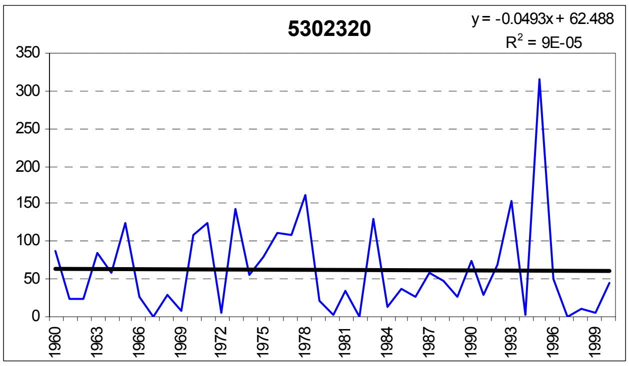


5302320: Moorabool River, Batesford (AU)
38.09 φ S, 144.28 λ E
Area: 1088 km^2

Data from 1960 to 2000 (41 years)

Mann-Kendall's test:
Test statistic: -0.628989
Significance level: 47.6%

Max: 316 m^3/s in 1995



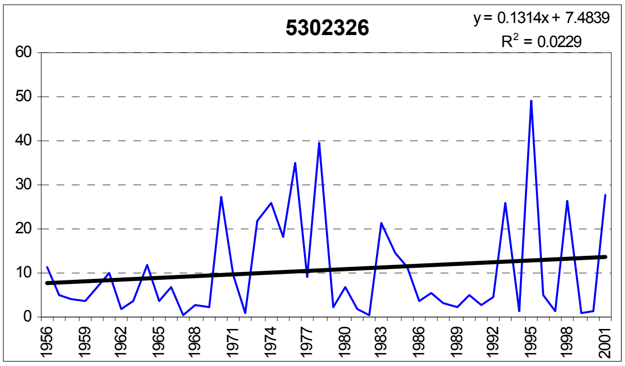
Region Nr 5 – Australia and the Pacific cont.

5302326: Barwon River, East Branch At Forrest Above Tunnel (AU)
38.53 φ S, 143.73 λ E
Area: 17 km^2

Data from 1956 to 2001 (46 years)

Mann-Kendall's test:
Test statistic: -0.208309
Significance level: 16.50%

Max: 48.9 m^3/s in 1995

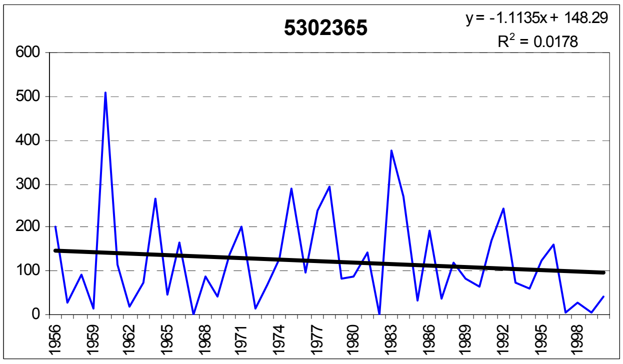


5302365: Hopkins River, Hopkins Falls (AU)
38.33 φ S, 142.63 λ E
Area: 8355 km^2

Data from 1956 to 2000 (45 years)

Mann-Kendall's test:
Test statistic: -0.645633
Significance level: 48.14%

Max: 508 m^3/s in 1960

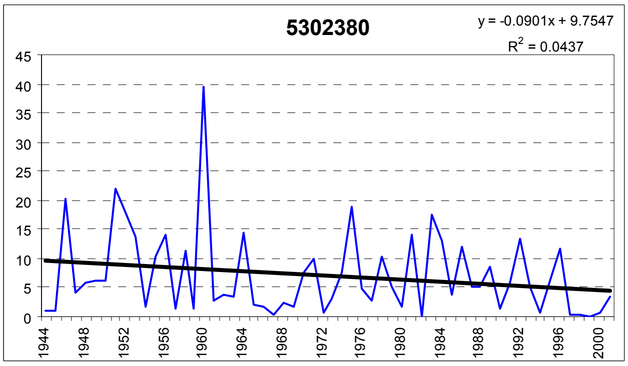


5302380: Wannon River, Dunkeld (AU)
37.63 φ S, 142.34 λ E
Area: 671 km^2

Data from 1944 to 2001 (58 years)

Mann-Kendall's test:
Test statistic: -1.4021
Significance level: 83.91%

Max: 39.6 m^3/s in 1960

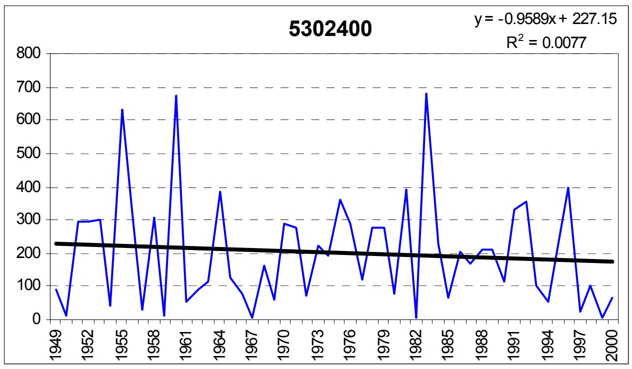


5302400: Glenelg River, Dartmoor (AU)
37.93 φ S, 141.28 λ E
Area: 11914 km^2

Data from 1949 to 2000 (52 years)

Mann-Kendall's test:
Test statistic: -0.347207
Significance level: 27.15%

Max: 679 m^3/s in 1983

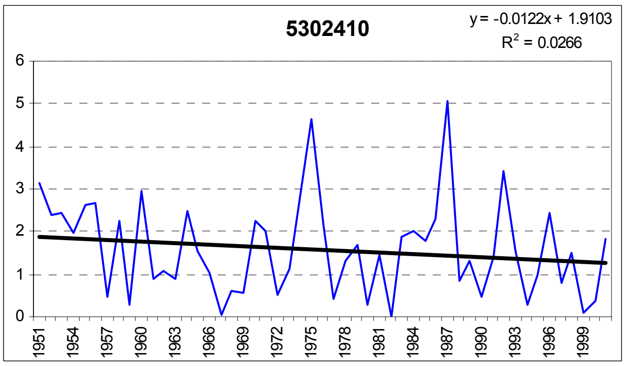


5302410: Jimmy Creek, Jimmy Creek (AU)
37.38 φ S, 142.51 λ E
Area: 23 km^2

Data from 1951 to 2001 (51 years)

Mann-Kendall's test:
Test statistic: -1.60836
Significance level: 89.22%

Max: 5.08 m^3/s in 1987



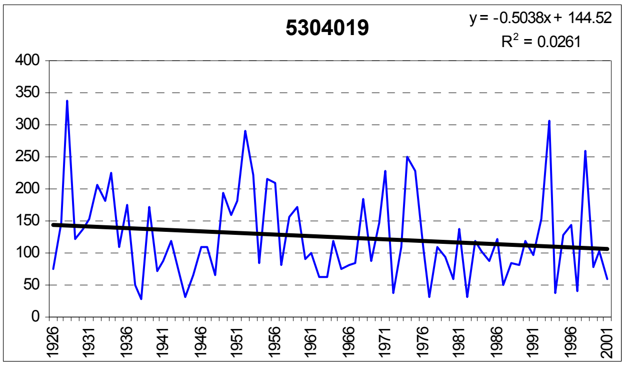
Region Nr 5 – Australia and the Pacific cont.

5304019: Mitta Mitta River, Hinnomunjie (AU)
36.94 φ S, 147.61 λ E
Area: 1533 km^2

Data from 1926 to 2001 (76 years)

Mann-Kendall's test:
Test statistic: -1.35443
Significance level: 82.44%

Max: 338 m^3/s in 1928

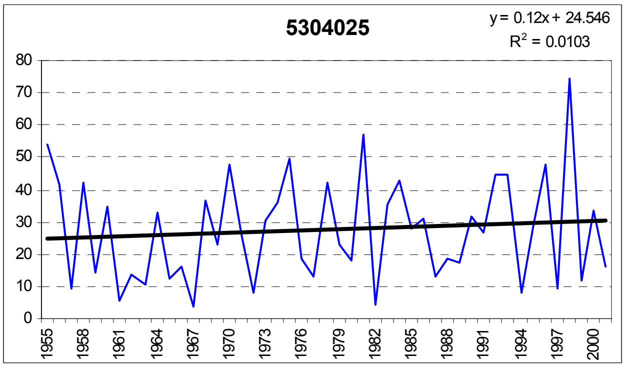


5304025: Nariel Creek, Upper Nariel (AU)
36.45 φ S, 147.83 λ E
Area: 252 km^2

Data from 1955 to 2001 (47 years)

Mann-Kendall's test:
Test statistic: 0.596079
Significance level: 44.88%

Max: 74.6 m^3/s in 1998

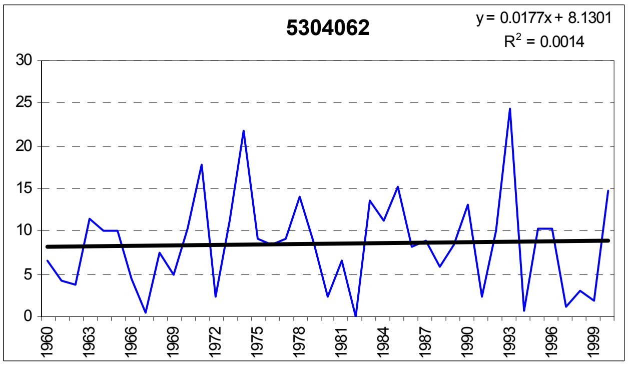


5304062: Campaspe River, Ashbourne (AU)
37.39 φ S, 144.45 λ E
Area: 39 km^2

Data from 1960 to 2000 (41 years)

Mann-Kendall's test:
Test statistic: 0.2022
Significance level: 16.2%

Max: 24.4 m^3/s in 1993

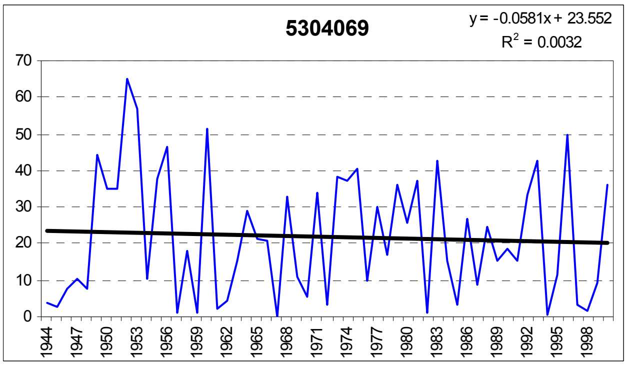


5304069: Creswick Creek, Clunes (AU)
37.3 φ S,143.45 λ E
Area: 308 km^2

Data from 1944 to 2000 (57 years)

Mann-Kendall's test:
Test statistic: -0.199636
Significance level: 15.82%

Max: 65.1 m^3/s in 1952

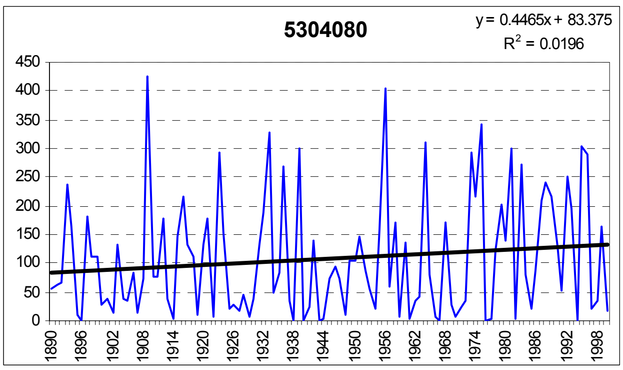


5304080: Avoca River, Coonooer (AU)
36.44 φ S, 143.3 λ E
Area: 2668 km^2

Data from 1890 to 2000 (111 years)

Mann-Kendall's test:
Test statistic: 0.945464
Significance level: 65.55%

Max: 426 m^3/s in 1909



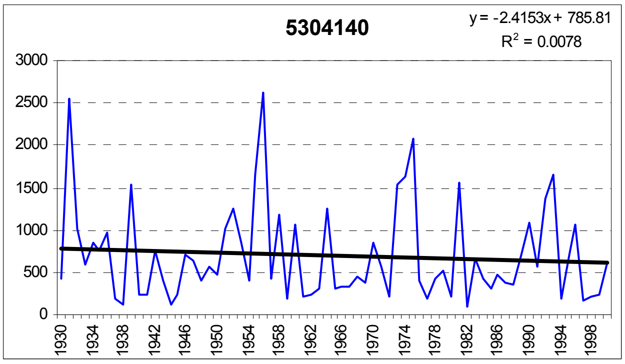
Region Nr 5 – Australia and the Pacific cont.

