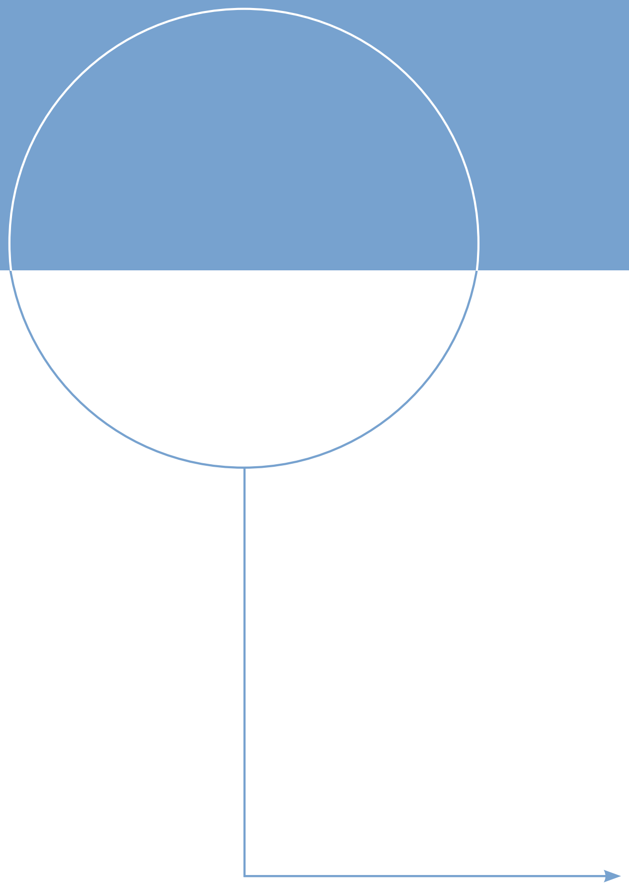

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Finally, and most importantly, my mother, who has always believed in me and encouraged me to move forward in each of my projects.

To each and every one, thank you!

Contents

List of Symbols

Symbol	**Meaning**
S	Mann Kendall test Statistics
n	Number of data points
i	Superior time series
j	Inferior time series
$\mathrm{x_i}$	Data values in the Superior time series
$\mathrm{x_j}$	Data values in the Inferior time series
sgn	Sign function
Var(S)	Variance
m	Amount of tied groups
$\mathrm{Z_s}$	Standard normal test statistic
t_i	Number of ties of extent i
τ	Kendall's tau
D	Maximum possible value of S
P	Probability value of S
$\mathrm{Q_i}$	Sen's slope trend test

List of Abbreviations

COSH	Characterisation of rapid fluctuations of flow and stage in rivers in consequence of hydropeaking
SINTEF	Stiftelsen for industriell og teknisk forskning (The Foundation for Industrial and Technical Research)
NTNU	Norwegian University of Science and Technology
NVE	Norwegian Water Resources and Energy Directorate
MW	Megawatt
TWh	Terawatt hour
DOR	Degree of regulation
Inc	Increasing
Dec	Decreasing
Max	Maximum
Min	Minimum
Avg	Average
RoR HP	Run-of-river Hydropower
Fig	Figure
HP	Hydropower plant
EUR	Euro
Sig	Significant

1 Introduction

Hydropower covers 96% of the electricity produced in Norway [1] and is a central matter in Norwegian water management. The growing interest in implementing an appropriate water regulation, re-licensing existent power plants and the protection of biodiversity has increased the focus on environmental management. In addition, hydropower plays a very important role in the mix of renewables as a balance for the intermittency that implies the implementation of solar and wind energies.

In 1991 a new energy law was passed in Norway that allowed trading of electricity in the market. This increased the incentives to adapt production to high prices in order to maximize revenue, which was different to the strategies of national demand coverage that was the objective before the new law. The Act No. 50 of 29 June 1990 or so called "Energy Act" came into force on 01.01.1991. It is the treaty responsible for managing and ensuring the proper use of energy through its entire cycle, including production, conversion, transmission, trading and distribution [2]. The creation of this law officially marked a change in the dynamics of the energy market. It modified the way in which the energy was generated and distributed in Norway and the other Nordic countries. From this moment on, markets opened up to competition and the possibility of including different actors in the commercialization of energy was generated [3].

It has been observed that after this Energy Act, the hydropower plants have intensified their production considerably in order to satisfy the demand in the energy market. Since the energy requirement is intermittent and obeys to consumption peaks that change depending on the time of the day and the period of the year, the plants must also operate in the same way. This is reflected in periodic and very rapid fluctuations in both, water level and discharge of the rivers located downstream the powerplant outlets. This phenomenon is called hydropeaking and can be observed more clearly the closer the measurement stations are to the hydroelectric plants.

There are many studies that show the negative effects of abrupt changes in the flow and water level in riverine ecosystems. It has been proven that these fluctuations can cause large-scale impacts in both, short and long term, in the organisms that live there, triggering mechanical, predatory and physiological stress [4]. Likewise, considerable increases in the flow can alter the transport of particles in the water which can end up hurting the fishes, thus generating a decrease in the primary production [5]. In addition, the fluctuations in the water temperature caused by hydropeaking can generate impacts on survival rates, growth, reproduction and biotic integrity of the organisms in the riverine ecosystems [6].

Most of the existing studies associated with the effect of hydropower regulation on environmental issues related to water management have been carried out in detail in very specific sites, but it is necessary to implement more general analysis, on a larger scale, both temporally and spatially, in order to have a clear idea of the current situation in Norway and thus assess the environmental impacts that these changes to the power market have caused. In this way, there would be better bases to take action against the possible consequences of an incorrect interpretation of the environmental law and an inadequate management of hydroelectric plants in order to increase revenues.

The purpose of this study is to assess the operational changes over time for part of the Norwegian hydropower system by evaluating trends on key hydrological indicators downstream of the power plant outlets. Twenty six measuring stations (gauges) located in rivers under the influence of hydroelectric plants will be analyzed. The information obtained from these gauges includes discharge [m^3/s] and water level [m] that have been registered since 1985 in most cases or a little later depending on the availability of the information. The idea is to carry out an exhaustive study of the behavior of these parameters and to observe if there is any change or increase after 1991, the year in which the liberalization of the energy market took place.

In the first place, a qualitative analysis will be done through graphs, in which a general overview of the information will be performed in order to define the possible presence of trends. This analysis will be carried out with COSH Tool, a software developed in Matlab by Julie Charmasson and Julian Sauterleute at SINTEF Energy Research (The Foundation for Industrial and Technical Research), which by means of algorithms, can define the presence of increasing and decreasing hydropeaking events, quantify and classify them depending on their frequency by hour, day and year. Once all the measurement stations have been analyzed, the existence of trends using Mann Kendal and Sen's slope test will be verified with the statistical software R. In this way it will be possible to define whether the detected trends are significant and thus, determine their magnitude and direction.

The same analysis will be done with a sample of unregulated rivers to illustrate the difference between the behavior of water bodies that are influenced by anthropogenic activities (hydroelectric plants) and those rivers that only have to deal with the natural changes of the environment and the weather.

2 Background

2.1 Hydropower

Hydropower, hydraulic power or water power is the power that is derived from the force or energy of moving water [7]. The principle of hydropower lies in generating electricity from a process of harnessing the potential energy generated by the elevation and topography in which the water bodies are located [8].

Many hydroelectric plants use water storage systems, or simply take advantage of lakes to use them as a reservoir that can be exploited later according to demand, weather conditions and the period of the year. It should be kept in mind that this capacity of storing water (and therefore future power) is a very valuable advantage that gives flexibility and support to this source of renewable energy, which is not the case with solar and wind energy. Apart from the reservoir scheme that uses the potential energy due to height differences between the water bodies that flow through slopes, there is also the so called run-of-river scheme that basically takes advantage of the natural flow rate of the rivers to generate power, but without the use of large reservoirs. Once in the power station, the collected water, independent of the chosen method, moves through one or several turbines, which impulse its movement and subsequently this mechanical energy is transformed into electrical energy by a generator [9].

Given that most hydroelectric plants in Norway handle such production schemes, each one of them will be explained below.

2.1.1 Run-of-river hydropower

The principle of this system is to take advantage of the water that flows through a stream which in most of the cases is a river. Here the water is not dammed but only diverted for a moment from its course in order to pass through a hydroelectric plant where it must cross a hydro-turbine generator to generate power that will later be converted into electricity. Once the water has passed through the turbine, it is returned to the river course, at a lower point than where it was initially collected. The water is usually diverted using a low barrier that is located across the river with the sole purpose of generating a small pond in which the water can be collected and then sent to the turbines through a penstock. Contrary to a dam, this barrier does not stop the passage of water nor retains it. Due to the principle that is used, most of these plants do not have storage, even so, some of them need to incorporate a small pond in order to conserve the flow to the plant when the water level is very low, in this way the plant can maintain its operation.

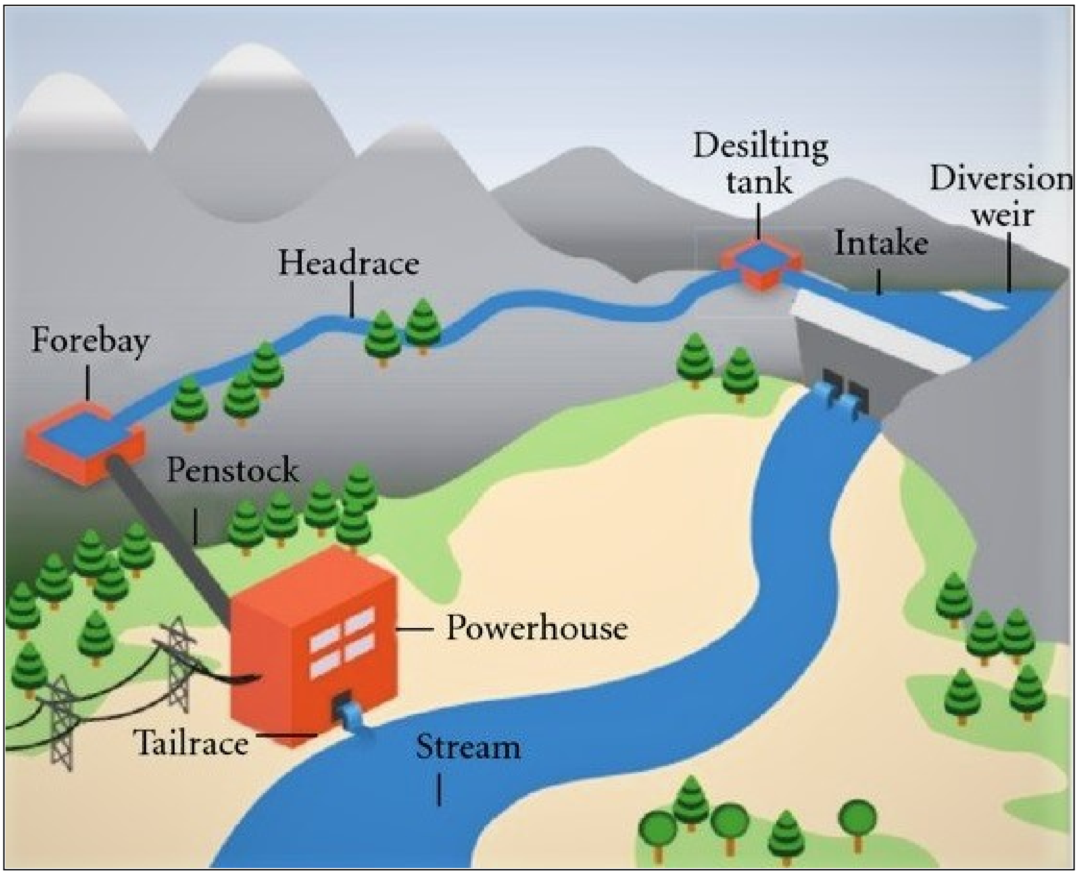


Figure 1: Scheme of a run-of-river power plant. Taken from [10]

The figure 1 shows a scheme of a run-of-river hydropower project (RoR HP). In order to increase the efficiency of the process, a diversion structure is built which aims to transport the water from the intake to the power station and its turbines taking advantage of as much energy as possible. First, the water is diverted from the river into the headrace which is a channel responsible for mobilizing water to the forebay that should be located slightly higher than the powerhouse. The headrace must be designed in order to take full advantage of the topography of the area, exploiting every possible difference in height since this is translated into energy.

Once the water has passed through the headrace, it is redirected to the powerplant and its turbines through a pipe called penstock, which has the function of eliminating unnecessary turbulence and with this, possible energy losses. As it can be seen in figure 1, the penstock intake is located at a higher point with respect to the powerhouse, this difference in height represents the head of water that will be used to take advantage of the potential energy and generate power in the plant. The height and slope of the penstock contribute to the generation of pressure in the water that reaches its bottom before passing to the turbines, the higher this head, the greater the potential energy available for generating power. Additionally, the force with which the water flows is translated into kinetic energy which will also help to drive the movement of the machines. Once the water has passed through the turbines, it is released downstream through the trailrace [8].

This scheme generates a lower impact on the entire ecosystem and the dynamics of the river, than the ones caused by a reservoir dam, and the costs are significantly reduced since no complicated engineering and construction processes are required, as it is the case of a dam.

On the other hand, since run-of-river hydropower is based mainly on the use of force and river flow (no storage), the power generated can be quite variable, taking into account the changes in flow and precipitation that occur during seasons, therefore the effectiveness of this system is quite reduced. Also when there are periods of abundant rainfall and high water flows, due to the lack of a storage system, part of the water must be spilled without its energy being used by the plant [8].

2.1.2 Dams and Reservoir Projects

This type of hydropower plant is widely used since it provides stability in production due to its storage scheme. In this case a large and solid structure (dam) is built across the river, which is responsible for the generation of large reservoirs of water. These lakes that are formed behind the dam have the functionality of storing the water in order to use it when it is necessary for the generation of power and also influence the control of the flowpeaks.

The principle used in a dam and reservoir project (figure 2) is very similar to the one explained above in the case of run-of-river plant. The water is collected in the reservoir and later it is extracted from the dam and transported through the penstock with the purpose of passing through the turbines and generate electricity. Later it is released to the river again through a trailrace. The design of this type of project can sometimes be more compact than that the one from a run-of-river plant since the main head of water can be controlled and generated directly from the dam [8].

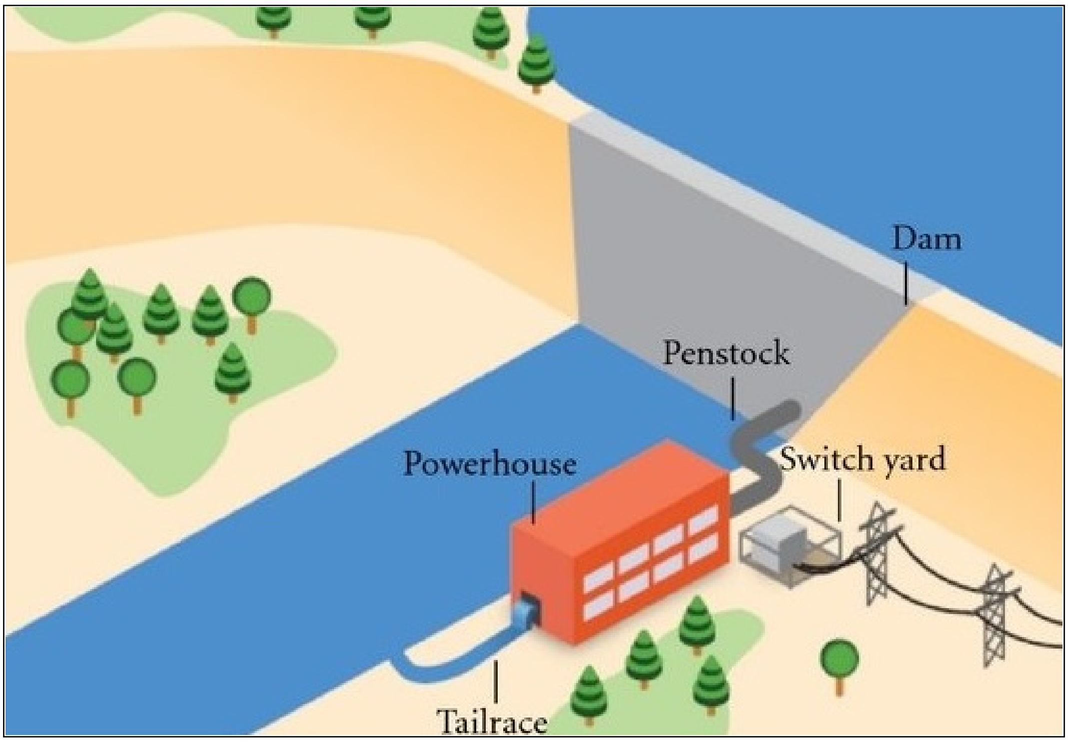


Figure 2: Scheme of a dam and reservoir. Taken from [10]

This scheme has great advantages since it increases the effectiveness of the power generation process by optimizing the use of water energy. Likewise, due to its large size, it causes impacts on the ecosystem around it, both during its construction and also when it is put into operation. The dam is a large structure that disrupts the landscape, and the lake that works as a reservoir of water occupies large tracts of land which significantly impacts not only the dynamics of the river but also the environment that surrounds it.

This system influences the flow of water since it tries to level it in some way, taking into account that it collects water during periods of abundant rainfall and releases it in times of drought, but such interventions with the natural dynamics of the river also creates a considerable impact on the ecosystems downstream as these tend to adapt to the natural changes of flow and stage of water due to the seasons.

This study will show how the behavior of hydropeaking has changed in a large sample of rivers in Norway since the environmental law of 1991 was decreed and some changes that have occurred since then in the flow of rivers, this through the analysis of the available databases and the information provided by The Norwegian Water Resources and Energy Directorate (NVE).

In the same way, it will be evaluated if the modification of the law and the incentives in the production have influenced the intensification of the use of the power plants and therefore the increase of the hydropeaking downstream the power plants outlets.

Types of Dams

A dam is a structure responsible for containing and accumulating the water that flows through a stream, thus generating a reservoir or lake. It can have multiple functions such as flood control, water supply, irrigation or electricity production, the latter will be our focus [11]. Apart from allowing the accumulation of water, the dams also provide other resources that contribute to the proper functioning of hydropower plants, as it is the case of the spillway that helps to prevent the complete filling of the reservoir by releasing part of its water when its level is approaching the top, thus avoiding the failure of the dam. Depending on its size, passages can also be built which allow the movement of fishes from one side to the other, or even, if the dam is of a considerable magnitude and takes place in a navigable course, ship locks can also be designed that allow the passage of the boats. According to the scheme adopted for hydropower, a powerhouse with turbine could be placed inside the dam, including inspection galleries [8].

Dams can be classified into two main groups taking into account the material used during the construction: embankment dams and concrete dams, emphasis will be placed on the latter since they are the most used in our study area.

Embankment dams

In this category two main types of dams can be found: earthfill and rockfill embankment dams. One of its main features is that its construction is made with a big amount of natural and geological materials, excluding those that can change their properties during the process for example dissolving or evolving. The construction process is based on the superposition of layers of previously compacted materials [11].

Concrete dams

This type of dam is made of concrete and its design depends mainly on the morphology of the area and the foundations of the terrain. There are 4 main types of dams within this category: Buttress dams, Arch dams, Double curved arch dams and Gravity dams [11]. Emphasis will be placed on the latter type given the nature of the dams in the area of study. The figure 3 shows the Zakarias Dam which is a concrete arch dam located in the Tafjord Valley in northwestern Norway. It is Europes second-highest magazine dam with 96 meter high and was built in 1967 [12].

Gravity dam

It is a massive dam that has been built with large volumes of concrete and/or masonry as its main materials. It works due to the effect that gravity exerts on its mass.

Its operating principle is based on the presence of an upstream phase with a very steep slope (vertical or semi-vertical), and a downstream side with a slope that results in a triangular structure. Its cross section must be designed to deal with the thrust of the water without problem. This type of dam must be built on strong and secure rock foundations to ensure resistance to water pressure and also prevent leaks below the dam. Gravity dams can be higher than embankment dams and likewise they could have different extensions due to its operating principle which allows them to be built in both narrow and extensive valleys. The tallest concrete gravity dam is the Grande Dixence dam in Switzerland with 285 m. high [8][11].

2.1.3 Norwegian Hydropower

More than 96% of Norway's energy comes from hydropower [1], which makes a big difference to the rest of Europe. Since the basis for the generation of hydroelectricity depends on precipitation, significant changes may occur throughout the year depending on the rate of rainfall and weather conditions. To counteract this instability in the supply, the Norwegians have taken advantage of their privileged topography and have made their large storage capacity one of the distinguishing features of the country's hydropower system. This scheme provides flexibility in production and allows it to be increased or decreased according to the supply and demand dynamics, offering the possibility of optimizing costs and also minimizing possible losses due to excess of production in periods of low demand.

More than 75% of the production capacity in Norway is flexible, which is understandable,

Figure 3: The Zakarias Dam, Second highest magazine dam of Europe. Taken from [12]

given that the country has almost half the reservoir capacity of Europe. This flexibility and storage capacity makes hydropower an excellent complement for the use of other renewable energies such as wind and solar and additionally serves as backup since these can be intermittent. At the beginning of 2018, Norway had an installed capacity of 33755 MW, and a normal annual production of 141 TWh. In terms of storage capacity, the country has more than 1,000 hydropower storage reservoirs with a total capacity of more than 86.5 TWh [15].