5304140: Murray, Below Wakool Junction (AU)
34.85 φ S, 143.34 λ E
Area: unknown

Data from 1930 to 2000 (71 years)

Mann-Kendall's test:
Test statistic: -0.501327
Significance level: 38.38%

Max: 2633 m^3/s in 1956

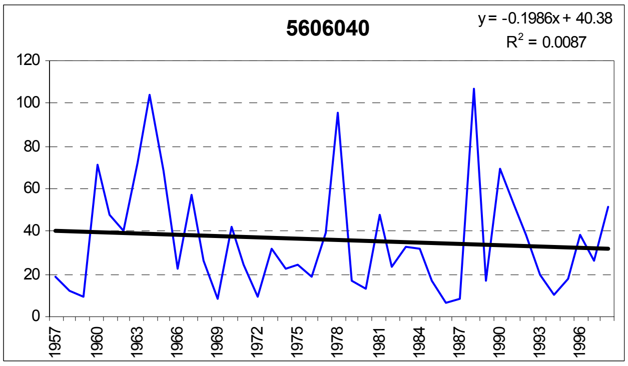


5606040: Kent River, Styx Junction (AU)
34.89 φ S, 117.09 λ E
Area: 1852 km^2

Data from 1957 to 1998 (42 years)

Mann-Kendall's test:
Test statistic: -0.596056
Significance level: 44.88%

Max: 107 m^3/s in 1988

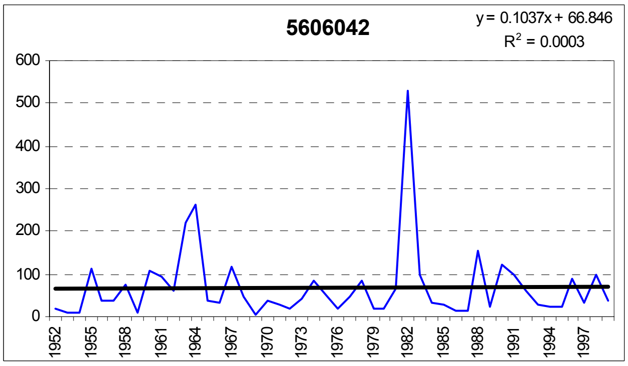


5606042: Frankland River, Mount Frankland (AU)
34.91 φ S, 116.79 λ E
Area: 5800 km^2

Data from 1952 to 1999 (48 years)

Mann-Kendall's test:
Test statistic: 0.302193
Significance level: 23.74%

Max: 527 m^3/s in 1982

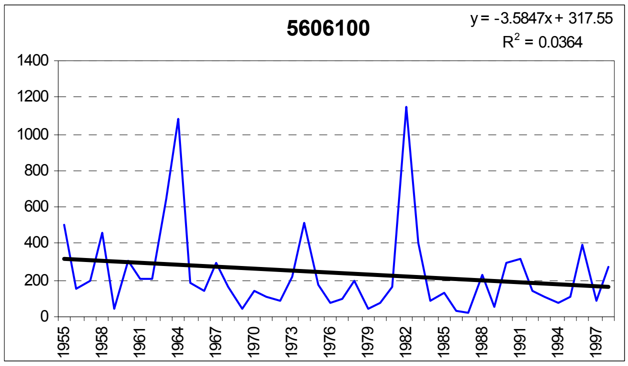


5606100: Blackwood River, Darradup (AU)
34.07 φ S, 115.62 λ E
Area: 20500 km^2

Data from 1955 to 1998 (44 years)

Mann-Kendall's test:
Test statistic: -1.65874
Significance level: 90.28%

Max: 1145 m^3/s in 1982

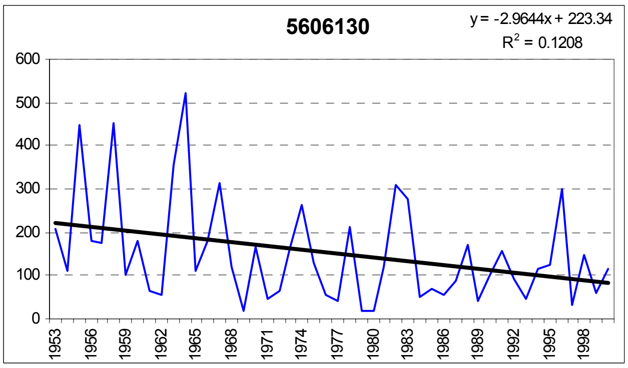


5606130: Murray River (South West Au), Baden Powell Wtr Sp (AU)
32.77 φ S, 116.08 λ E
Area: 6840 km^2

Data from 1953 to 2000 (48 years)

Mann-Kendall's test:
Test statistic: -2.0798
Significance level: 96.24%

Max: 519 m^3/s in 1964



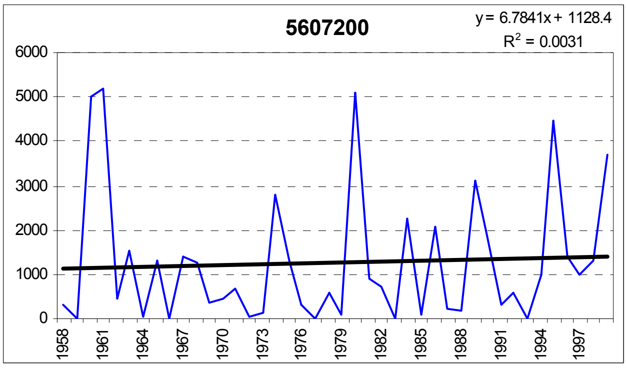
Region Nr 5 – Australia and the Pacific cont.

5607200: Gascoyne River, Nune Mile Bridge (AU)
24.83 φ S, 113.77 λ E
Area: 73400 km^2

Data from 1958 to 1999 (42 years)

Mann-Kendall's test:
Test statistic: 0.932216
Significance level: 64.87%

Max: 5198 m^3/s in 1961

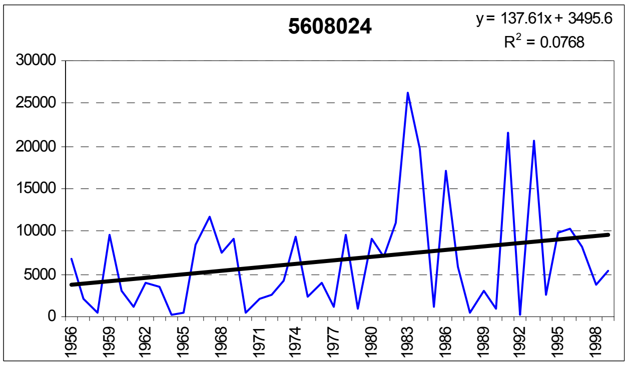


5608024: Fitzroy River, Fitzroy Crossing (AU)
18.21 φ S, 125.58 λ E
Area: 45300 km^2

Data from 1956 to 1999 (44 years)

Mann-Kendall's test:
Test statistic: 1.53737
Significance level: 87.57%

Max: 26344 m^3/s in 1983

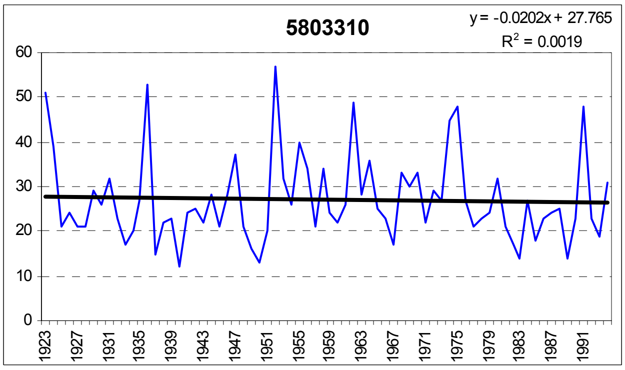


5803310: Hellyer River, Guildford Junction (AU)
41.25 φ S, 145.67 λ E
Area: 101 km^2

Data from 1923 to 1994 (72 years)

Mann-Kendall's test:
Test statistic: -0.15587
Significance level: 12.38%

Max: 57 m^3/s in 1952

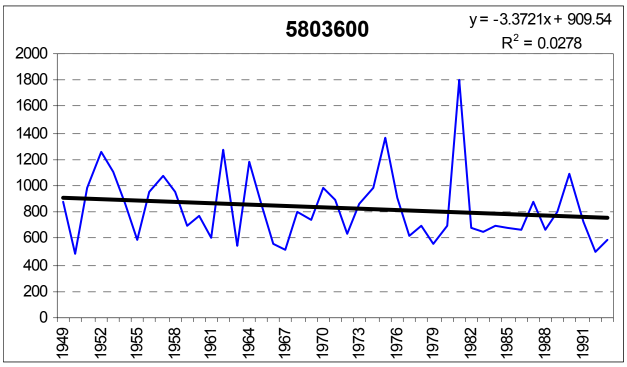


5803600: Huon River, Above Frying Pan Creek (AU)
43.04 φ S, 146.84 λ E
Area: 2098 km^2

Data from 1949 to 1993 (45 years)

Mann-Kendall's test:
Test statistic: -1.49691
Significance level: 86.55%

Max: 1805 m^3/s in 1981

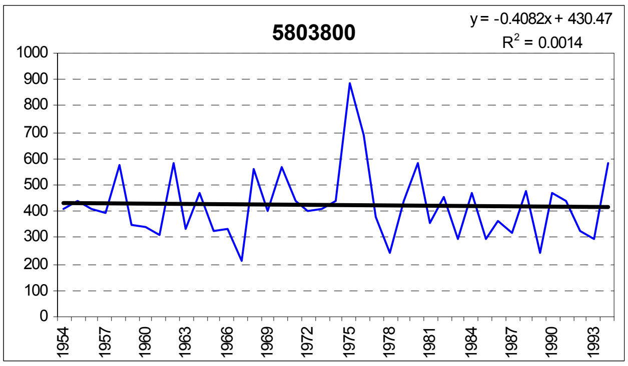


5803800: Franklin River (Tasmania), Mt. Fincham Track (AU)
42.24 φ S, 145.77 λ E
Area: 757 km^2

Data from 1954 to 1994 (41 years)

Mann-Kendall's test:
Test statistic: -0.258416
Significance level: 20.39%

Max: 887 m^3/s in 1975



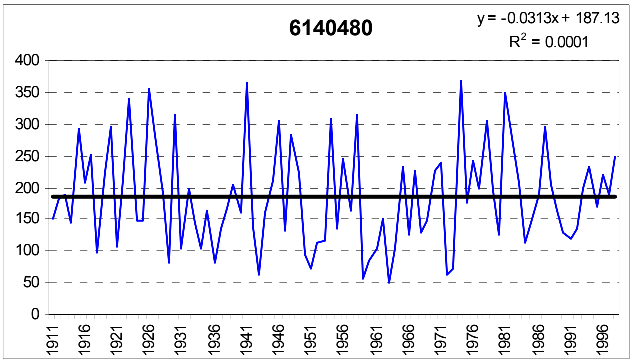
Region Nr 6 – Europe

6140480: Jizera, Turice (CZ)
50.24 φ N, 14.78 λ E
Area: 2159 km^2

Data from 1911 to 1998 (88 years)

Mann-Kendall's test:
Test statistic: 0.11894
Significance level: 9.46%

Max: 370 m^3/s in 1974

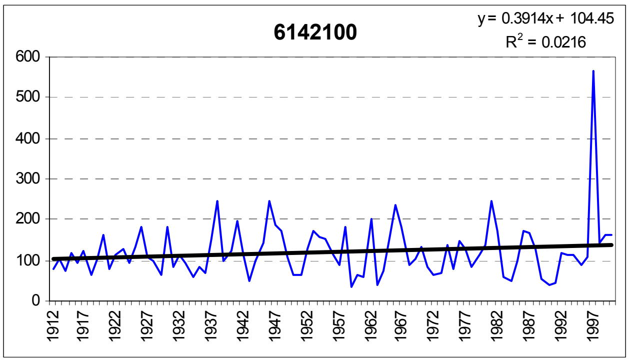


6142100: Morava , Moravicany (CZ)
49.76 φ N, 16.98 λ E
Area: 1559 km^2

Data from 1912 to 2000 (89 years)

Mann-Kendall's test:
Test statistic: 0.68404
Significance level: 50.60%

Max: 567 m^3/s in 1997

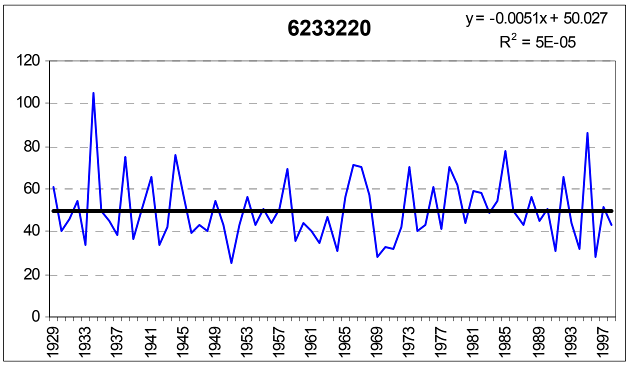


6233220: Taenndalssjoen, Taenndalen, (SE)
62.43 φ N, 12.69 λ E
Area: 227 km^2

Data from 1929 to 1998 (70 years)

Mann-Kendall's test:
Test statistic: 0.375507
Significance level: 29.27%

Max: 105 m^3/s in 1934

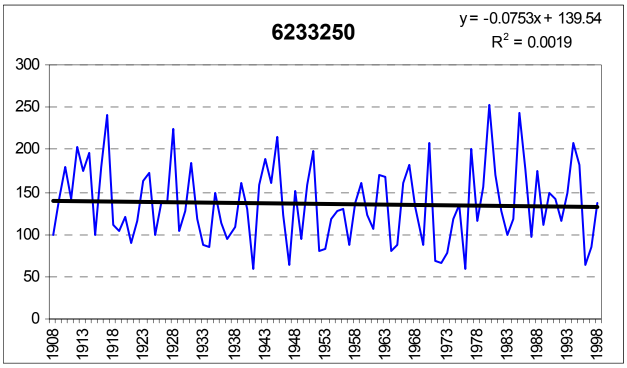


6233250: Helge A, Torsebro Krv (Powerstat.), (SE)
55.10 φ N, 14.13 λ E
Area: 3665 km^2

Data from 1908 to 1998 (91 years)

Mann-Kendall's test:
Test statistic: -0.510903
Significance level: 39.5%

Max: 252 m^3/s in 1980

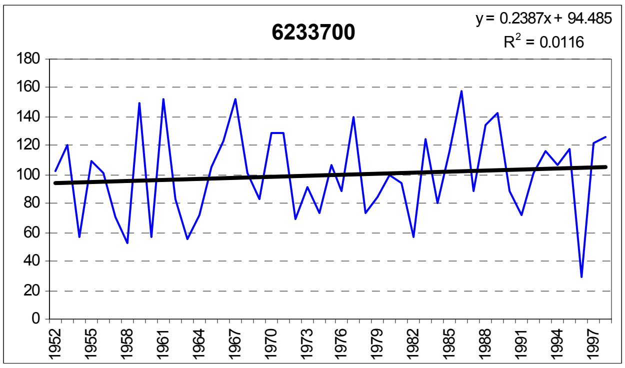


6233700: Moaelven, Vaestersel (SE)
63.26 φ N , 12.69 λ E
Area: 1465 km^2

Data from 1952 to 1998 (47 years)

Mann-Kendall's test:
Test statistic: 1.14708
Significance level: 74.86%

Max: 158 m^3/s in 1986



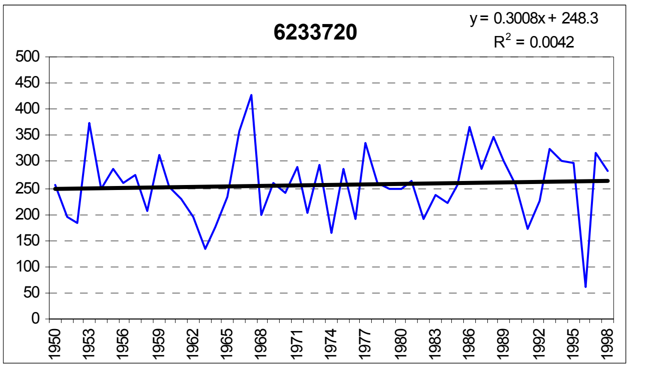
Region Nr 6 – Europe cont.