Although many variations occur and the hydropower plants must adopt different schemes depending on the geographical and geological conditions of each zone, it is interesting to illustrate an example of the operation of a common hydropower project in Norway. Generally the hydropower plant has a reservoir located high-up in a mountainous area, which can also have a second level storage facility such as a glacier. In these cases the water that melts is conducted towards the plants through tunnels. After the force of the water has been used by the generators, it is released into a lake, a fjord or even a river, in that matter, the energy of the water can also be used to put into operation run-of-river power plants that could be designed in a cascade arrangement one after the other in such a way that full utilization of the resource is made before it finally reaches the sea [16].

The Fig 4a shows a dam on intake reservoir Lake Viddalsvatn. The power plant in charge of producing electricity from this reservoir is Aurland I and is situated in the Aurland

(a) Barrier dam at Aurland I Power Plant [13]
(b) Gravity dam at Alta Power Plant. [14]

Figure 4: Examples of dams in Norwegian power plants

Municipality, specifically in the Sogn og Fjordane County [13]. The Fig 4b shows a gravity dam at Alta Power Plant which is located in Sautso, Alta Municipality in Finnmark County [17].

It is important to note that there is also a classification for hydropower projects according to the difference in height that exists between the inlet or headrace and the outlet or tailrace (see figure 1). This difference is called head and is important in the design of a hydropower plant since it defines the force with which the water acts on the turbines and thus influences the power output. The Norwegian hydropower is characterized as a high head reservoir system. There are several classifications, according to the European Small Hydropower Association the hydropower projects are categorized according to the head as follows: low head includes the plants with less than 40 m, medium head is located between 30 and 100 m and high head involves the projects that exceed 100 m [10]. The flow fluctuations induced by the high-head storage power plants in general present very high frequencies and intensities [4].

2.1.4 Hydropeaking and environmental impacts

Hydropeaking can be considered as the action of releasing pulses of water that is stored in reservoirs in order to increase hydroelectric power production and fulfill the electricity demand [18] [19]. These changes in the demand for electricity, the market and the management carried out by hydroelectric plants together with their efforts to comply with production standards are closely related to the behavior of prices, offer and demand.

These periods of hydropeaking are characterized by continuous variations in the production of electrical energy that can vary in their duration and frequency throughout the day. These changes are usually repetitive during the week and likewise it can be seen little or no activity during the weekends [20].

There are many studies that show negative effects due to abrupt changes in the discharge and water level in aquatic ecosystems.[21] [22]

Water from hydroelectric plants can be released into different water bodies like rivers, reservoirs or even the sea. This document will discuss the alteration of the natural flow and stage of the rivers due to the release of production water, a phenomenon that is called "stream hydropeaking". This type of hydropeaking is characterized by abrupt alterations in the discharge and water level of the rivers that are located downstream from the power plant outlets. The consequences of these unnatural alterations are very varied and affect a great number of factors in the entire riverine ecosystem [20].

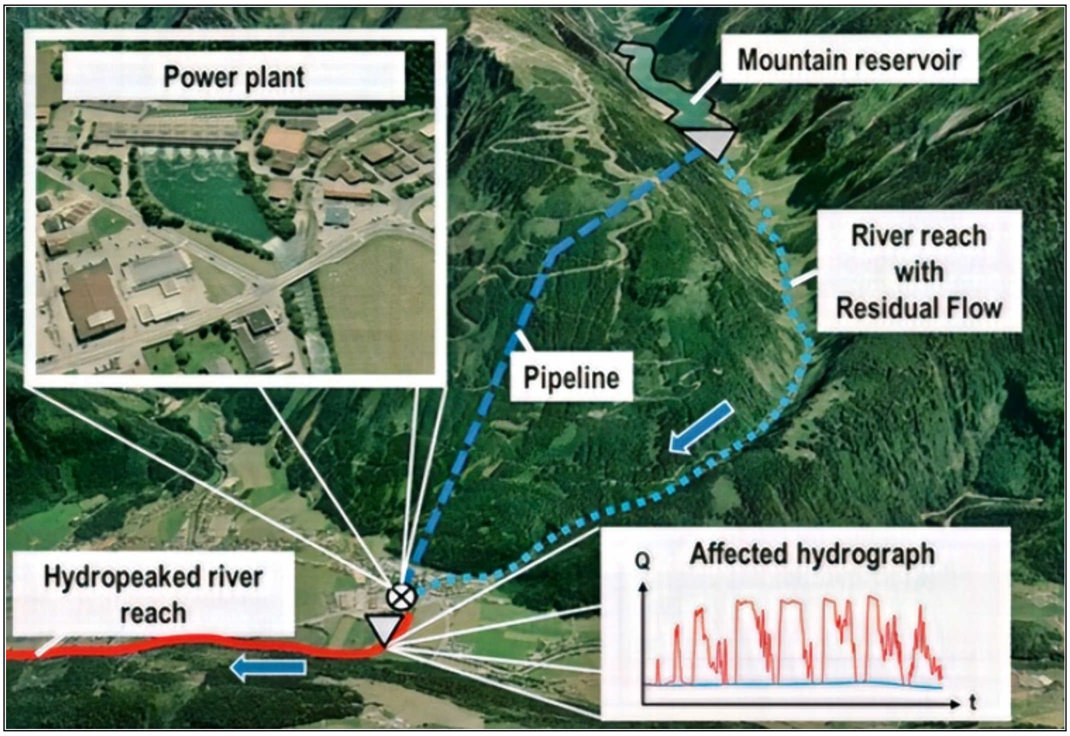


Figure 5: Scheme of a high-head storage power plant and discontinuous release of turbined water due to peaks of energy demand (hydropeaking). [4]

Figure 5 shows a model of high-head storage power plant. This type of scheme is usually characterized by inducing significant changes in the flow of rivers that are located downstream of the reservoirs, these impacts are even greater than those generated by other anthropogenic activities as it is the case of run-of-the-river power plants, which also intervenes in the natural dynamics of the river due to gate manipulation, turbine regulation and pumping stations [4].

The diagram shows a reservoir located on top of a mountain, which facilitates the use of the potential energy in the water due to height. It also shows a river reach with the residual flow that is not used to generate electricity as well as the pipeline that transports the water from the reservoir to the turbines located downstream in the power plant. Once the water has been used for the generation of energy, it is returned to its natural course where is combined with the watercourse, this causes an impact on the flow and water level of the river. The image also ilustrates an example of a hydrograph affected by hydropeaking in which the intermittence of the flow can be obsserved [4].

These fluctuations in the flow of rivers caused by the intermittency in the operation of hydroelectric plants can generate large-scale impacts both at short and long term in riverine ecosystems. Fish, benthic and hyporheic communities can be affected by this phenomenon that can significantly alter their abundance and faunal composition [23] [24].

Occasionally, these sudden increases in the discharge of watercourses force the organisms to invest large amounts of energy in order to remain in the desired position, avoid being removed from the underlying substrate and subsequently dragged downstream. This can occur when the peak is quite intense and the efforts of the organisms to remain in the respective position are not enough which at the same time can make them end up in habitats that are not the most appropriate and trigger mechanical, predatory and physiological stress [4]. Therefore hydropeaking influences the increase in fish and invertebrate stranding which can be defined as any event that restricts fish to habitats that are not very suitable for them, as a consequence of their separation from the water body that comprises their usual surroundings [25].

It is important to study the operational changes of the hydroelectric plants in order to determine how high their impact is and thus be able to define appropriate mitigation measures for the effects of hydropeaking that are mainly related to the frequency and duration of the peaking events. In the case of stranding risk, which is one of the most frequent effects, it is suggested to consider diurnal and seasonal fish behavior to define the operation of hydroelectric plants [26].

The increment in the mobilization of sediments can increase the levels of mechanical stress as well as transportation of particles which can damage organisms, reduce biomass considerably and decrease primary production [5].

Additionally, hydropeaking can also trigger fluctuations in water temperature which impacts on survival rates, growth, reproduction and biotic integrity in the riverine ecosystem [27]. Likewise, when there are decreases in the water level some areas are discovered, this phenomenon is called dewatering and can generate negative impacts in the local stream food web [6].

2.2 Power market in Norway

2.2.1 Regulation and liberalization of the European electricity market

In order to understand the process by which the energy market in Europe has passed in terms of its operation and legal framework, it is first necessary to introduce the concepts of regulation and liberalization of the market.

A regulated market is characterized by having vertical/integrated utilities that control the entire process of generation, transmission and distribution of energy and all the characteristics that this encompasses, in such a way that it is not possible to choose who transports or provides electric power to the end-users from a certain region. Under this concept, the energy market does not depend on the dynamics of supply and demand. On the contrary, such imposed regulation is in charge of controlling and formulating the rules of the game including the guarantee of an appropriate supply to the community.

With the reform of the market dynamics and the transition to liberation, regulation still takes on an important role as a controlling entity that seeks to ensure a smooth and efficient process by applying different rules and laws [28].

Liberalization is defined as the process of suppressing monopolies [28] and can be considered as the removal of barriers to free competition. The main objective of liberalization is to avoid the phenomenon of market power abuse, in which only large companies have control over the entire commercial dynamics. This new modality prohibits for example the union of two large companies in order to control all trade in their region. Liberalization also seeks to stimulate economic efficiency as long as it is possible through competition

[29].

This process can be summarized as the retail and unbundling of generation, transmission, and distribution of energy [30]. With this new modality consumers can establish contracts according to their preferences with generators located even far from their regional environments. Unbundled, competitive energy market refers to the whole process of energy commercialization from the beginning to the end, going from one to several separate markets, a fact that generates competition and benefits the consumer.

Since this process has been developed in different countries and has been implemented in different ways, liberalization may include the entry into the market of independent generators, the creation of a power pool, or the horizontal separation of mandatory generators. It can also refer to the vertical disintegration of the market, this seeks to eliminate state-owned monopolies in the businesses that encompass generation, transmission and distribution of energy within independent processes and under the control of different actors. In this study, emphasis will be placed on this last modality since it is the one adopted in the Nordic countries and therefore the focus of interest [30].

Now that the two concepts (regulation and liberalization) have been explained, it is important to bring up some of the reasons why a government may decide to reform its energy trading method. There are many theories on this particular topic and some of them will be explained below. In the first place, the theory of property rights enunciates that the efficiency with which state-owned electricity utilities are run is not the same as the one in the private sector. Likewise, due to its own orientation and management, the companies possessed by the state are not obliged to minimize costs, as in fact it happens with private associations [31].

Another reason that supports the decision to stop the regulation is based on the bureaucracy theories, which indicates that the managers of the state-owned companies sometimes focus their attention on the search for budget growth, given that their nature is not of commercial or economic origin, and do not focus on increasing revenues or reduce costs related to the activity [32].

On the other hand, there are also those who support regulation, arguing that although privatization can improve the performance of a firm, it can influence the decrease in economic efficiency as well, this because such activities must be regulated and these regulations generate costs which could lead into negative incentives, less likely to occur in the public sector [33].

Both types of control, public or private, have advantages and disadvantages, the management of the market by private firms reflects a better service given its competitive nature and the continuous search to meet each of the objectives of the company. On the other hand, public ownership is very useful when dealing with situations related to coordination and restructuring. At the end of the day there is a confrontation between a competitive market that presents strong incentives with respect to least-cost production but limited incentives for cost-reflective output prices or a regulated market that offers limited incentives for least-cost production but significantly more cost-reflective output prices [30].

Finally, and observing the examples of countries that have been very successful with the regulation together with others in which this reform has not worked as it should, it can be inferred that the relative performance of the energy industry depends on many factors such as the state of development of the industry in each country and its advances in technology, as well as the political and economic factors that may affect this improvement, beyond the mere fact that the industry is under public or private control [34].

Given that the objective of this study is to analyze the impact of the reform on the regulation of the energy market in Norway and the consequences that it has generated in different areas of the energy industry in this country, a brief summary will be given of how this transition has been done in the Nordic countries and the success of such a market liberalization.

2.2.2 Liberalized market in the Nordic Countries

Once the market was unregulated, the energy began to work exactly as a commodity. There are three main actors in the exchange dynamics: producers, retailers and end users. In the new energy market, two additional parts are included: traders and brokers. The figure 6 shows the scheme of the electricity exchange [35].

In the first place, the producers are in charge of transforming the potential and mechanical energy of the water into actual power. The trader owns the electricity during the commercialization process, since in this new modality there are many ways in which the energy goes from the producer to the end user, the trader can buy the available energy of the different parts and in multiple arrangements, for example, it can be bought from producers or even from retailers and then sold to other retailers and so on.

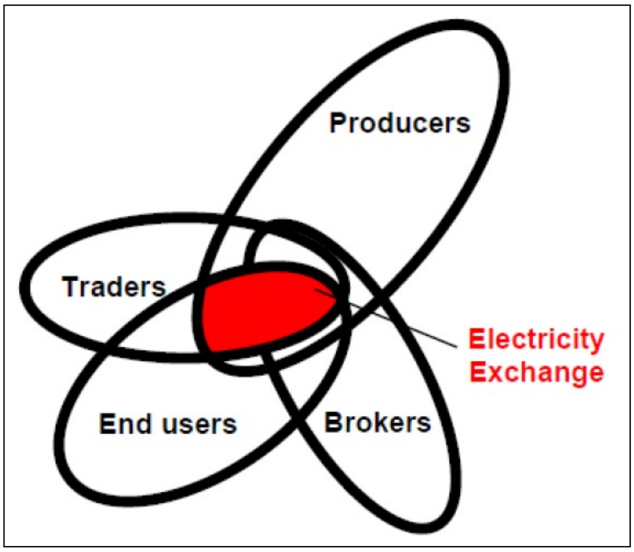


Figure 6: The dynamic of the electricity exchange. [35]

The broker on the other hand is an intermediary that does not own the product (in this case the electricity), but can facilitate the interactions between the different players. It can provide information about producers, prices, etc. This could be an analogy with the state agent in the property market. Finally the end-user market takes place, in which agreements are established for consumers in order to purchase electricity from a power supplier of their choice. In the case of Norway, this market is composed of one-third industry, one-third medium-sized consumers and one-third household costumers [36].

With respect to the Nordic electricity exchange, Nord Pool Spot, there is an interaction between the member countries. In that instance, the customers are the producers, retailers, traders and the large end users, who together take part in the dynamics of energy exchange [35].

2.2.3 Current dynamics of the energy market in Norway

After the Norwegian parliament's decided to deregulate the market for trading of electrical energy in 1991, Norwegian consumers were among the first in the world to have the opportunity to choose their energy supplier based on the criteria of their preference. This dynamic also created competition among energy suppliers, who now, as in any business, would have to strive to be the best alternative for buyers or consumers, fact that also encouraged competition.

For its part, the Nord Pool Spot Power Exchange was established in 1996. It is a trade that serves the players at the wholesale market for electricity. The customers on Nord Pool Spot are the producers, retailers, traders and also large end users who choose to deal with the electricity exchange. It runs the largest market for electrical energy in Europe and it was the world's first multinational exchange at trading electric power across borders [35].

The Nordic countries that are part of this union are Norway, Sweden, Denmark and Finland and this alliance is also integrated with the European market through interconnectors to Germany, the Netherlands, Estonia, Poland and Russia [37].

Due to these connections between countries, it was possible to optimize the market dynamics by facilitating energy trade according to supply and demand. It is important to take into account factors such as the water inflow and the installed capacity of every place, due to the high fluctuation of energy production from hydroelectric plants. It is known, for example, that the inflow varies considerably throughout the year, being the highest in spring, and decreasing gradually until the end of summer, due to the lack of rain, it increases again in autumn and reduces its value in winter [38].

These dynamics and also the lifestyle of the inhabitants of each region influence the prices of energy. For example when there is very little rain, and the temperatures are quite cold, energy production will be low but demand will be high, in those cases the prices increase and it is quite convenient to import cheaper energy from other countries. On the other hand, when production in Norway is high and energy demand is low, as it happens in spring, it is beneficial to export power to other countries where prices are higher. In this way it can be assured that the power flows in the direction in which its value is the largest, from low-price areas to high-price areas [37].

Power producers, suppliers brokers, energy companies and consumers exchange large volumes of power every day through the Nord Pool Spot. The clients that buy the power for their own consumption can be classified as end users. Due to the dynamics of the business, they are equally free to choose their power suppliers. There is also a website designed and controlled by the Norwegian Consumer Council and the Norwegian Water Resources and Energy Directorate in which it is possible to find complete information on energy prices and also offers the possibility of switching suppliers. This web page is strømpris.no [38].

2.2.4 How is the price of the energy defined

The price of energy must be established by the Nord Pool Spot power exchange based on a forecast that takes into account the balance between generation and consumption in each hour of the next day after the calculations. These prices are determined considering factors such as supply and demand, variations in climate, precipitation and temperature, also the transmission conditions within the Nordic region and between that area and the rest of Europe. Likewise, the periodic restrictions on grid capacity can generate different prices depending on the region in which they are located, the values fluctuate and can vary considerably from one station to another.

Every day the price of the system is established for the next day by the Nord Pool power Exchange. This dynamic is called day-ahead market. Apart from the factors mentioned above, the calculations should also be based on an ideal condition in which there are no congestions in the Nordic grid of transmission. The calculated value applies to the entire Nordic market. The producers send bids indicating how much energy they are willing to generate according to a specific price (evidencing the costs that a hydroelectric plant represents) and in the same way the end users send their proposal of what they want to consume at a certain price; in this way, the final price is determined, seeking a balance in the supply and demand of said market [39].

Next to the Nord Pool Spot, there is also Statnett, which since 1997 has been in charge of settling the imbalances in the Norwegian power market, in a process that, as the name implies, is called balance settlement. The idea is to preserve a balance in the power market and also to ensure that the dynamics of energy supply and consumption are defined in an appropriate way. In this case, the term balance refers to the compliance with the agreements made beforehand by the market participants regarding the volume of its power generation or consumption. In order to take part of the wholesale market, participants must have a direct balance agreement with Statnett. Each party must either ensure to meet their own balance or have an agreement with a balance responsible so that they can settle their imbalances for them [36].

Finally, the bill that must be paid by the end-user is composed of various costs arising from the service and which include: power price (represents the value of the energy by itself), grid tariff that constitutes the charge for the use of the power grid, electricity tax and value added tax. Additionaly, there is a charge for electricity certificates and a payment assigned to the Energy Fund (Enova). If an end-user chooses a power company that is responsible for grid operations, they will only receive one bill, otherwise it is necessary to pay the fees for grid and energy separately [37].

2.3 Act on the generation, transmission, trading, distribution and use of energy – Energy Act 1991

The Act No. 50 of 29 June 1990 or so called "Energy Act" came into force on 01.01.1991. It is the treaty responsible for managing and ensuring the proper use of energy through its entire cycle, including production, conversion, transmission, trading and distribution. It also states that the energy resource should be used in the best way, rationally and always seeking the benefit for society, which covers both the public and private sectors. This treaty contains a scheme that regulates competition between the electricity generation and trading sectors. For reasons of convenience and to avoid congestion in the lines, it was decided to allow the grid to continue acting as a natural monopoly, nevertheless the act by itself establishes a legal regulation for the grid companies in such a way that despite continuing to be part of the monopoly they must comply with certain rules for their operation.

The energy act is also responsible for controlling cross-border interconnections, market places in the area of trading of electrical energy, district heating facilities, energy supply quality and since energy delivery must be guaranteed to end users, in the same way it must have contingency plans to guarantee the supply of energy [2].

The entity in charge of applying these regulations in the energy market is the Norwegian Water Resources and Energy Directorate (NVE) and among its functions is the monitoring of market access by consumers, it also seeks to facilitate the procedures to make changes between different energy suppliers, monitor the quality of supply and also ensure it as well as regulating effectively the operation in the country's energy system [40]. The Energy Act does not intervene in the management of watercourses and waterfalls.

The creation of this law officially marked a change in the dynamics of the energy market. It modified the scheme with which the energy was generated and distributed in Norway an in the other Nordic countries, which also adopted this method of energy trading and started a common association with the pure purpose of managing the Nordic power exchange. From this moment on, markets opened up to competition and the possibility of including different actors in the commercialization of energy was generated [3].

This transition was reflected in the activity of the hydropower plants that began to operate with a more economic approach and aimed at satisfying the changes in the supply and demand of their clients. These changes also generated impacts on the rivers located downstream the hydropower plants, their intermittent operation, the more frequent opening of dam gates to generate greater amounts of energy, triggered hydropeaking phenomena as well as changes in the behavior of rivers, specifically in the flow and stage.

These changes have been registered in the measuring stations located in the rivers in which water level and discharge controls are carried out every 15, 30 or 60 minutes. For this study some stations located along the Norwegian coast have been selected and thorough a very detailed statistical analysis it has been possible to define a clear pattern that relates marked increases in these parameters after the transition of the energy market and the Energy Act.

3 Methods

3.1 Data aquisition

In this study an extensive compilation of information related to measuring stations that were located both, downstream of hydroelectric plants (regulated rivers) and others that were not affected by any external activity related to the generation of energy (unregulated rivers) was carried out. The oldest collected data starts in 1985 which is an ideal situation because those time series show the behavior of the different parameters before the 1991 environmental law. Due to the large amount of gathered information, the data had to be sorted out in a systematic way in order to have a general idea of the flow and stage of the different rivers. These analyzes were performed with Excel and then an evaluation of all the parameters was done with COSH Tool. In this way, several graphs were plotted which showed the evolution and the diverse changes presented in the behavior of the rivers with the time.

With COSH it was possible to determine the general graphs of all the parameters in each one of the measurement stations, this included peaking events on hour of day, number of peaking events per day, number of peaks per year, flow ratio, average and maximum rate of change (both monthly and yearly) as the most important ones. With all the graphs obtained it was already possible to observe the trends of the rivers, some very marked, showing a clear and gradual increase in the number of peaking events, for both parameters (flow and stage).