6233720: Oereaelven, Torrboele (SE)
63.53 φ N, 19.73 λ E
Area: 2860 km^2

Data from 1950 to 1998 (49 years)

Mann-Kendall's test:
Test statistic: 1.01737
Significance level: 69.10%

Max: 429 m^3/s in 1967

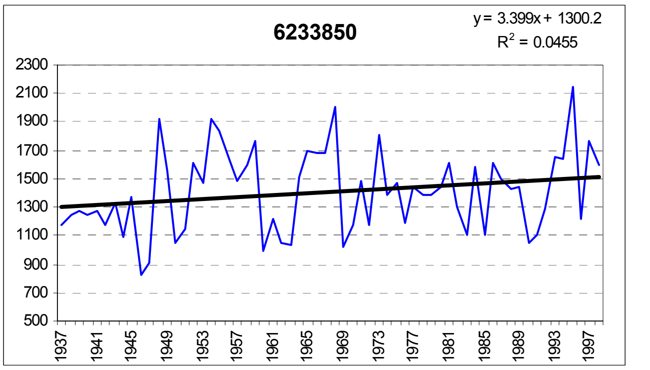


6233850: Kalixaelven, Raektfors (SE)
65.82 φ N, 23.21 λ E
Area: 23103 km^2

Data from 1937 to 1998 (62 years)

Mann-Kendall's test:
Test statistic: 1.54296
Significance level: 87.71%

Max: 2140 m^3/s in 1995

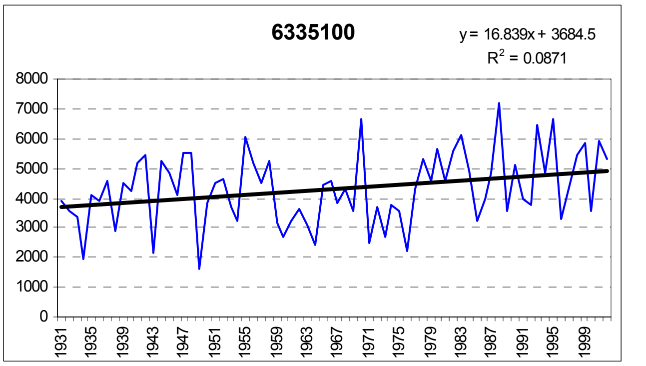


6335100: Rhine River, Kaub (DE)
50.09 φ N, 7.76 λ E
Area: 103488 km^2

Data from 1931 to 2002 (72 years)

Mann-Kendall's test:
Test statistic: 2.24606
Significance level: 97.52%

Max: 7160 m^3/s in 1988

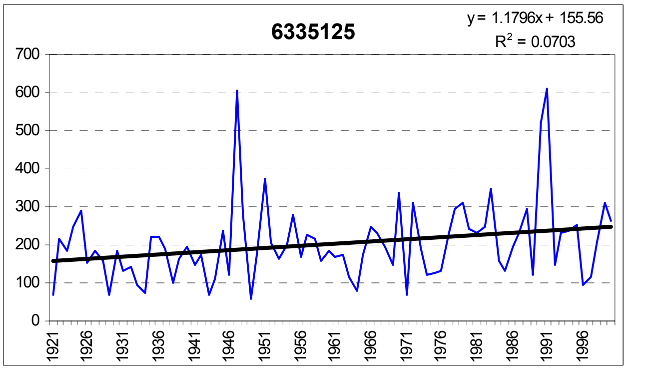


6335125: Kinzig, Schwaibach (DE)
48.39 φ N, 8.03 λ E
Area: 954 km^2

Data from 1921 to 2000 (80 years)

Mann-Kendall's test:
Test statistic: 2.48866
Significance level: 98.71%

Max: 611 m^3/s in 1991

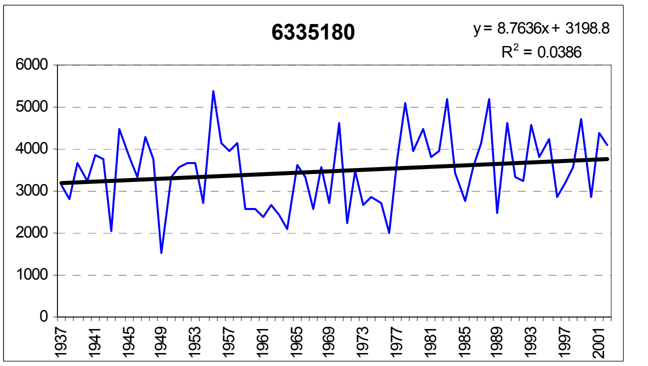


6335180: Rhine River, Worms (DE)
49.63 φ N, 8.38 λ E
Area: 68827 km^2

Data from 1937 to 2002 (66 years)

Mann-Kendall's test:
Test statistic: 1.45005
Significance level: 85.29%

Max: 5400 m^3/s in 1955



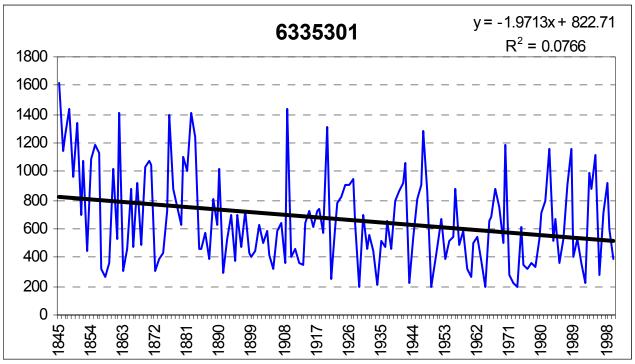
Region Nr 6 – Europe cont.

6335301: Main, Schweinfurt (DE)
50.03 φ N, 10.22 λ E
Area: 12715 km^2

Data from 1845 to 2000 (156 years)

Mann-Kendall's test:
Test statistic: -2.81511
Significance level: 99.51%

Max: 1614 m^3/s in 1845

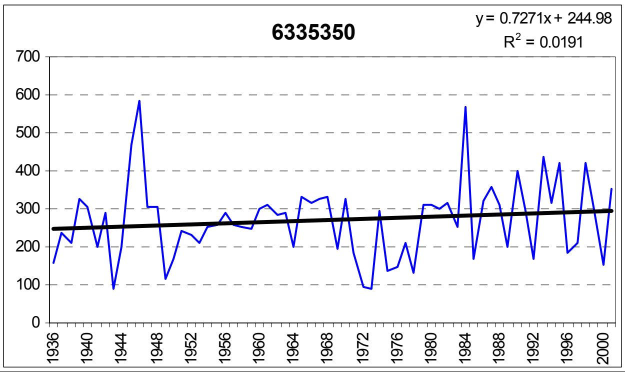


6335350: Lahn, Leun (Neu) (DE)
50.54 φ N, 8.36 λ E
Area: 3571 km^2

Data from 1936 to 2001 (66 years)

Mann-Kendall's test:
Test statistic: 1.7269
Significance level: 91.58%

Max: 582 m^3/s in 1946

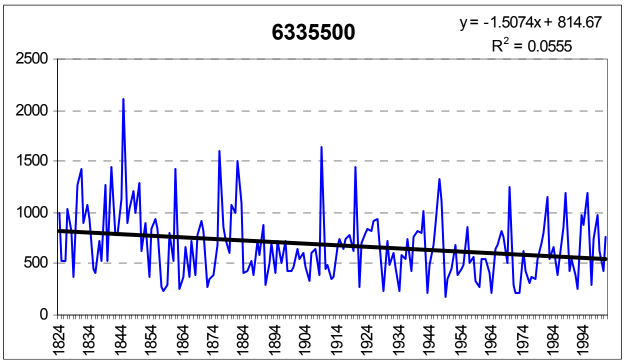


6335500: Main, Wuerzburg (DE)
49.80 φ N, 9.93 λ E
Area: 14031 km^2

Data from 1824 to 2001 (178 years)

Mann-Kendall's test:
Test statistic: -2.72616
Significance level: 99.35%

Max: 2100 m^3/s in 1845

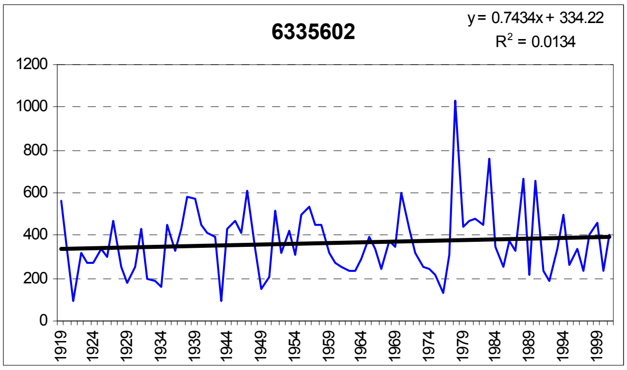


6335602: Neckar, Plochingen (DE)
48.71 φ N, 9.42 λ E
Area: 3995 km^2

Data from 1919 to 2001 (83 years)

Mann-Kendall's test:
Test statistic: 0.416877
Significance level: 32.32%

Max: 1031 m^3/s in 1978

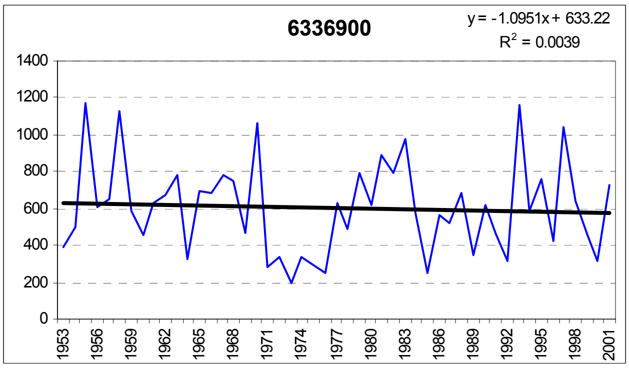


6336900: Saar River, Fremersdorf (DE)
49.41 φ N, 6.65 λ E
Area: 6983 km^2

Data from 1953 to 2001 (49 years)

Mann-Kendall's test:
Test statistic: -0.344793
Significance level: 26.97%

Max: 1171 m^3/s in 1955



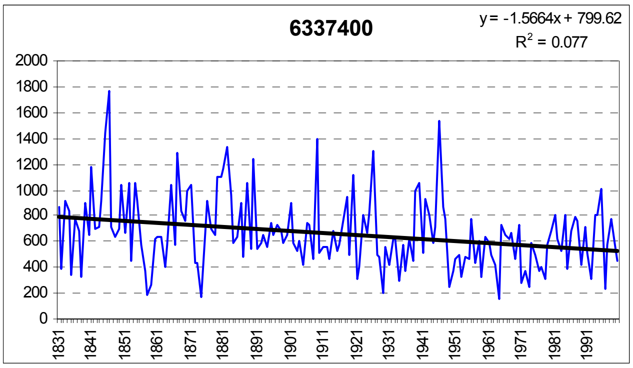
Region Nr 6 – Europe cont.

6337400: Weser, Hann.-Muenden (DE)
51.43 φ N, 9.64 λ E
Area: 12442 km^2

Data from 1831 to 2000 (170 years)

Mann-Kendall's test:
Test statistic: -3.56717
Significance level: 99.96%

Max: 1768 m^3/s in 1846

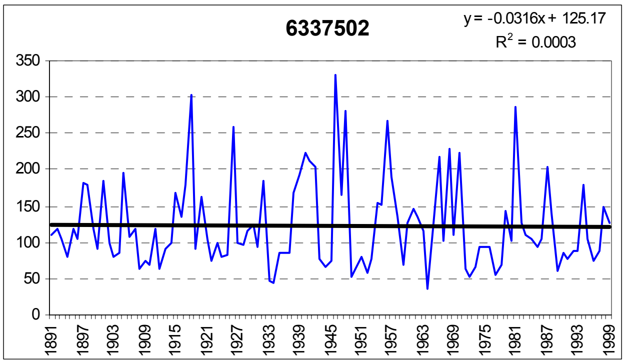


6337502: Aller, Celle (DE)
52.62 φ N, 10.06 λ E
Area: 4374 km^2

Data from1891 to 1999 (109 years)

Mann-Kendall's test:
Test statistic: -0.489734
Significance level: 37.56%

Max: 330 m^3/s in 1946

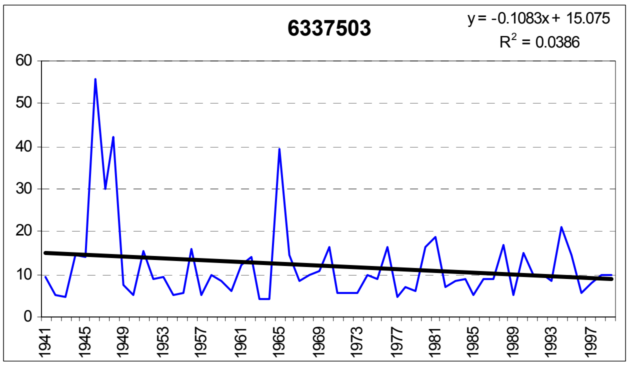


6337503: Diemel, Helminghausen (DE)
51.38 φ N, 8.73 λ E
Area: 103 km^2

Data from 1941 to 1999 (59 years)

Mann-Kendall's test:
Test statistic: 0.307426
Significance level: 24.14%

Max: 55.6 m^3/s in 1946

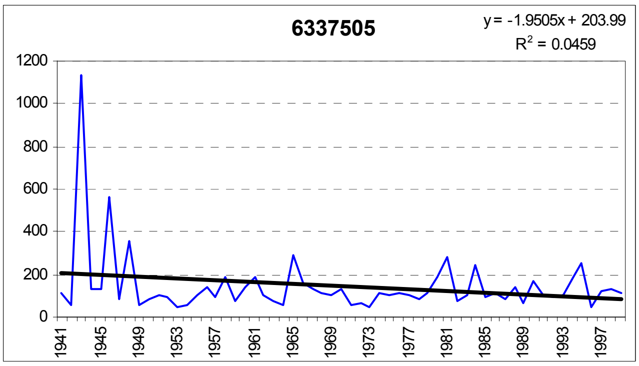


6337505: Eder, Affoldern (DE)
51.16 φ N, 9.09 λ E
Area: 1452 km^2

Data from 1941 to 1999 (59 years)

Mann-Kendall's test:
Test statistic: 0.313965
Significance level: 24.64%

Max: 1135 m^3/s in 1943

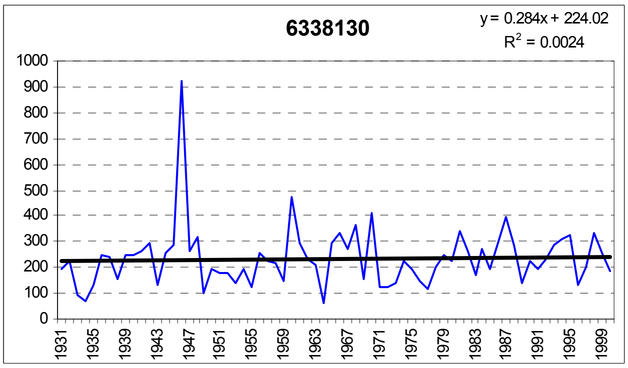


6338130: Ems, Rheine Unterschleuse Up (DE)
52.29 φ N, 7.43 λ E
Area: 3740 km^2

Data from 1931 to 2000 (70 years)

Mann-Kendall's test:
Test statistic: 1.4501
Significance level: 85.29%

Max: 920 m^3/s in 1946



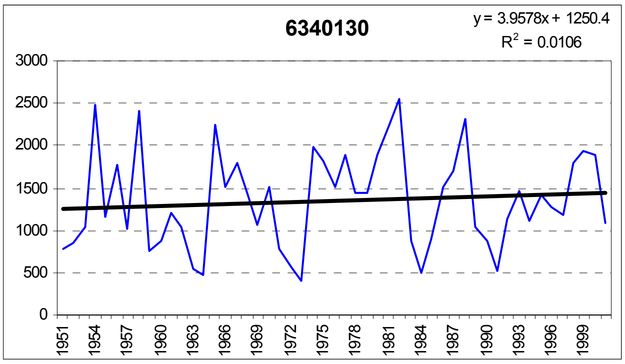
Region Nr 6 – Europe cont.