In addition to this compilation of data, all the hydropower plants that generated some influence in these rivers were also analyzed, from these plants, information that was more specific was obtained such as the number of turbines, installed power (measured in MW), annual production (GWh), distance from the HP outlet to the measurement point [m], the volume of the reservoirs of each one of the plants [Mill. m^3]. Also additional data from the gauging stations was collected as the Degree of Regulation (DOR) which is the proportion of the river's average annual discharge that can be stored in a reservoir [41].

Part of the hydrological information was extracted from the database of Norges vassdrags og energidirektorat (NVE) or by its acronym in English "The Norwegian Water Resources and Energy Directorate" which is the entity responsible for ensuring an integrated and environmentally sound management of the country's water resources, promote efficient energy markets and cost-effective energy systems and contribute to efficient energy use. NVE is involved in research and development in its fields and is the national center of expertise for hydrology in Norway [42]. From there it was possible to obtain information such as energy equivalent from the hydropower plants, the volume of the reservoirs and some annual production data.

For more specific information about hydrological data related to water level and water flow, it was necessary to request permits from the relevant departments. In this way it was possible to access directly to Hydra's databases (Hydrologisk avdeling i NVE) or by its acronym in English "The hydrological department of the NVE" which is the national professional group for hydrology and ensures a proper collection and interpretation of hydrological data [43]. In order to acquire the necessary information, the Hydra's remote desktop located in Oslo (Norway) was used, from where it was possible to extract information contained in the main databases, this was performed by using the HYSOPP software that provides specific information related to each gauging station in Norway.

After having this specific data, it was also necessary to define the general information of each of the hydroelectric plants, which was provided by their owners. Subsequently, a database was created which gathered all the important information in different kind of tables according to every specific purpose. It will be explained lately in the analysis of results and the tables will be shown in the appendix 2.

Once having all the base information, a statistical analysis of all the data was performed in order to find relations between all the studied parameters and thus corroborate the previous hypothesis. As mentioned before, when observing the graphs it was possible to detect clear increasing trends. In order to go beyond the visual part and for analysis purposes, it was decided to quantify those trends in order to define whether they were really significant or not, likewise calculate their magnitude and in this way be able to assess the impact in each one of the studied areas. To quantify this mathematically, an evaluation of the trends was performed using the statistical software R, which has specialized packages in these types of analysis and additionally can work with robust groups of data (See section 3.2).

3.1.1 Selected Gauges and location

Figure 7: Location of the measurement stations

3.1.2 Data input and preparation

As mentioned above, 30 measurement stations (26 located in regulated rivers and 4 situated in unregulated rivers) were chosen to analyze the behavior of the flow and stage since 1985 (or as early as possible based on the available information), in order to see if there was any change in those parameters before and after the implementation of the environmental law. The Figure 7 shows the location of the studied stations. It can be seen that they are very well distributed throughout the country.

The discharge and water level data were collected with a hourly resolution. Every data set had to be uploaded to the program as an Excel file, in which the time series of each of the measurements were compiled into separate sheets. Each file contained two columns, the first had to include the exact date and time of the measurement, and the second one, the value of the selected parameter, whether it was flow or stage. Subsequently, the outliers were selected whose objective was to exclude from the analysis those data that were outside a reasonable range, due to errors in the measurement or loss of information, for example a discharge of -9,999 m^3/s is an indicative that there was something wrong in the moment of getting the data and therefore it should be excluded from the calculations. After experimenting with different values, it was found that the optimum limit was the 90th percentile, it restricted the range of flow and stage, excluded errors and also detected the signals that were necessary for the analysis. The data that exceeded this value were not taken into account, which gave greater accuracy to the results.

Once the limits were defined, the criteria to classify the increasing and decreasing peaks were determined, in this case, the upper and lower percentiles and the frequency with which these peaks should be evaluated. By trial and error it was possible to determine that percentiles 97 and 3 were the most appropriate to designate the limits in which the peaking events should be defined. This range was chosen since it covers the measures of interest and excludes the values that can be the product of errors or lack of measurement. In the same way it was determined that the appropriate time step to process the information was 30 minutes since it includes all important peaking events.

After following those steps it was possible to obtain the general Excel document, which showed the complete statistical analysis. Subsequently, the different graphs were downloaded, in this study emphasis was placed on distribution of peaking events on hour of day, number of peaking events per day and number of peaks per year. The final plots for all the studied stations will be attached in the appendix 1.

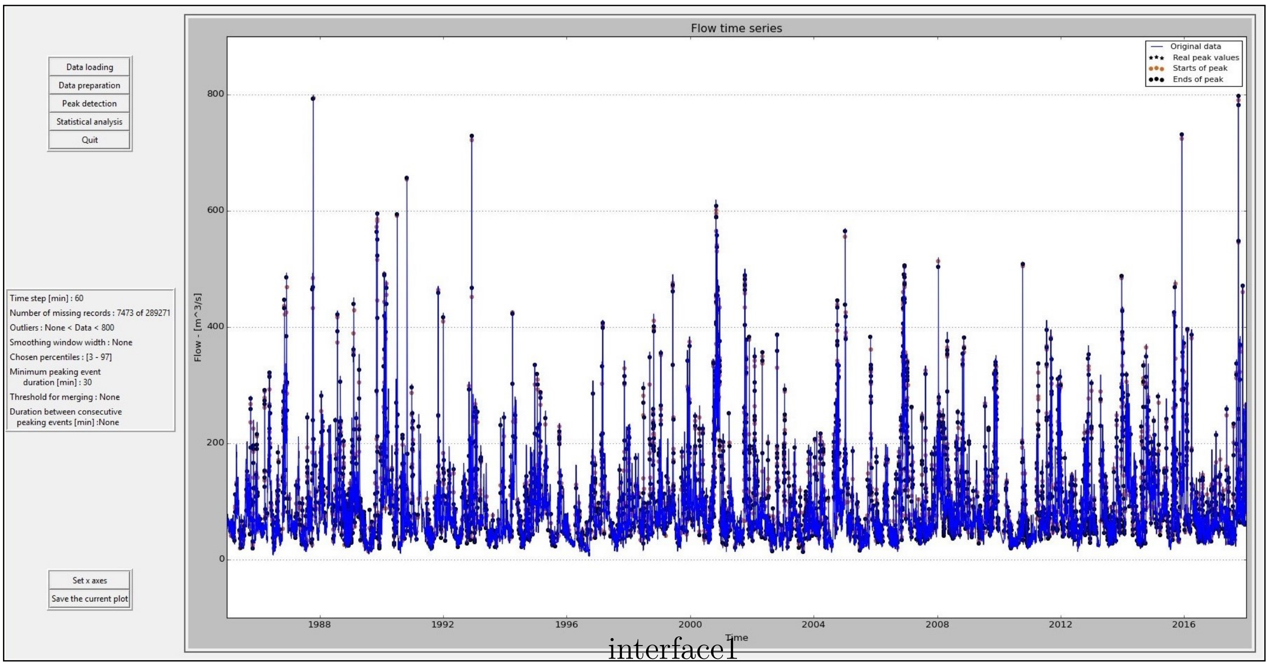
3.2 Data Analysis

3.2.1 Used tools and software

COSH-Tool

COSH-Tool is a software that allows quantification of fluctuations in water level or discharge, which may occur in rivers subjected to hydropeaking. Power production by hydroelectric plants in response to short-term variations in the energy demand and market may lead to frequent and rapid fluctuations in flow and stage in rivers downstream of power plant outlets [18].

The tool focuses on analyzing time series of the signal X(t) and is designed to quantify these rapid fluctuations. The abrupt changes can be identified by means of specific information to the river and precise data of the measurement stations or gauges, such as stage in [m], flow in [m^3/s] and also date and time so that it is possible to calculate the rates of change and other peaking event parameters, depending on the desired output.



Time step [min] : 60
Number of missing records : 7473 of 289271
Outliers : None < Data < 800
Smoothing window width : None
Chosen percentiles : [3 - 97]
Minimum peaking event duration [min] : 30
Threshold for merging : None
Duration between consecutive peaking events [min] :None

interface1

Figure 8: Interface COSH Tool

These peaking events are analyzed individually and divided into rapid increases and rapid decreases. With the tool it is possible to evaluate other factors such as daylight conditions during peaking events and calculate both mean and maximum rates of change in flow and stage. It is useful with respect to environmental impact assessment and mitigation related to stream hydropeaking [20].

The tool differentiates between increasing and decreasing peaking events taking into account that there are differences in the effects produced by each of them, these events are related to rising or falling segments. The process to determine a peaking event is based on the definition of a threshold for the rate of change X=dX/dt, which corresponds to the first derivative of the signal present in the time series X(t).

When the derivative is positive, an increase is defined and when it is negative the presence of a decrease is determined. In both cases thresholds are defined for each rate of change by implementing an iterative process. The magnitude of each threshold is determined taking into account the absolute maximum values of the rate of change that takes place at each of the peaks (increases or decreases). After defining the starting points for the increasing or decreasing peaking events, a comparison is made between the rate of change of the signal and the threshold corresponding to each data point of the time series. When the absolute value of the rate of change is higher than the threshold, the data point is cataloged as part of a peaking event that will be increasing or decreasing depending on its initial sign. Subsequently, the maximum and minimum points of the peaking event are assigned to the time series. [20]

The discharge registered at the beginning of a rapid increase represents the minimum flow associated with a increasing discharge peaking event (Q_{min}, Inc), on the other hand, the discharge registered at the end of a rapid increase represents the flow maximum associated with the same parameter (Q_{max}, Inc). This principle is also used to define the values of maximum and minimum flow associated with a rapid decrease and in the same way this applies to the analysis related to stage [20].

Output obtained with COSH Tool

Figure 8 shows the initial interface of the software, that is, the first image obtained when loading the Excel file with the signals (stage or flow). Subsequently, in the data preparation section, the cutoff value must be defined, taking into account the 90th percentile of each group of data. Afterwards, in the peak detection part, the range and time step are defined. Once the data has been delimited, it is possible to go to the next section (statistical analysis) in which the results obtained by the software can be visualized.

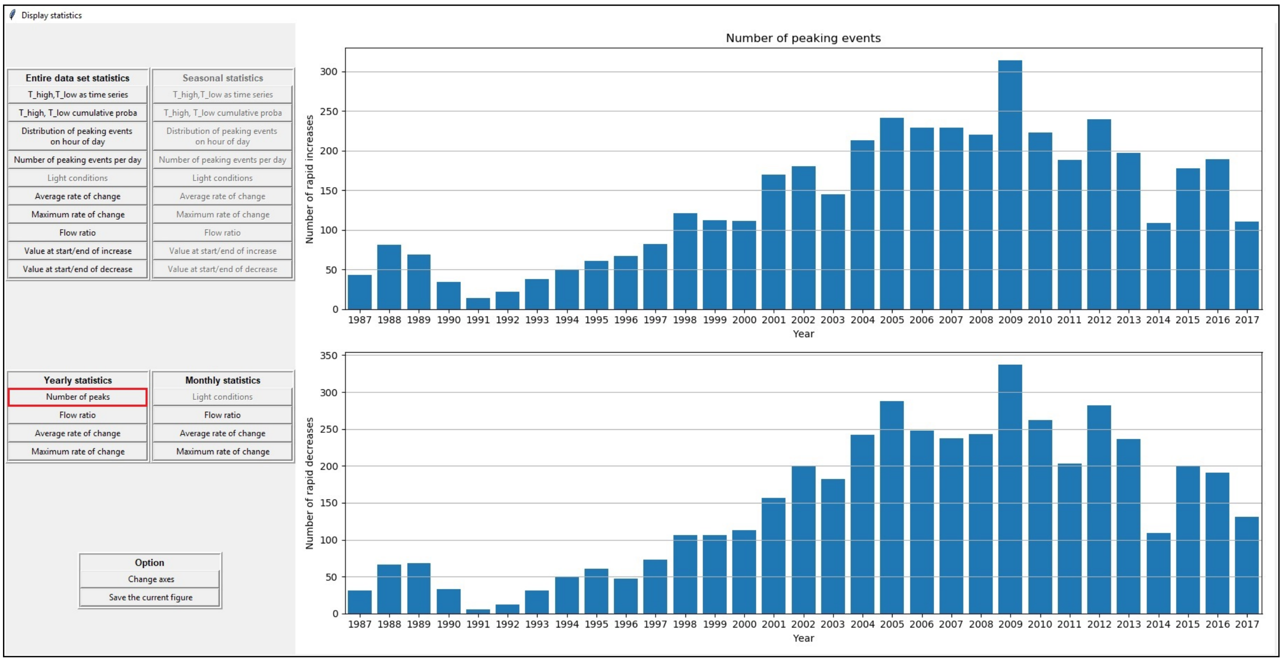


Figure 9: Number of peaking events per year

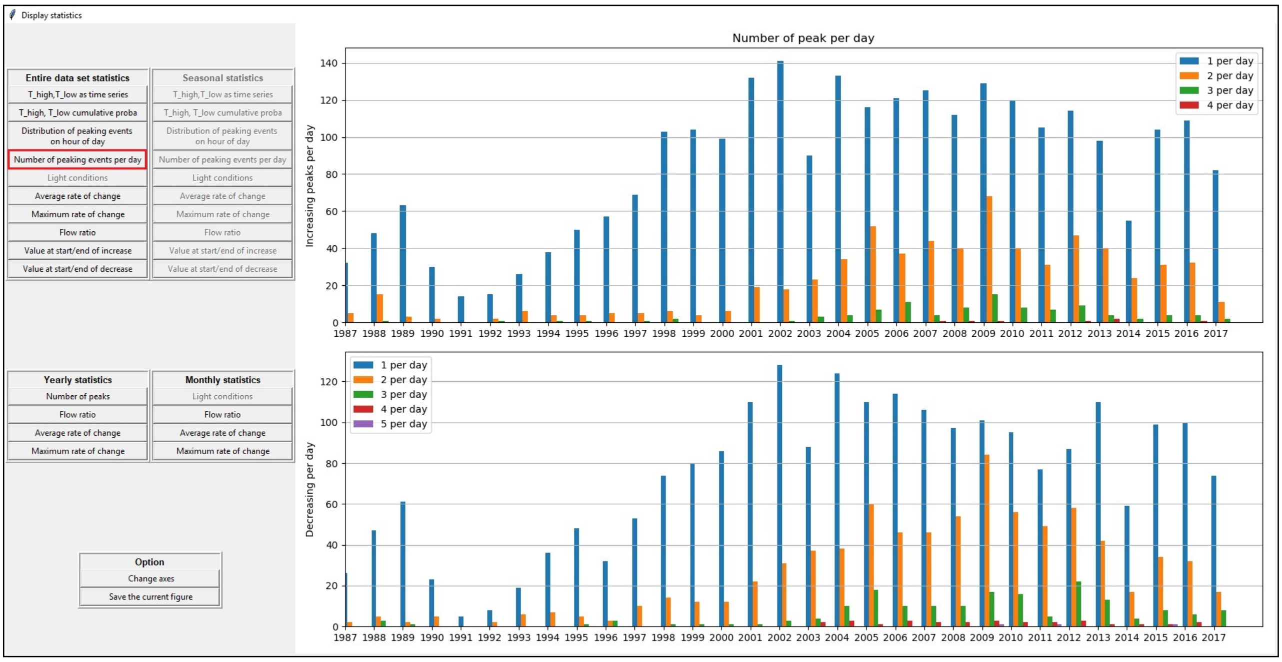


Figure 10: Number of peaking events per day

By means of the tool, different kind of plots can be downloaded according to the objective of each analysis. The key parameters and the main focus of this study are number of peaks per year (figure 9), number of peaks per day (figure 10) and number of peaks per hour (figure 11). Additionally, another kind of graphs are available such as average and maximum rate of change and flow ratio both per month and per year. Along with

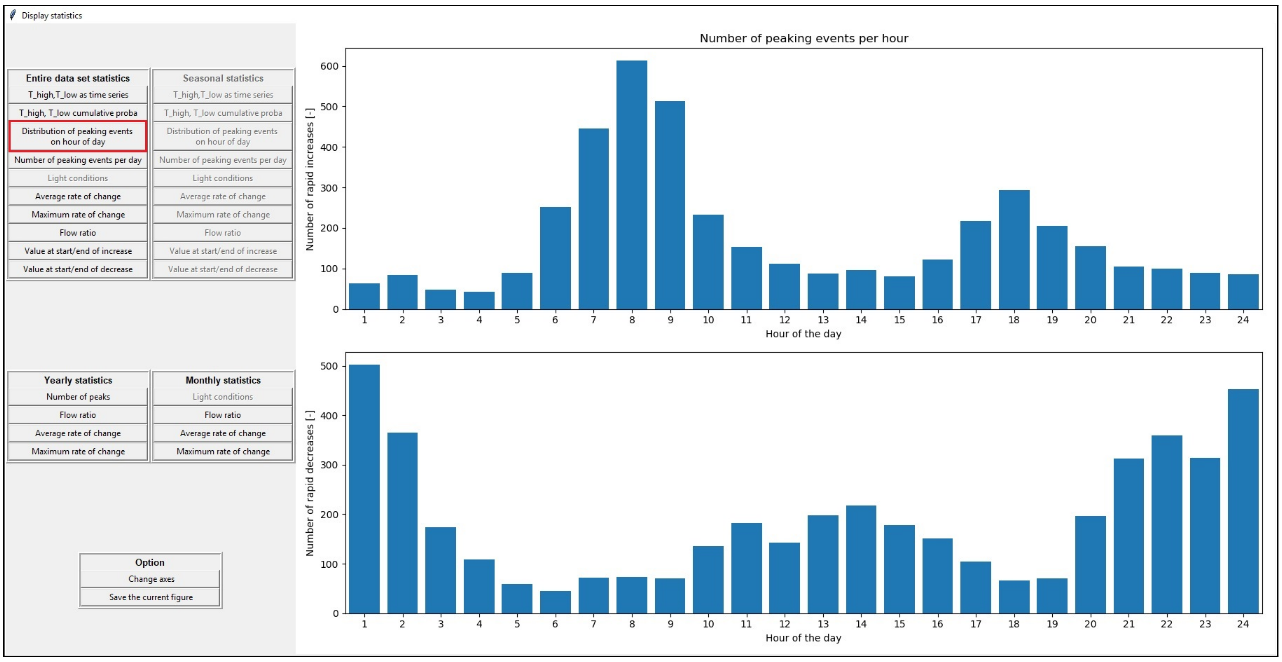


Figure 11: Number of peaking events per hour of day

this, it is possible to obtain seasonal statistics that analyze further parameters such as temperature and light conditions.

The results can be found summarized in a general table and also organized in different types of graphs like box plots, cumulative distribution functions and bar charts. These parameters show the abrupt changes of discharge and water level in the selected measurement stations.

3.2.2 Significant Trend Tests

In general, when studying climatologic and hydrologic time series, it is very useful to evaluate the presence of significant trends, which is one of the main objectives of this study. These tests can be divided into two categories: Parametric and Non-parametric methods. The parametric trend tests use data normally distributed and independent of each other, on the other hand non-parametric trend tests only require the data to be independent, which is the method that will be used for this analysis.

To find the trends and calculate their significance and magnitude, two non-parametric methods will be used: Mann-Kendall and Sen's slope estimator [44].

3.2.3 Mann-Kendal Trend Analysis

There are many studies that have used the Mann-Kendall test as the tool to quantify significant trends in hydrological and meteorological time series [45] [46].

This trend test focus on comparison of the relative magnitudes of the sample data instead of the data values themselves. This method was chosen because it allows missing values (which are present in the measurements of our parameters) and also the dataset does not need a specific distribution. it can be normal or not. [47]. Additionally, this trend test has a very low sensitivity to abrupt breaks due to inhomogeneous time series.

The Mann Kendall test statistics (S) is calculated as follows: [48] [49]

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_{\mathrm{j}} - x_{\mathrm{i}}) \tag{1}$$

Where n is the number of data points, x_i and x_j are the data values in time series *i* and *j(j<i)* respectively, and *sgn(x_j-x_i)* is the sign function as:

$$sgn(x_{\mathrm{j}} - x_{\mathrm{i}}) \begin{cases} +1, & \text{if } x_{\mathrm{j}} - x_{\mathrm{i}} > 0 \\ 0, & \text{if } x_{\mathrm{j}} - x_{\mathrm{i}} = 0 \\ -1, & \text{if } x_{\mathrm{j}} - x_{\mathrm{i}} > 0 \end{cases} \tag{2}$$

The null hypothesis of the Mann-Kendall test is that the observations are randomly permuted, and the alternative hypothesis implies a monotone trend [50]. A positive value of S indicates the presence of an upward trend which means an increase of the different parameters in the time series (case of many of the selected gauges that present and increment in the stage and the flow through the years). In the same way, when the S value is negative, the trend adopts a downwards behaviour.