6340130: Elbe River, Wittenberg (DE)
51.86 φ N, 12.6 λ E
Area: 61879 km^2

Data from 1950 to 2001 (52 years)

Mann-Kendall's test:
Test statistic: 0.982852
Significance level: 67.43%

Max: 2560 m^3/s in 1982

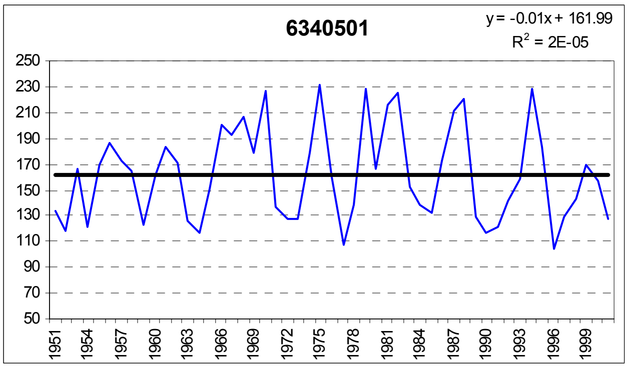


6340501: Havel, Rathenow Hauptschleuse Up (DE)
52.60 φ N, 12.32 λ E
Area: 19288 km^2

Data from 1951 to 2001 (51 years)

Mann-Kendall's test:
Test statistic: 0.0243698
Significance level: 1.94%

Max: 232 m^3/s in 1975

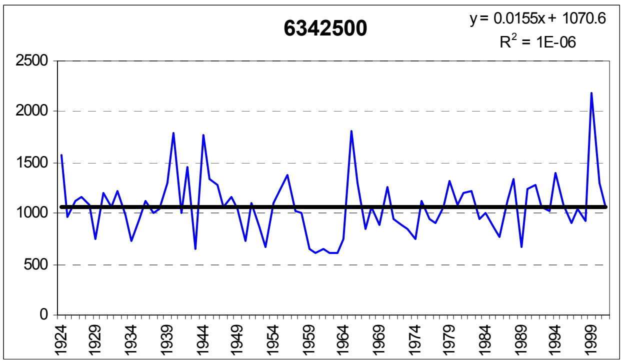


6342500: Danube River, Ingolstadt (DE)
48.75 φ N, 11.42 λ E
Area: 20001 km^2

Data from 1924 to 2001 (78 years)

Mann-Kendall's test:
Test statistic: -0.112178
Significance level: 8.93%

Max: 2191 m^3/s in 1999

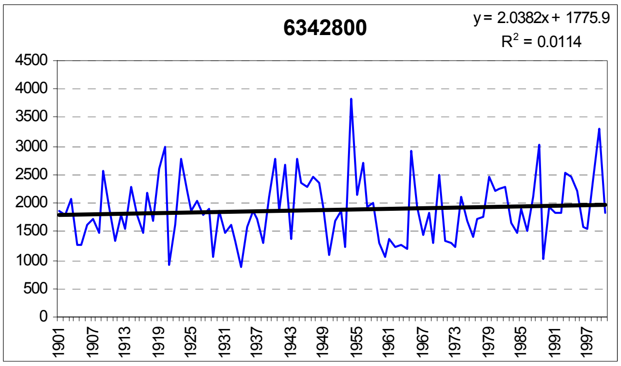


6342800: Danube River Hofkirchen (DE)
48.68 φ N, 13.12 λ E
Area: 47496 km^2

Data from 1901 to 2000 (100 years)

Mann-Kendall's test:
Test statistic: 1.00972
Significance level: 68.73%

Max: 3830 m^3/s in 1954

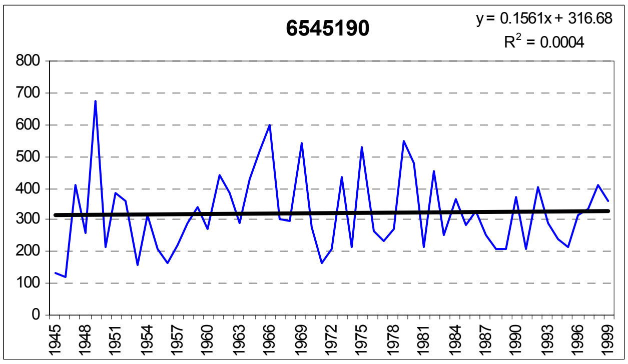


6545190: Sava, Radovljica I (SI)
46.34 φ N, 14.17 λ E
Area: 895 km^2

Data from 1945 to 1999 (55 years)

Mann-Kendall's test:
Test statistic: 0.522701
Significance level: 39.88%

Max: 675 m^3/s in 1949



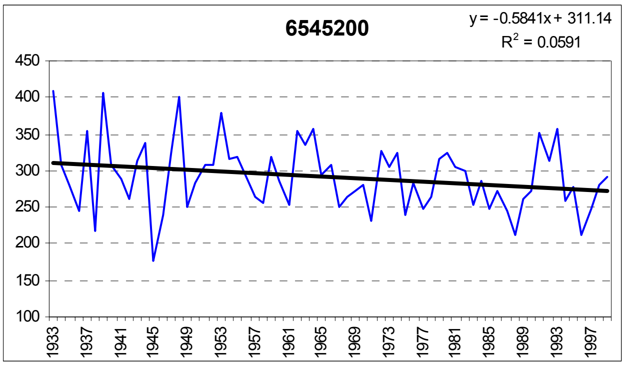
Region Nr 6 – Europe cont.

6545200: Krka, Podbocje (SI)
45.86 φ N, 15.46 λ E
Area: 2238 km^2

Data from 1933 to 1999 (67 years)

Mann-Kendall's test:
Test statistic: -1.95398
Significance level: 94.92%

Max: 408 m^3/s in 1933

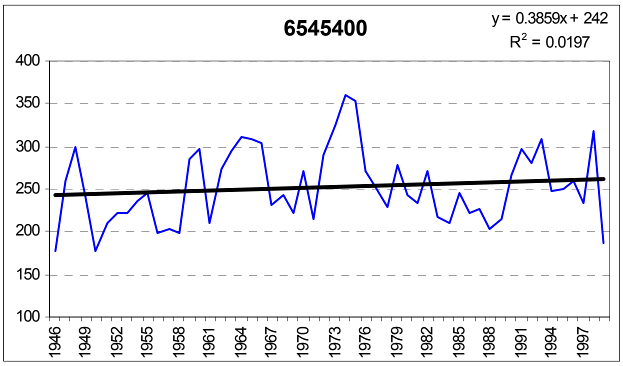


6545400: Ljubljanica, Moste (SI)
46.05 φ N, 14.55 λ E
Area: 1763 km^2

Data from 1946 to 1999 (54 years)

Mann-Kendall's test:
Test statistic: 1.07445
Significance level: 71.73%

Max: 360 m^3/s in 1974

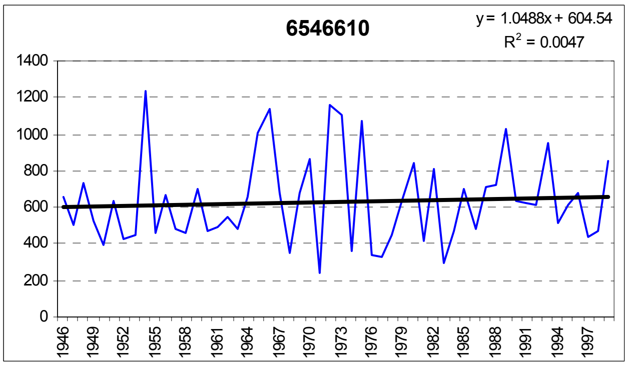


6546610: Mura, Gornja Radgona (SI)
46.68 φ N, 16.00 λ E
Area: 10197 km^2

Data from 1946 to 1999 (54 years)

Mann-Kendall's test:
Test statistic: 0.604293
Significance level: 45.43%

Max: 1241 m^3/s in 1954

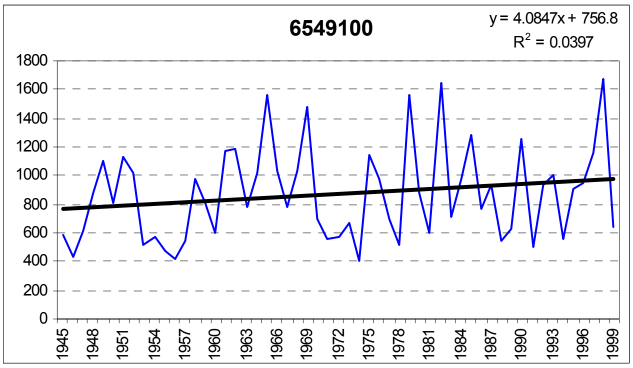


6549100: Soca, Solkan I (SI)
45.98 φ N, 13.66 λ E
Area: 1573 km^2

Data from 1945 to 1999 (55 years)

Mann-Kendall's test:
Test statistic: 1.27042
Significance level: 79.60%

Max: 1670 m^3/s in 1998

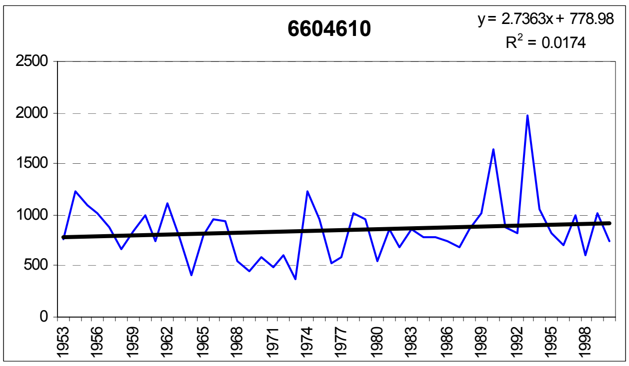


6604610: Tay, Ballathie (GB)
56.51 φ N, 3.39 λ W
Area: 4587 km^2

Data from 1953 to 2000 (48 years)

Mann-Kendall's test:
Test statistic: 0.32887
Significance level: 25.77%

Max: 1965 m^3/s in 1993



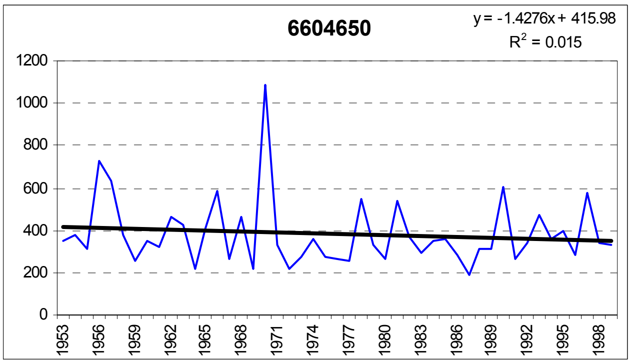
Region Nr 6 – Europe cont.

6604650: Spey, Boat O Brig (GB)
57.55 φ N, 3.14 λ W
Area: 2861 km^2

Data from 1953 to 1999 (47 years)

Mann-Kendall's test:
Test statistic: -0.458542
Significance level: 35.34%

Max: 1089 m^3/s in 1970

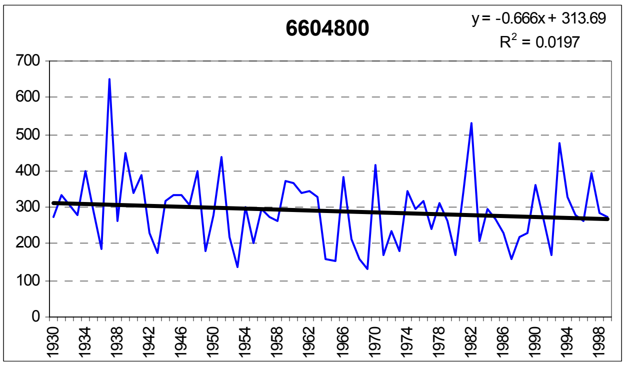


6604800: Dee, Woodend (GB)
57.05 φ N, 2.60 λ W
Area: 1370 km^2

Data from 1930 to 1999 (70 years)

Mann-Kendall's test:
Test statistic: -1.13056
Significance level: 74.17%

Max: 649 m^3/s in 1937

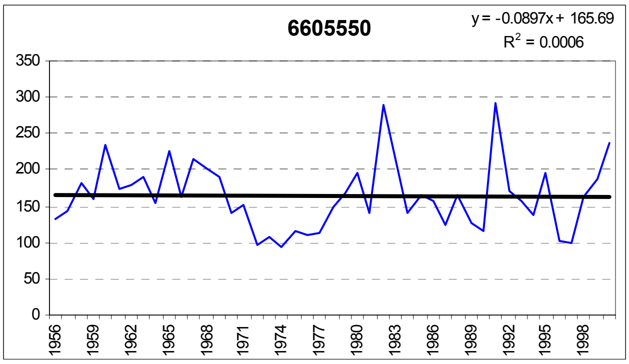


6605550: Wharfe, Flint Mill Weir (GB)
53.92 φ N, 1.36 λ W
Area: 759 km^2

Data from 1956 to 2000 (45 years)

Mann-Kendall's test:
Test statistic: -0.430422
Significance level: 33.31%

Max: 293 m^3/s in 1991

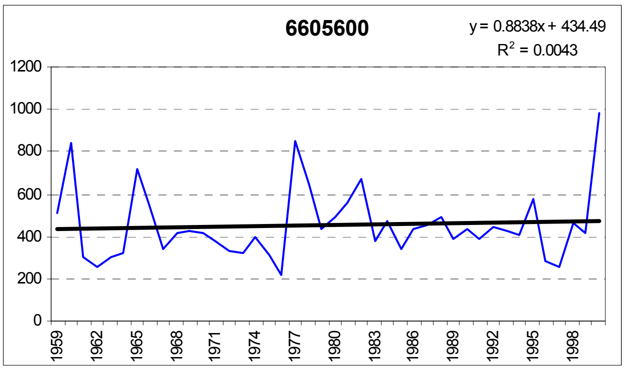


6605600: Trent, Colwick (GB)
52.95 φ N, 1.08 λ W
Area: 7486 km^2

Data from 1959 to 2000 (42 years)

Mann-Kendall's test:
Test statistic: 0.736986
Significance level: 53.88%

Max: 982 m^3/s in 2000

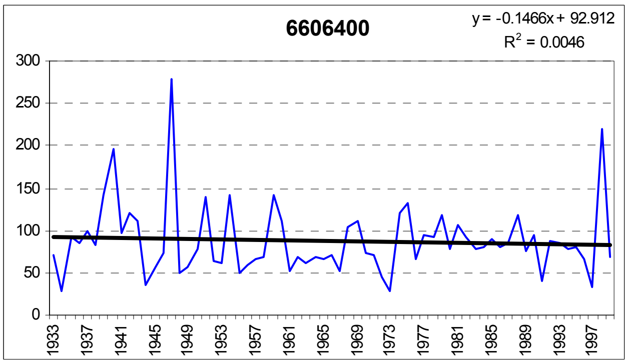


6606400: Bedford Ouse, Bedford (GB)
52.13 φ N, 0.46 λ W
Area: 1460 km^2

Data from 1933 to 1999 (67 years)

Mann-Kendall's test:
Test statistic: 0.0541176
Significance level: 4.31%

Max: 278 m^3/s in 1947



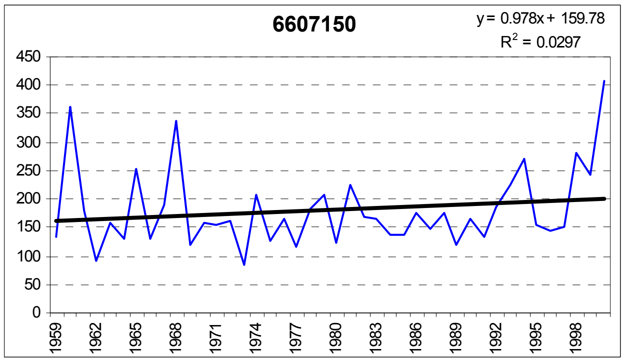
Region Nr 6 – Europe cont.