The variance is calculated as follows:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_{\mathrm{i}}(t_{\mathrm{i}} - 1)(2t_{\mathrm{i}} + 5)}{18} \tag{3}$$

Where *n* is the number of data points, *m* is the amount of tied groups or sets of data having the same value and t_i represents the number of ties of extent *i*.
When the sample size is greater than 10 (as it is our case), the standard normal test

statistic Z_s is calculated by using the following equation:

$$Z_s = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}}, & \text{if } S = 0 \end{cases} \tag{4}$$

Positive or negrative values of Z_s indicate increasing or decreasing trends respectively. The statistic S in the last equation is a count of the number of times x_j exceeds x_k, for j>k, more than x_k exceeds x_i. The maximum possible value of S is called D and occurs when $x_1 < x_2 < \ldots x_n$. A statistic which is closely related to S in (1) is $Kendall'stau$ [51] defined by:

$$\tau = \frac{S}{D} \tag{5}$$

Where:

$$D = \left[\frac{1}{2}n(n-1) - \frac{1}{2}\sum_{j=1}^{p} t_j(t_j-1)\right]^{\frac{1}{2}} - \left[\frac{1}{2}n(n-1)\right]^{\frac{1}{2}} \tag{6}$$

When ties are no present in the dataset, the last equation can be resumed in:

$$\tau = \frac{S}{\frac{1}{2}n(n-1)} = \frac{S}{\begin{bmatrix} n \\ 2 \end{bmatrix}} \tag{7}$$

The probability value P of the MK statistic S of sample data can be estimated using the normal cumulative distribution function:

$$P = \frac{1}{\sqrt{2\pi}} \int_{\infty}^{z} e^{-t^2/2}\, dt \tag{8}$$

A significant monotonic trend must have a p-value less than 0.05, when that is the case, it can be declared that the Null hypothesis is rejected and therefore the validity of the alternative hypothesis that indicates the presence of a trend in the time series data is confirmed. Having defined the presence of a trend, it is possible to determine its direction by using the Kendall's tau, depending on whether the sign of this value is positive or negative, it can be said that the trend shows an upwards or downwards direction respectively

[52]. In the same way, it is possible to calculate the magnitude of said trends through the Sen's Slope analysis which will be explained below.

3.2.4 Sen's Slope Analysis

After defining the presence of a trend and its significance with the Mann Kendall test, it is necessary to calculate its magnitude, for the purposes of this study it was decided to use the Sen's Slope method. This quantification of the trend was made by using the slope (change per unit time), nevertheless it is relevant to clarify that this does not imply that the trends present a linear behavior.

Given that there is a group of measuring stations, it is important to identify those gauges in which the trends are big in relation to the general mean. It can also be interesting to recognize which specific points have very steep slopes in order to establish relations with external factors that can influence those results. For example, the proximity of the measurement station to the outlet of each hydropower plant or even the number of turbines that each plant owns. These relations, analyzes and graphs will be shown later in the results chapter [53].

The Sen's slope trend test is a non-parametric procedure developed by Sen and explained in [54] that estimates the slope of trends in a sample of N pairs of data. According to [44]:

$$Q_{\mathrm{i}} = \frac{X_{\mathrm{j}} - X_{\mathrm{k}}}{j - k} for i = 1, ..., N, \tag{9}$$

where X_j and X_k are the data values at times j and k (j>k), respectively.

If the total amount of data measurements in the time series in n there will be $N = \frac{n(n-1)}{2}$ slope estimates and the test statistic Q_{i} is the median of all these slope estimates.If there are multiple observations in one or more time periods, then $N < \frac{n(n-1)}{2}$, where n is the total number of observations. Positive and negative sign of Q_{i} indicate increasing trend and decreasing trends respectively [44] [55]. Similarly, zero value indicates no trend. The unit of resultant Q_{i} would be the slope magnitude in original units per year or percent per year [56].

4 Results

The results obtained after analyzing 26 measuring stations located downstream power plants (regulated) will be shown below. In the same way, four measuring stations located on unregulated rivers (not influenced by hydroelectric plants) were selected which can be used as a reference point to compare the effect (if any) of the hydroelectric plants located upstream the watercourses.

The data collected from the measurement stations shows the behavior of the discharge and water level of the rivers before and after the energy act was decreed. In the first section there will be a general analysis of the information, the database will show data collected from each of the gauges together with the information of the respective closest hydropower plant given their direct influence on the behavior of the rivers, which will allow to establish relations between these characteristics and the results.

The same analysis will be carried out with the stations that are not influenced by any hydropower plant in their course in such a way that it will be possible to define if there is any relationship with the trends observed after 1991 and the presence of hydropower plants in their surroundings.

Subsequently, using COSH tool, an analysis of the peaks in both flow and stage will be made and the graphs of the most relevant stations will be shown and the remaining plots will be included in the appendix 1. These graphs will be grouped in distribution of peaking events on hour of day, number of peaking events per day and number of peaking events per year. Since COSH only supports the analysis of one parameter at each time, it was necessary to perform separate procedures, therefore the plots for Discharge and water level will be shown individually, even when the behaviour is very similar for both parameters.

In the end, a quantitative analysis with Mann Kendall and Sen's slope will be done in order to corroborate the presence of trends and define relations between the different results.

Table 1: Stations located on the regulated rivers

Station	**Name HP1**	**Distance [m]**	**Avg annual prod [GWh]**	**DOR**
Bertnem	Nedre Fiskumfoss	32207.12	272	0.118
Brulandsfoss ndf	Brulandsfoss	873.6	59.3	0.062
Fosshaug	Straumsmo	13663.24	678	0.494
Meråker (Samløp Funna)	Funna	1373.12	67.8	0.341
Hegra bru	Meråker	40442.06	463.8	0.314
Håverstad	Håverstad	923.67	282	0.18
Kjølemo	Laudal	16366.09	146	0.149
Laudal	Laudal	142.78	146	0.148
Låvisbrua	Aurland I	2010.61	2015	0.778
Rate	Leirfossene	604.12	150	0.486
Ruud	Hol I (Votna)	594	380	0.928
Skibotn bru	Skibotn	8502.05	371	0.246
Surna v/Skjermo	Trollheim	1489.62	805	0,294
Stuvane	Stuvane	1461.84	165	0.283
Syrstad	Grana	14776.7	280	0.278
Sælthun	Borgund	4246.34	985	0.283
Tørrisdal	Nedre Fiskumfoss	1281.74	272	0.175
Harestrømmen_Alta	Alta	3009.74	655	0.054
Heisel	Vigelandsfoss	1006.8	180	1153
Holm Bru	Guolásjohka	2247.47	316	0.357
Jørundland	Jørundland	836.61	188	-
Kista / Cyst	Alta Kraftverk	18663.15	655	0.053
Kobbvatn	Kobbelv	527.07	720	1211
Kongsfjordelv	Kongsfjord	2834.45	20	0.592
Kongsfjordfoss	Kongsfjord	5263.05	20	0.503
Kulset Bru	Nedre Nea	2150.54	392	0.434

Table 1 shows the 26 measurement stations located in regulated rivers, that is, they are under the influence of one or more hydropower plants. The name of each station is shown along with the nearest HP plant, the distance measured in meters from the hydropower outlet to the measurement point, as well as the average annual production of each plant and the degree of regulation (DOR) which is the proportion of the river's average annual discharge that can be stored in a reservoir [41]. These information is important since a relation between these parameters and the data obtained from each measurement station will be established. The complete information of each station and power plant can be found in the Appendix 2.

4.1 Number of peaks per year

In this section the graphs corresponding to the number of peaks per year obtained with COSH Tool will be presented. The analysis carried out for both, regulated and unregulated rivers will be shown and, in the same way, the respective division will be made in discharge and water level since the tool processes each one of the parameters independently. It will also be possible to observe that the behavior of flow and stage keeps the same pattern. To facilitate the understanding of the data, two stations were selected for regulated rivers (Stuvane and Rate) and two for unregulated rivers (Hugdal bru and Bjoreio). The analysis was carried out for all the stations and the results are consistent, therefore the other graphs corresponding to the remaining gauges will be attached to the Appendix 1.

4.1.1 Regulated rivers

Discharge

Figure 12 and figure 13 correspond to the number of peaking events per year in the Stuvane and Rate measurement stations respectively. It shows both the number of rapid increases and the number of rapid decreases which refers to the peaks presented when there are sudden increments or reductions in the discharge (in this case, this could be due to the operation of the hydroelectric plants that are located upstream the waterways). One possible reason of the increases is the fact of opening up the floodgates of the dams in order to increase the flow of water and vice-versa.

At first glance it can be seen that there is a tendency to increase the number of peaking events over the years, the first measurement at Stuvane dates from 1987, when 27 rapid

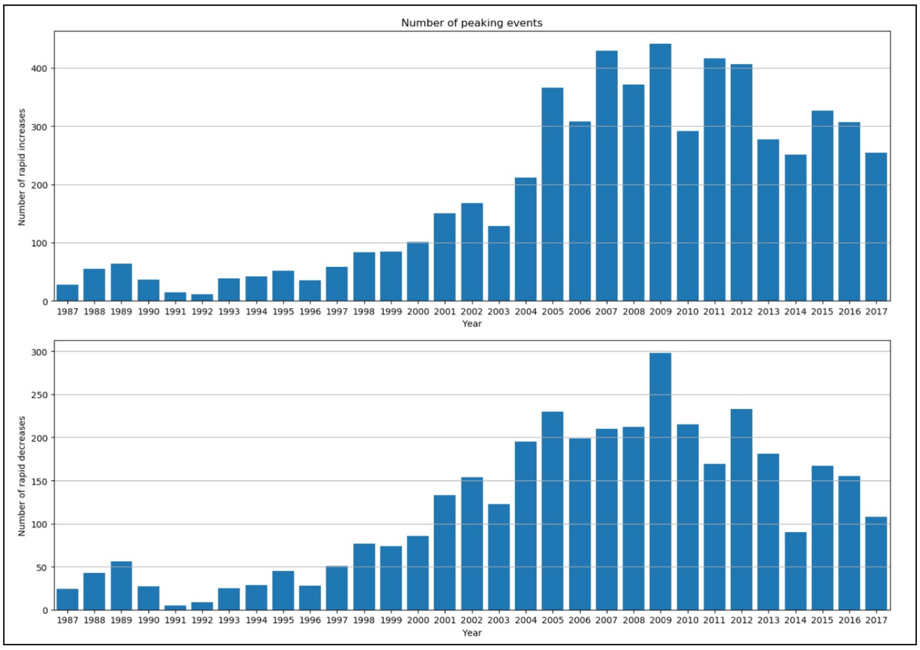


Figure 12: Number of increasing and decreasing discharge peaks per year - Stuvane Station

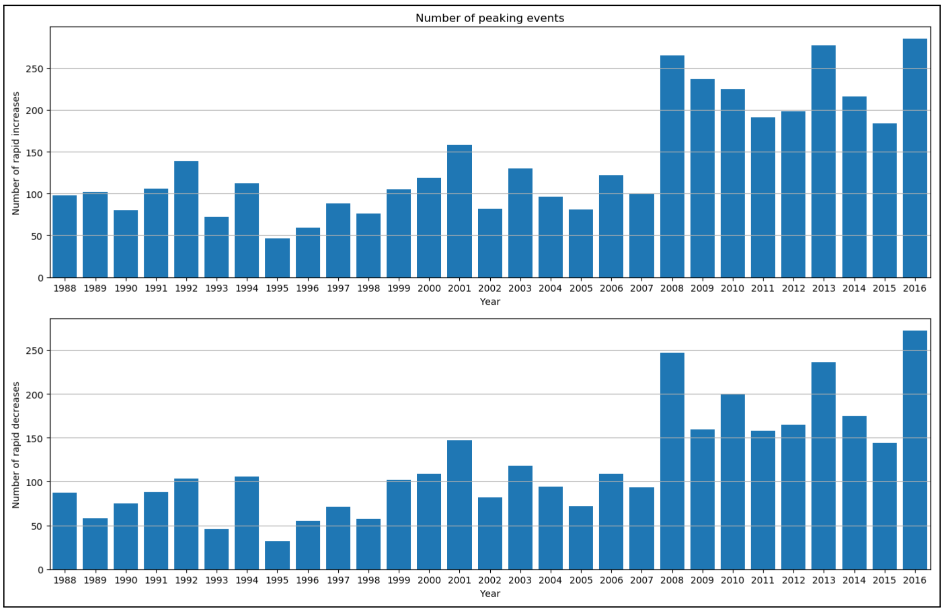


Figure 13: Number of increasing and decreasing discharge peaks per year - Rate Station

increases and 24 decreasing peaks were recorded, an amount that continued raising until reaching its maximum in 2009 with 441 and 298 peaks respectively. This indicates that the amount of peaking events (both increasing and decreasing) was multiplied more than 10 times with respect to its initial value. Even when the tendency can be observed directly, the same data will be analyzed later using Mann Kendall, in such a way that the results can be quantified.