6607150: Taw, Umberleigh (GB)
51.00 φ N, 3.98 λ W
Area: 826 km^2

Data from 1958 to 2000 (43 years)

Mann-Kendall's test:
Test statistic: 1.48472
Significance level: 86.23%

Max: 409 m^3/s in 2000

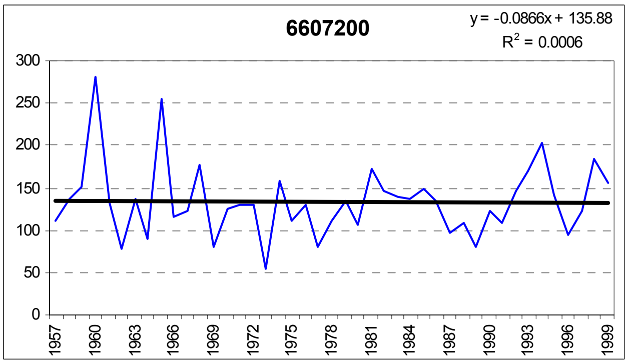


6607200: Exe, Thorverton (GB)
50.80 φ N, 3.51 λ W
Area: 601 km^2

Data from 1957 to 1999 (43 years)

Mann-Kendall's test:
Test statistic: 0.575661
Significance level: 43.51%

Max: 282 m^3/s in 1960

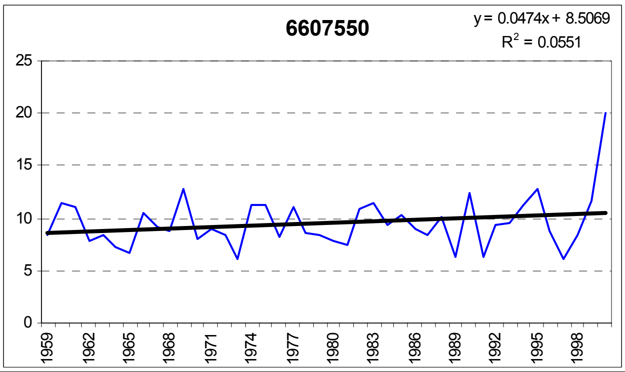


6607550: Itchen, Highbridge-Allbrook (GB)
50.99 φ N, 1.33 λ W
Area: 360 km^2

Data from 1959 to 2000 (42 years)

Mann-Kendall's test:
Test statistic: 1.00788
Significance level: 68.64%

Max: 20.1 m^3/s in 2000

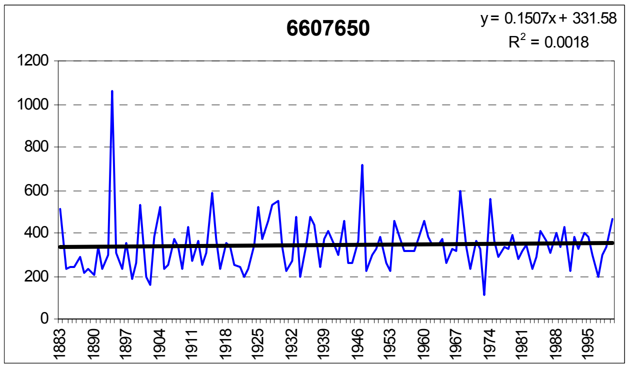


6607650: Thames, Kingston (GB)
51.80 φ N, 0.80 λ W
Area: 9948 km^2

Data from 1883 to 2000 (118 years)

Mann-Kendall's test:
Test statistic: 1.83758
Significance level: 93.38%

Max: 1065 m^3/s in 1894

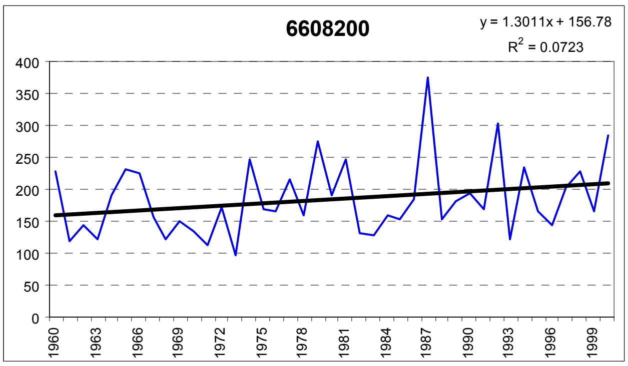


6608200: Teifi, Glan Teifi (GB)
52.04 φ N, 4.56 λ W
Area: 894 km^2

Data from 1960 to 2000 (41 years)

Mann-Kendall's test:
Test statistic: 1.74128
Significance level: 91.83%

Max: 374 m^3/s in 1987



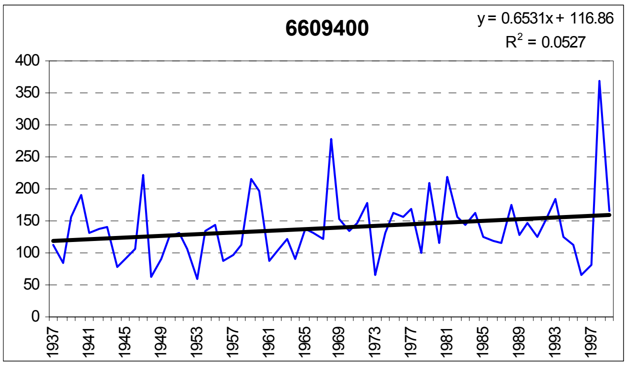
Region Nr 6 – Europe cont.

6609400: Avon, Evesham (GB)
52.06 φ N, 1.56 λ W
Area: 2210 km^2

Data from 1937 to 1999 (63 years)

Mann-Kendall's test:
Test statistic: 1.78532
Significance level: 92.57%

Max: 370 m^3/s in 1998

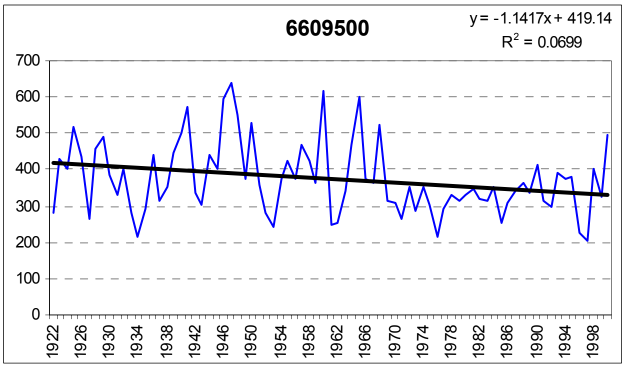


6609500: Severn, Bewdley (GB)
52.37 φ N, 2.32 λ W
Area: 4330 km^2

Data from 1922 to 2001 (80 years)

Mann-Kendall's test:
Test statistic: -2.10414
Significance level: 96.46%

Max: 637 m^3/s in 1947

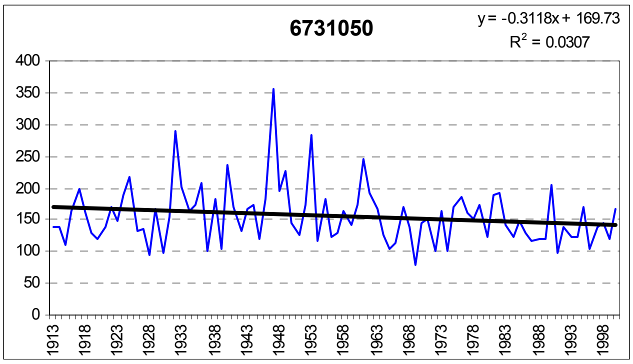


6731050: Stjordalselva, Hoggas Bru (NO)
63.49 φ N, 11.32 λ E
Area: 491 km^2

Data from 1913 to 2000 (88 years)

Mann-Kendall's test:
Test statistic: -1.56788
Significance level: 88.30%

Max: 355 m^3/s in 1947

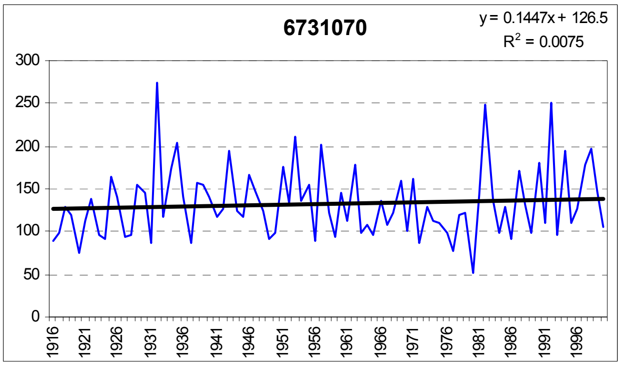


6731070: Nordelva, Krinsvatn (NO)
63.79 φ N, 10.23 λ E
Area: 205 km^2

Data from 1916 to 2000 (85 years)

Mann-Kendall's test:
Test statistic: 0.75912
Significance level: 55.22%

Max: 274 m^3/s in 1932

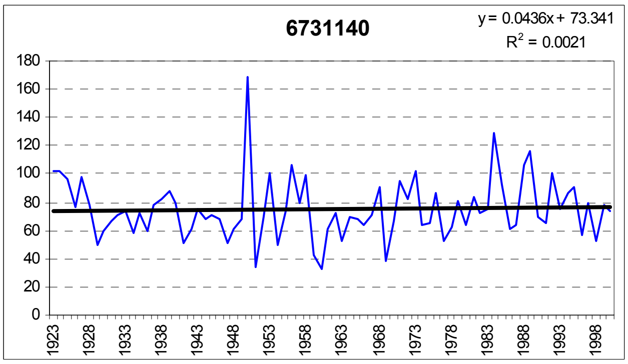


6731140: Kinso, Holen (NO)
60.38 φ N, 6.74 λ E
Area: 229 km^2

Data from 1923 to 2000 (78 years)

Mann-Kendall's test:
Test statistic: 0.444562
Significance level: 34.33%

Max: 169 m^3/s in 1950



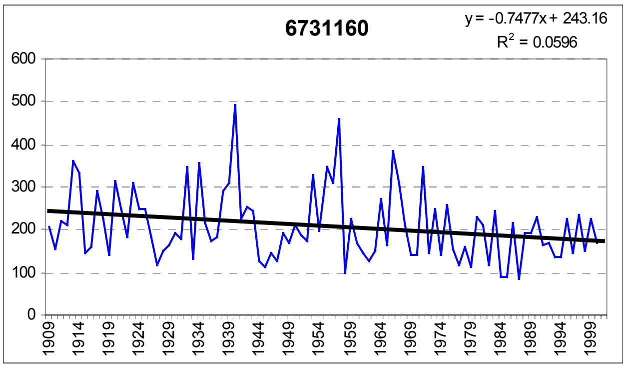
Region Nr 6 – Europe cont.

6731160: Nausta, Nausta (NO)
61.25 φ N, 5.39 λ E
Area: 220 km²

Data from 1909 to 2000 (92 years)

Mann-Kendall's test:
Test statistic: -2.04795
Significance level: 95.94%

Max: 493 m³/s in 1940

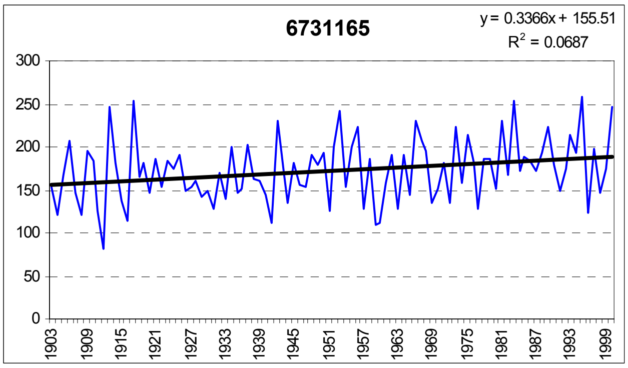


6731165: Gaular, Viksvatn (NO)
61.33 φ N, 5.87 λ E
Area: 505 km²

Data from 1903 to 2000 (98 years)

Mann-Kendall's test:
Test statistic: 2.48019
Significance level: 98.68%

Max: 258 m³/s in 1995

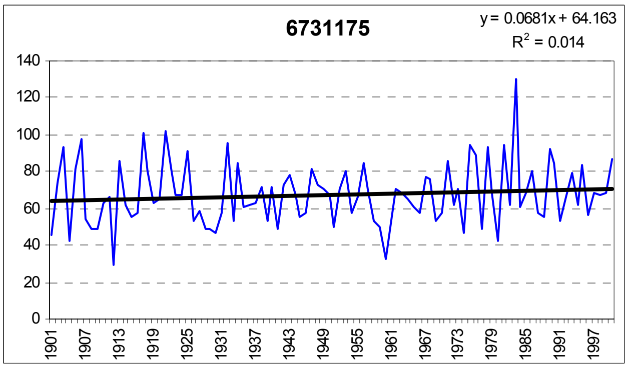


6731175: Eidselv, Hornindalsvatn (NO)
61.92 φ N, 6.09 λ E
Area: 378 km²

Data from 1901 to 2000 (100 years)

Mann-Kendall's test:
Test statistic: 1.20042
Significance level: 77.0%

Max: 130 m³/s in 1983

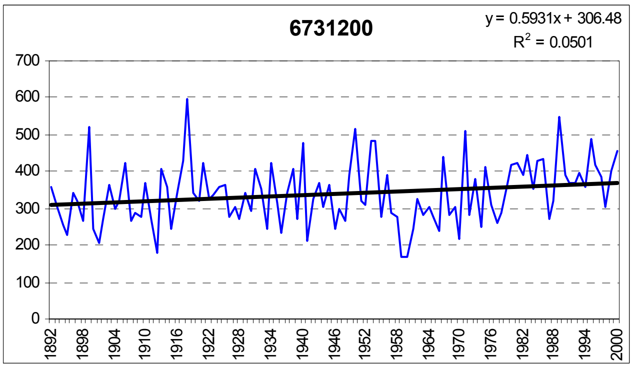


6731200: Vosso, Bulken (NO)
60.63 φ N, 6.28 λ E
Area: 1102 km²

Data from 1892 to 2000 (109 years)

Mann-Kendall's test:
Test statistic: 2.5874
Significance level: 99.3%

Max: 599 m³/s in 1918

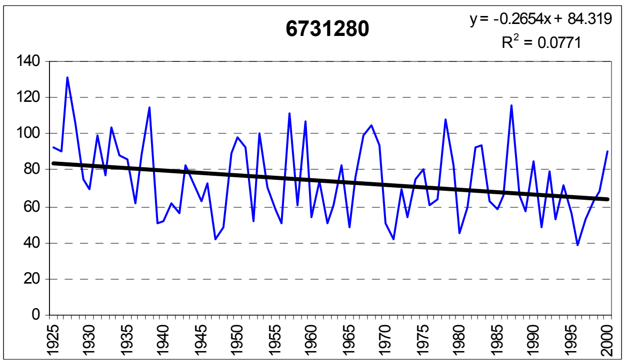


6731280: Austena, Austena (NO)
58.85 φ N, 8.10 λ E
Area: 286 km²

Data from 1925 to 2000 (76 years)

Mann-Kendall's test:
Test statistic: -2.17095
Significance level: 97.0%

Max: 131 m³/s in 1927



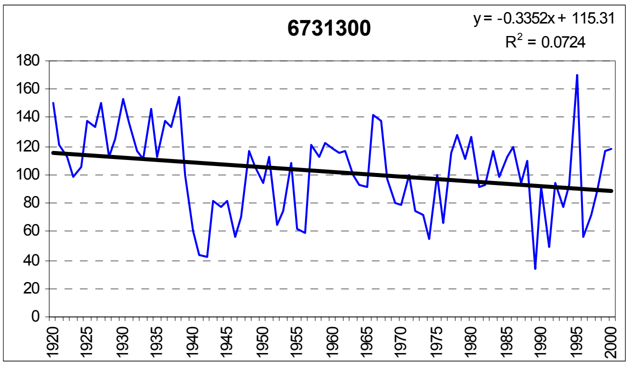
Region Nr 6 – Europe cont.

6731300: Etna, Etna (NO)
60.93 φ N, 9.43 λ E
Area: 557 km^2

Data from 1920 to 2000 (81 years)

Mann-Kendall's test:
Test statistic: -2.58628
Significance level: 99.2%

Max: 170 m^3/s in 1995

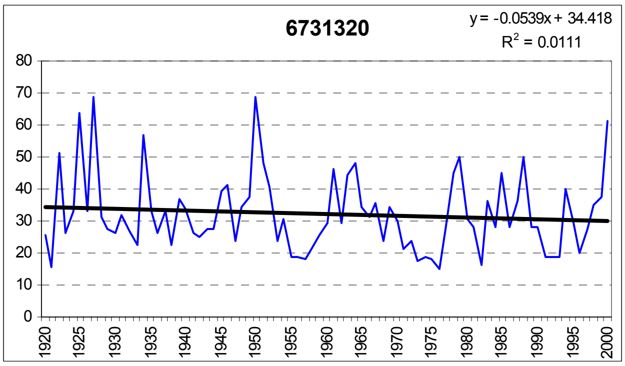


6731320: Jondalselv, Jondal (NO)
59.70 φ N, 9.55 λ E
Area: 150 km^2

Data from 1920 to 2000 (81 years)

Mann-Kendall's test:
Test statistic: -0.497778
Significance level: 38.13%

Max: 68.8 m^3/s in 1927 and 1950

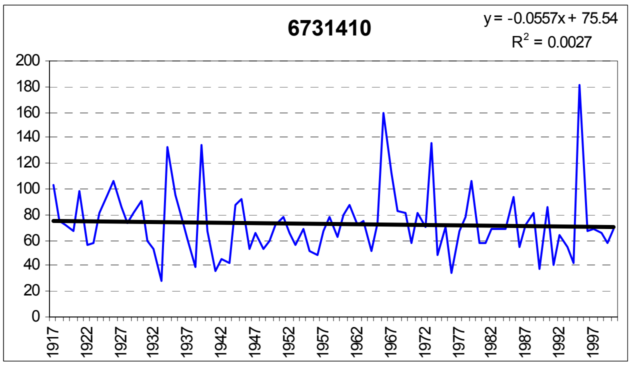


6731410: Atna, Atnasjo (NO)
61.85 φ N, 10.22 λ E
Area: 465 km^2

Data from 1917 to 2000 (84 years)

Mann-Kendall's test:
Test statistic: -1.14762
Significance level: 74.88%

Max: 182 m^3/s in 1995

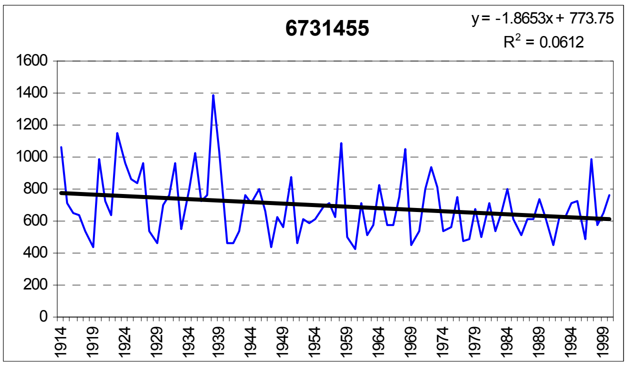


6731455: Otta, Lalm (NO)
61.83 φ N, 9.27 λ E
Area: 3982 km^2

Data from 1914 to 2000 (87 years)

Mann-Kendall's test:
Test statistic: -1.80769
Significance level: 92.93%

Max: 1387 m^3/s in 1938

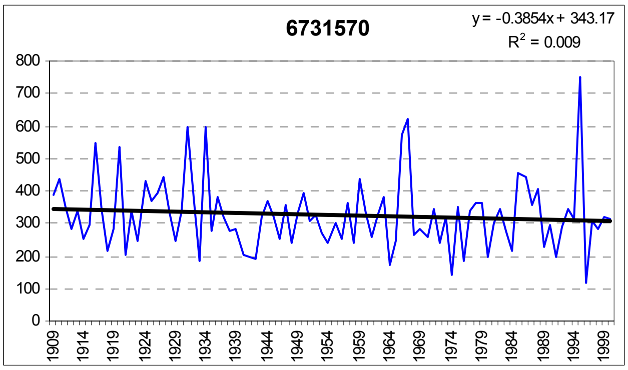


6731570: Klara, Nybergsund (NO)
61.26 φ N, 12.23 λ E
Area: 4410 km^2

Data from 1909 to 2000 (92 years)

Mann-Kendall's test:
Test statistic: -1.2446
Significance level: 78.67%

Max: 751 m^3/s in 1995



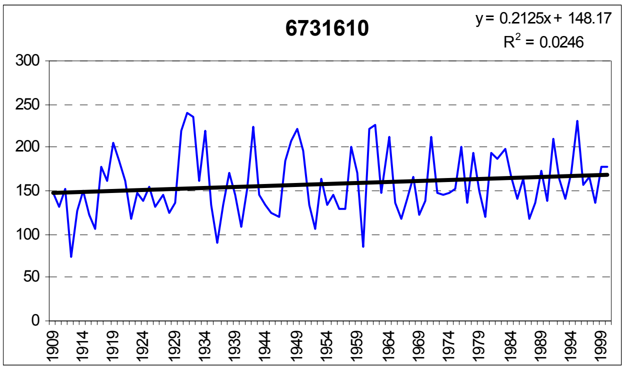
Region Nr 6 – Europe cont.

6731610: Fusta, Fustvatn (NO)
65.90 φ N, 13.30 λ E
Area: 520 km^2

Data from 1909 to 2000 (92 years)

Mann-Kendall's test:
Test statistic: 1.69327
Significance level: 90.95%

Max: 240 m^3/s in 1931

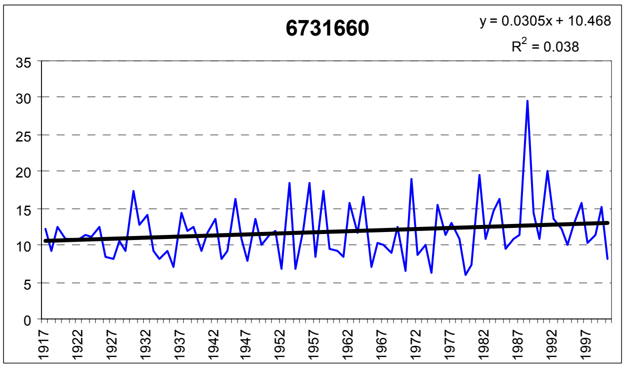


6731660: Strandvass A, Stranda (NO)
67.32 φ N, 14.53 λ E
Area: 23 km^2

Data from 1917 to 2000 (84 years)

Mann-Kendall's test:
Test statistic: 1.25243
Significance level: 78.95%

Max: 30 m^3/s in 1988

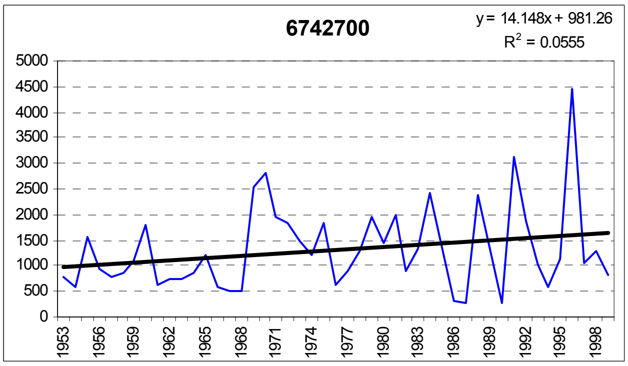


6742700: Siret, Lungoci (RO)
45.55 φ N, 27.51λ E
Area: 36030 km^2

Data from 1953 to 1999 (47 years)

Mann-Kendall's test:
Test statistic: 1.15553
Significance level: 75.21%

Max: 4457 m^3/s in 1996

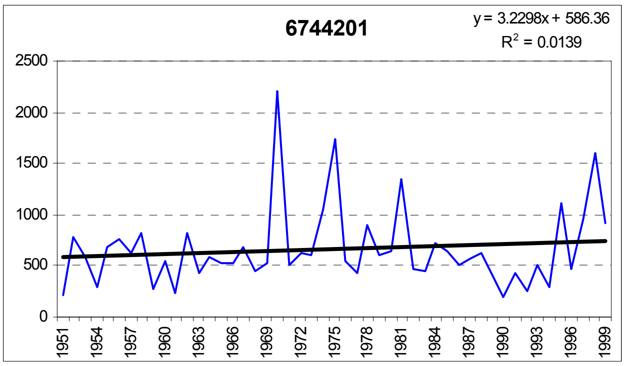


6744201: Mures, Alba Iulia (RO)
46.04 φ N, 23.60 λ E
Area: 18055 km^2

Data from 1951 to 1999 (49 years)

Mann-Kendall's test:
Test statistic: 0.258614
Significance level: 20.40%

Max: 2215 m^3/s in 1970

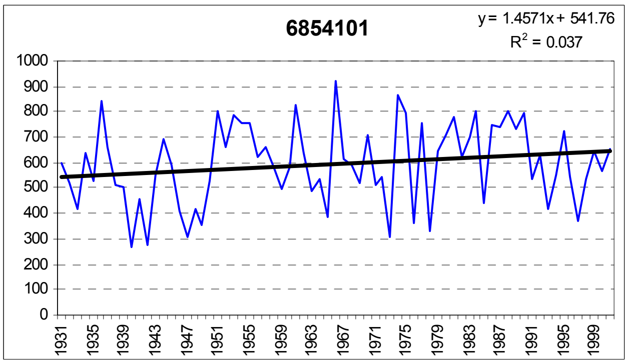


6854101: Kokemaenjoki, Harjavalta (FI)
61.20 φ N, 22.07 λ E
Area: 26117 km^2

Data from 1931 to 2001 (71 years)

Mann-Kendall's test:
Test statistic: 1.52392
Significance level: 87.24%

Max: 918 m^3/s in 1966



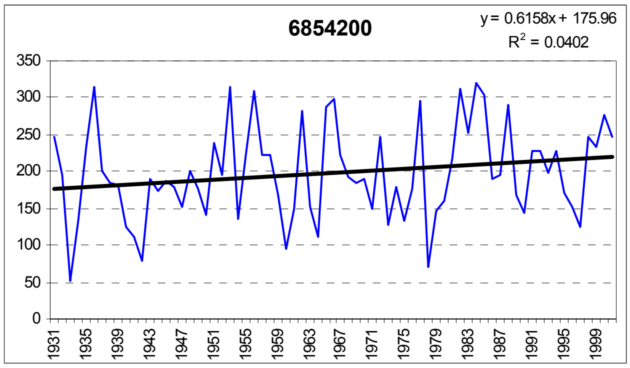
Region Nr 6 – Europe cont.

6854200: Lapuanjoki, Keppo (FI)
63.37 φ N, 22.70 λ E
Area: 3949 km^2

Data from 1931 to 2001 (71 years)

Mann-Kendall's test:
Test statistic: 1.42475
Significance level: 84.57%

Max: 320 m^3/s in 1984

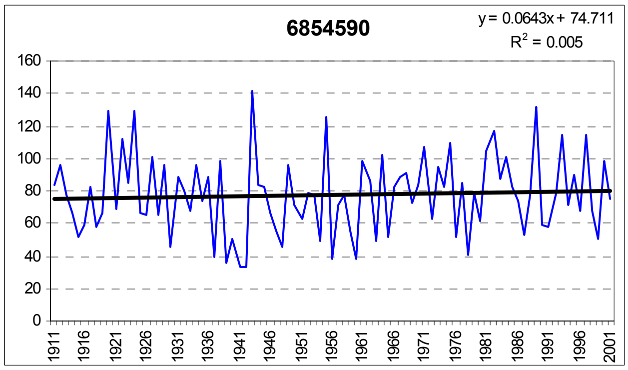


6854590: Oulujoki, Lake Lentua Outlet (FI)
64.20 φ N, 29.58 λ E
Area: 2045 km^2

Data from 1911 to 2001 (91 years)

Mann-Kendall's test:
Test statistic: 0.751053
Significance level: 54.73%

Max: 142 m^3/s in 1943

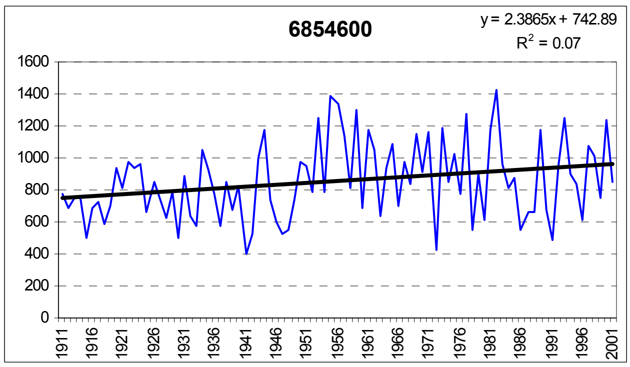


6854600: Iijoki, Raasakka (Near The Mouth) (FI)
65.32 φ N, 25.43 λ E
Area: 14191 km^2

Data from 1911 to 2001 (91 years)

Mann-Kendall's test:
Test statistic: 2.33815
Significance level: 98.6%

Max: 1429 m^3/s in 1982

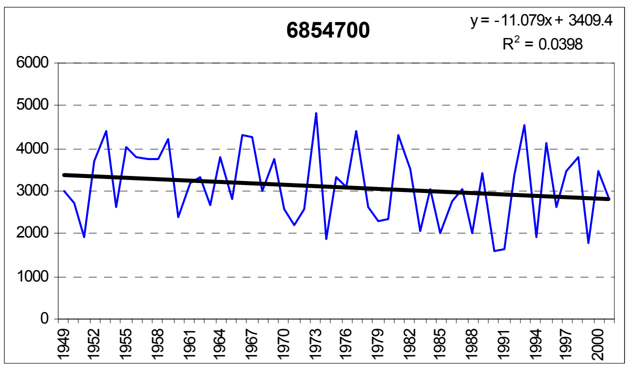


6854700: Kemijoki, Isohaara (Near The Mouth) (FI)
65.78 φ N, 24.55 λ E
Area: 50686 km^2

Data from 1949 to 2001 (53 years)

Mann-Kendall's test:
Test statistic: -1.47277
Significance level: 85.91%

Max: 4824 m^3/s in 1973

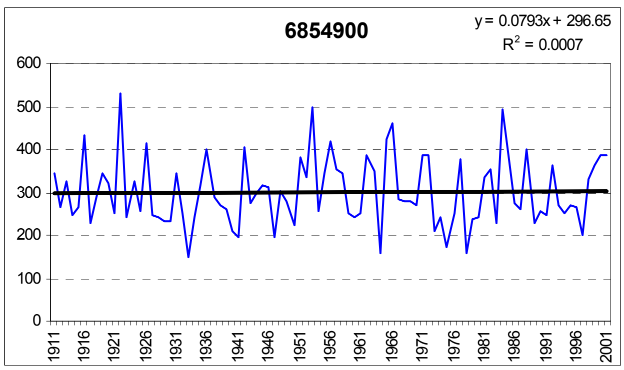


6854900: Kyronjoki, Skatila (Lansorsund) (FI)
63.13 φ N, 21.85 λ E
Area: 4833 km^2

Data from 1911 to 2001 (91 years)

Mann-Kendall's test:
Test statistic: 0.353178
Significance level: 27.60%

Max: 528 m^3/s in 1922



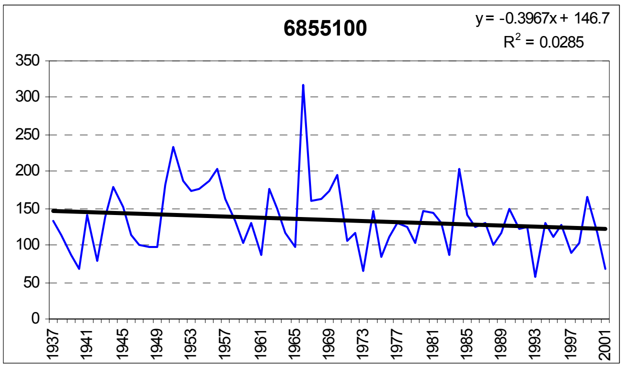
Region Nr 6 – Europe cont.

6855100: Vantaanjoki, Oulunkyla (Near The Mouth) (FI)
60.23 φ N, 24.98 λ E
Area: 1680 km^2

Data from 1937 to 2001 (65 years)

Mann-Kendall's test:
Test statistic: -1.44961
Significance level: 85.28%

Max: 317 m^3/s in 1966

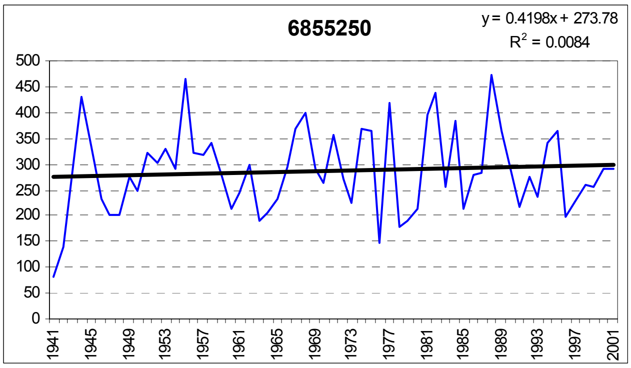


6855250: Leppavesi-Paijanne, Vaajakoski (FI)
62.23 φ N, 25.88 λ E
Area: 17684 km^2

Data from 1941 to 2001 (61 year)

Mann-Kendall's test:
Test statistic: 0.385836
Significance level: 30.3%

Max: 471 m^3/s in 1988

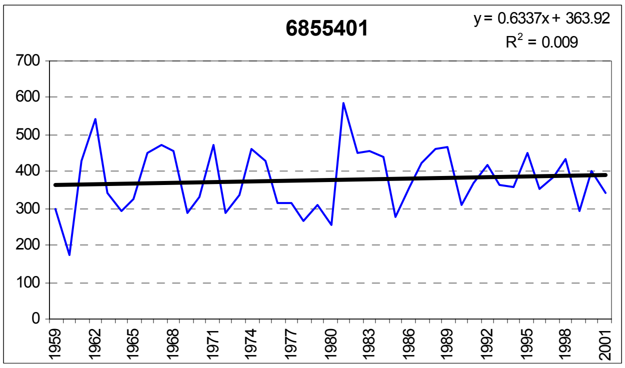


6855401: Pielisjoki, Kaltimo (FI)
62.78 φ N, 30.13 λ E
Area: 20975 km^2

Data from 1959 to 2001 (43 years)

Mann-Kendall's test.
Test statistic: 0.30353
Significance level: 23.85%

Max: 584 m^3/s in 1981

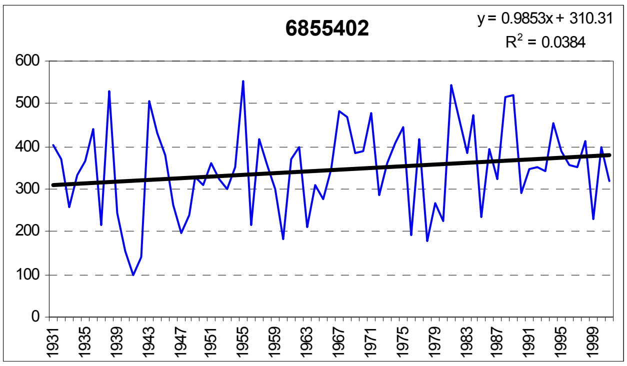


6855402: Kallavesi, Kallavesi-Konnus-Karvio (FI)
62.53 φ N, 27.77 λ E
Area: 16270 km^2

Data from 1931 to 2001 (71 years)

Mann-Kendall's test:
Test statistic: 1.45936
Significance level: 85.55%

Max: 554 m^3/s in 1955

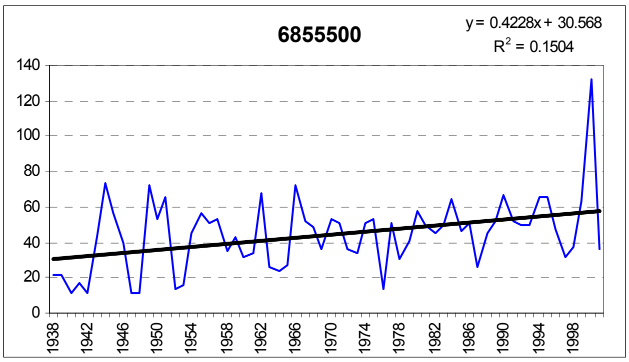


6855500: Karjaanjoki, Lohjanjarvi-Peltokoski (FI)
60.15 φ N, 23.83 λ E
Area: 1935 km^2

Data from 1938 to 2001 (64 years)

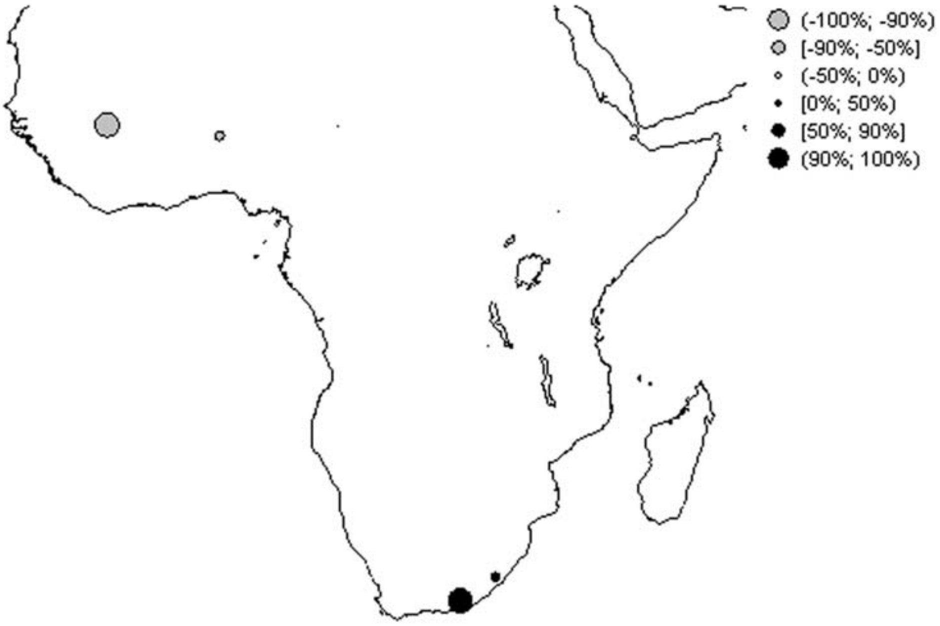
Mann-Kendall's test:
Test statistic: 2.40474
Significance level: 98.38%

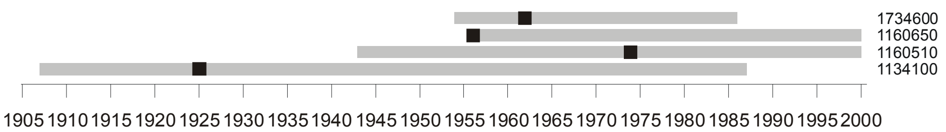
Max: 132 m^3/s in 2000



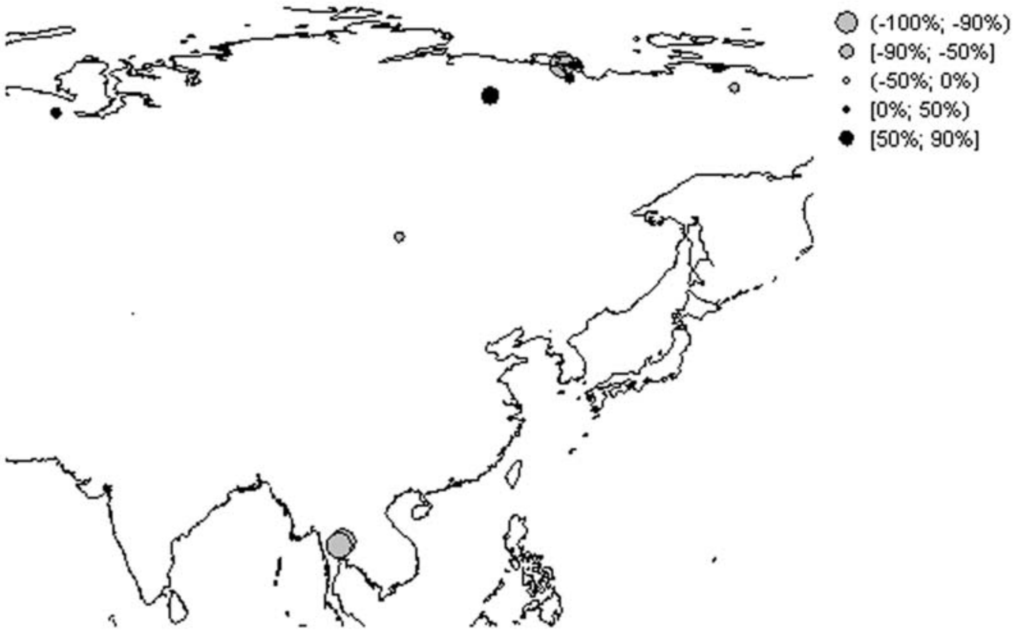
Appendix B

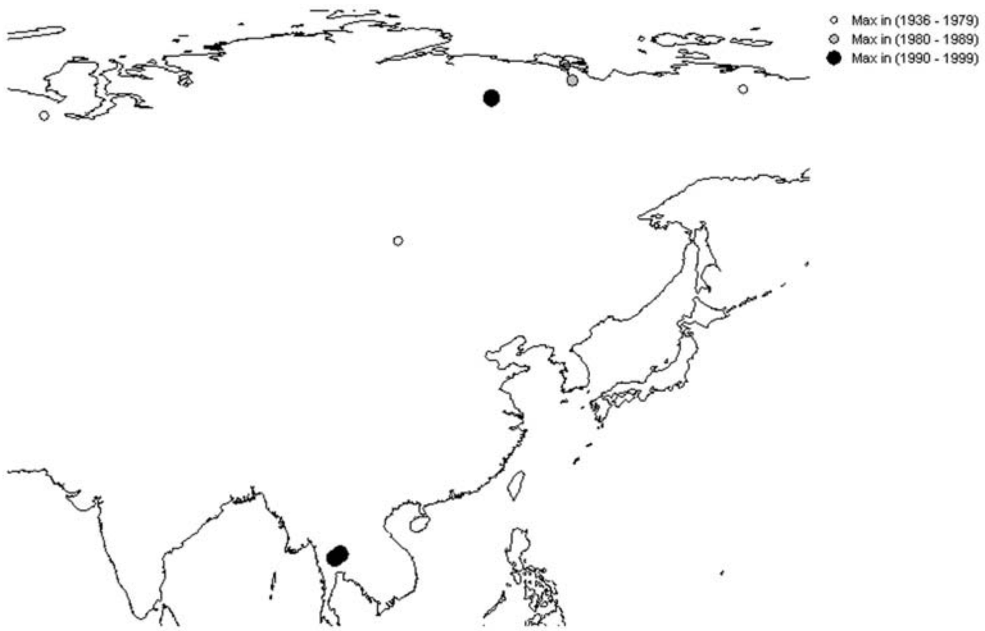
Region Nr 1 - Africa

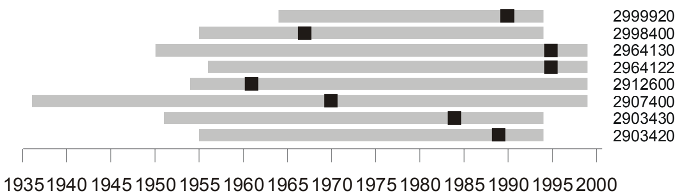




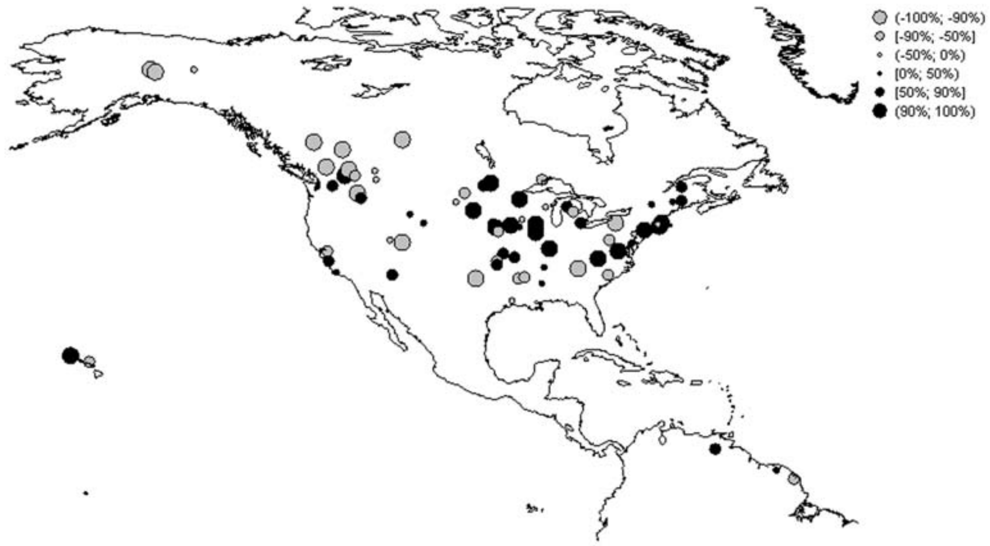
Region Nr 2 - Asia



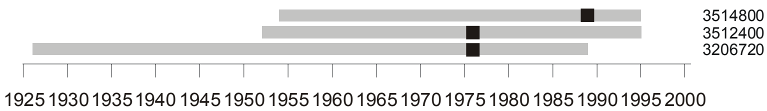




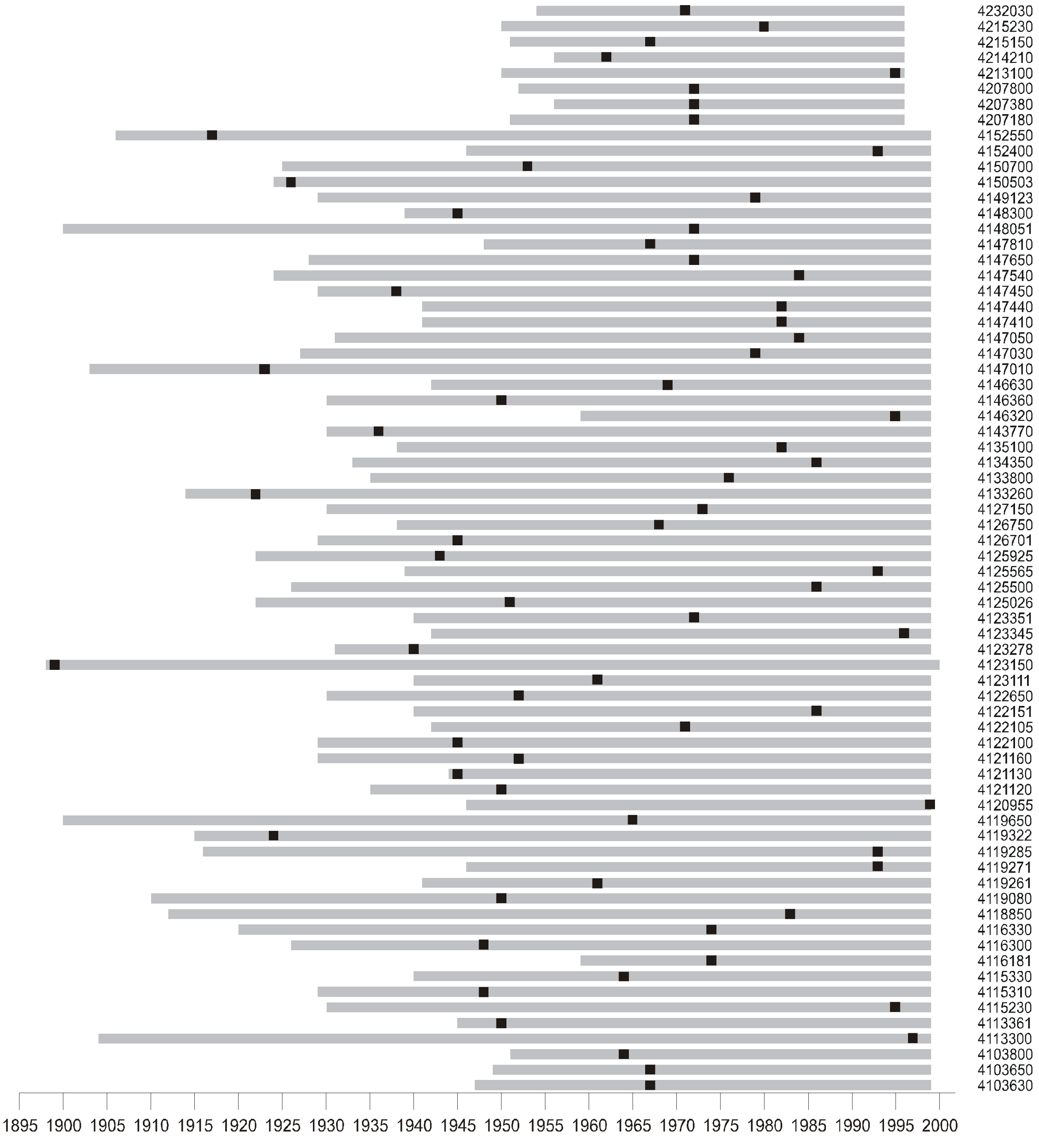
Region Nr 3 - South America and Region Nr 4 - North America



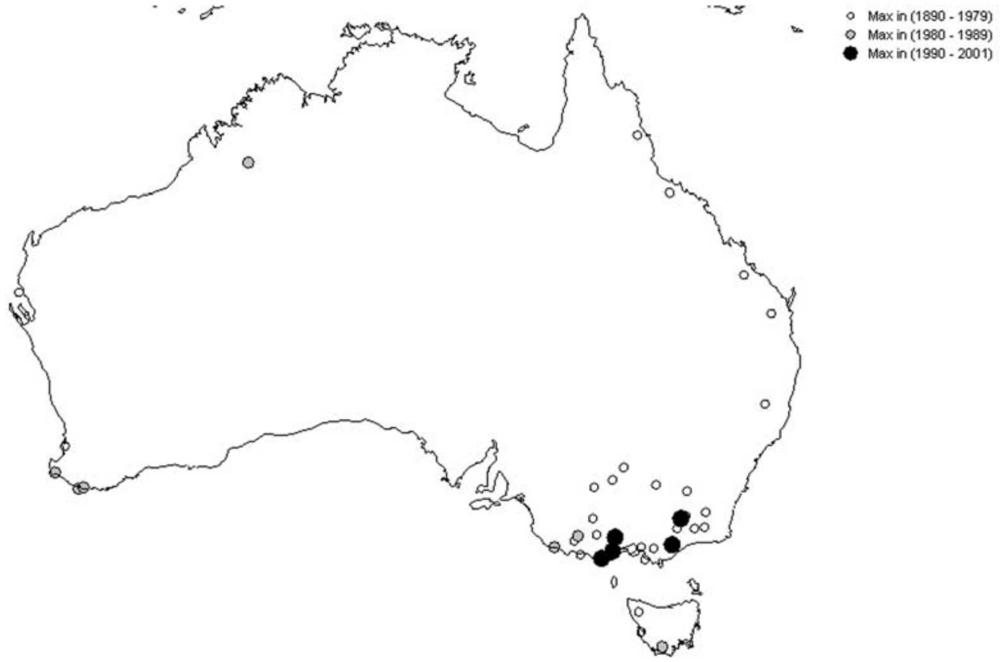
South America

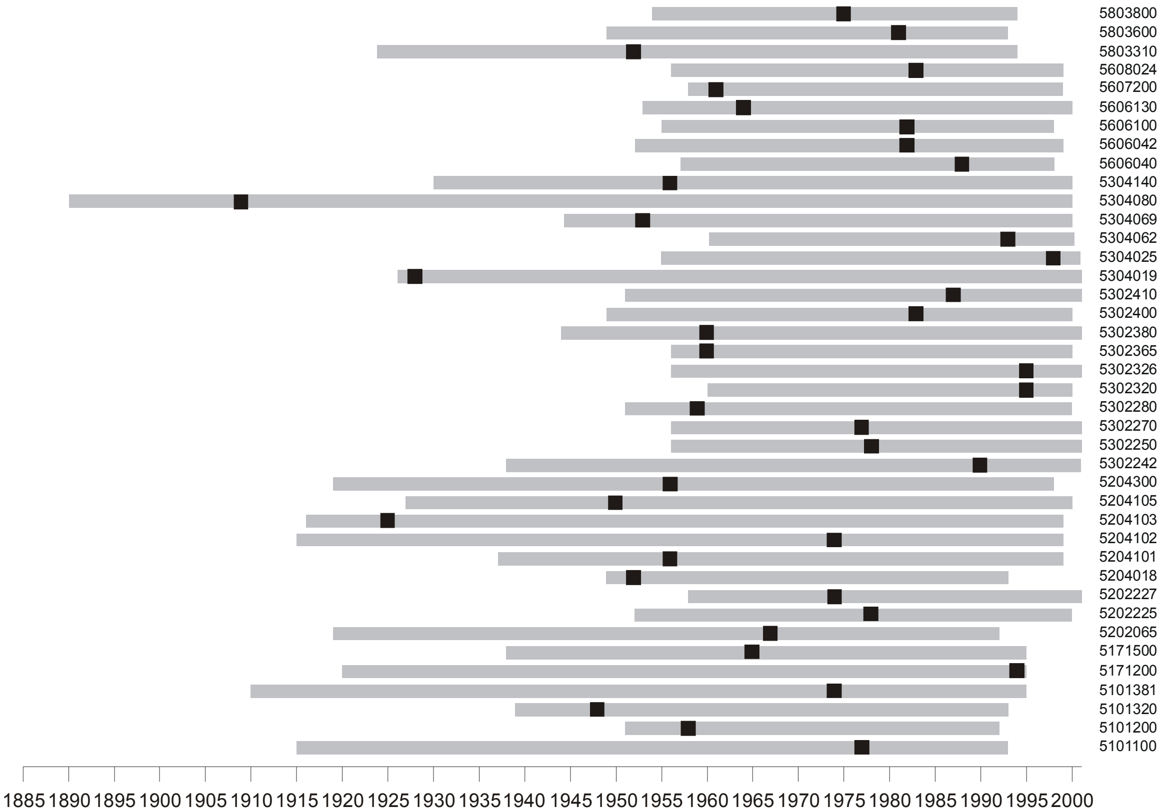


North America



Region Nr 5 - Australia and the Pacific





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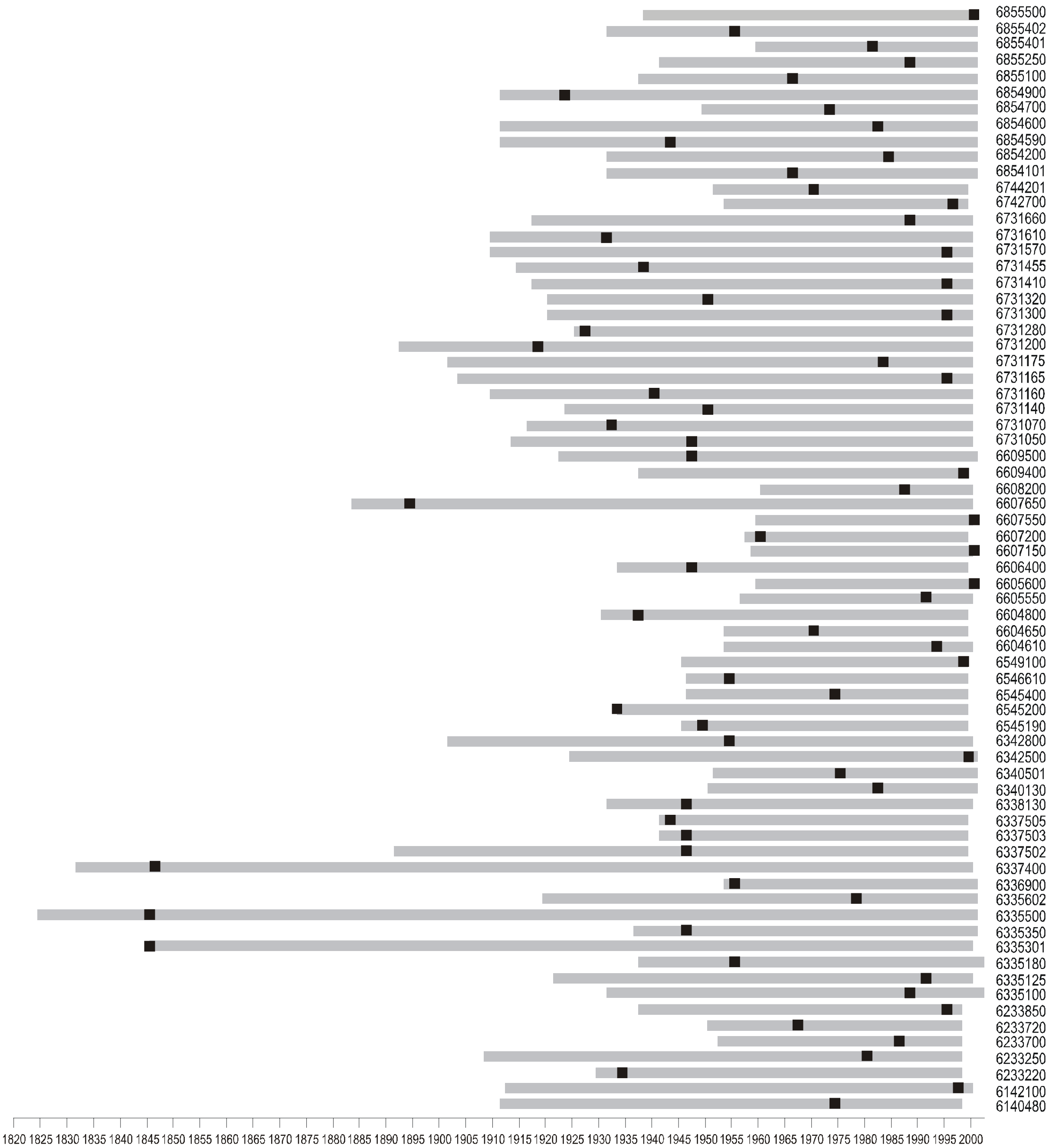
Region Nr 6 – Europe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Koblenz, November 2004

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