Water Level

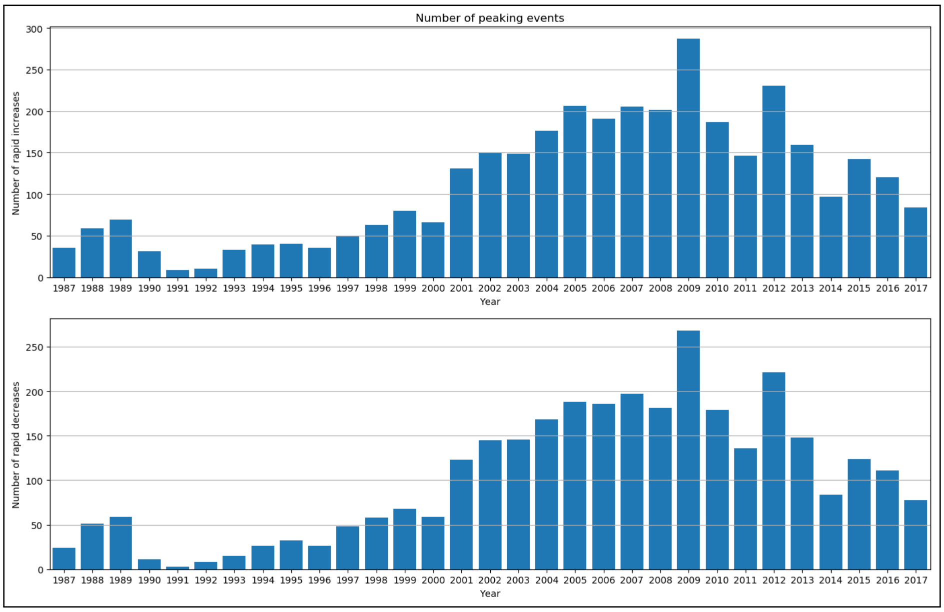


Figure 14: Number of increasing and decreasing water level peaks per year - Stuvane Station

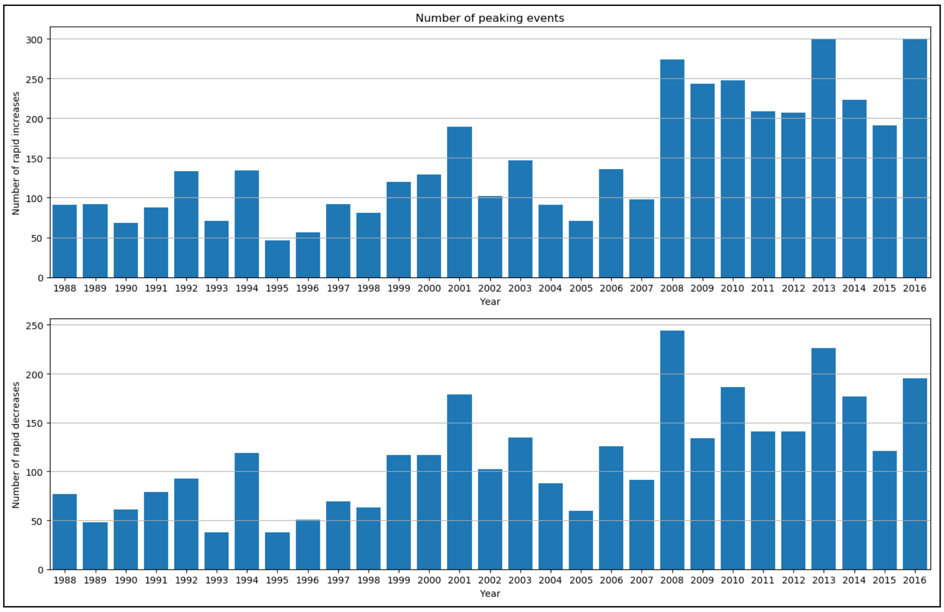


Figure 15: Number of increasing and decreasing water level peaks per year - Rate Station

The behavior of the peaks with reference to water level is very similar to that presented in the case of discharge. Figures 14 and 15 show the record of peaking events per year since 1987 for the Stuvane and Rate stations. Here there is also a marked increase and the trend is directly proportional to the one presented for discharge.

For Stuvane, there were a total of 35 peaks in the first year of the measurements and 287 when its maximum took place in the year 2009. For 2017, 84 peaks were observed, although it is not as high as that presented in the particular case of 2009, is even more than twice the initial amount. In the case of decreasing peaks, an initial value of 24 peaking events was recorded and a final value of 78 peaks in 2017. Its maximum increase was also presented in 2009 with 268 decreasing peaking events which is more than 11 times the observed value in the first measure.

4.1.2 Unregulated rivers

The same previous analysis will be carried out for the Hugdal bru and Bjoreio stations, which are not influenced by hydroelectric plants. Here, it is not possible to see a trend as clear as it was presented in the previous cases, it can be said that the peaking events show intermittent behavior. In this case, the analysis with Mann Kendal will be very helpful and also be done in such a way that it will be possible to define whether there is a trend and if it exists, its magnitude can be calculated.

Discharge

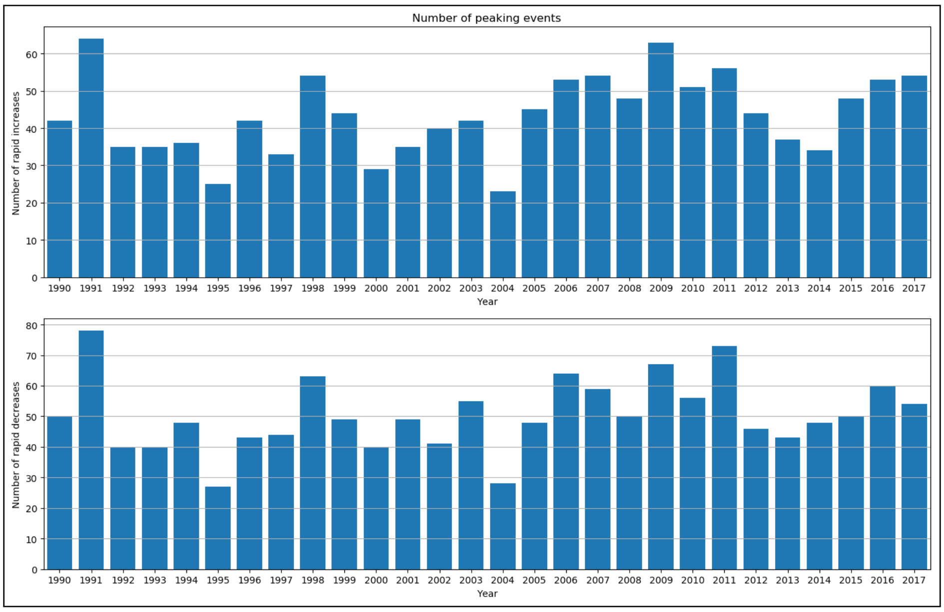


Figure 16: Number of increasing and decreasing discharge peaks per year - Hugdal bru Station

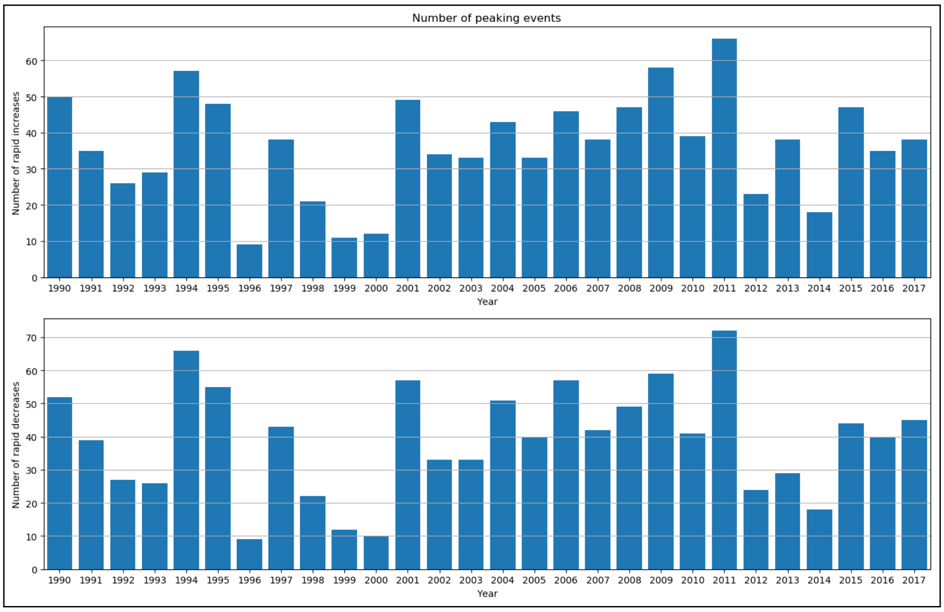


Figure 17: Number of increasing and decreasing discharge peaks per year - Bjoreio Station

Figures 16 and 17 show the number of increasing and drecreasing peaking events in relation to discharge. Figure 16 shows the data collected from the Hugdal bru station. As mentioned above, there is no clear trend here, contrary to the case of regulated rivers. Regarding increasing peaks, 42 events were presented in 1990 when the first measure was taken, and 54 events in 2017, with a total average of 43 peaks per year. A fairly regular behavior can be observed, without a noticeable increase. In the matter of decreasing peaks, there were a total of 50 events in 1990 and 54 events in 2017, with an average of 50 peaks per year, a similar behaviour to that presented with the increasing peaks.

Figure 17, on the other hand, shows the behavior of peaking events in relation to water level. As in the previous case, a series of highs and lows can be observed, without a specific trend. With respect to increasing peaks, 50 events were detected in 1990 and 38 events in 2017, with an annual average of 36 peaks, here a considerable reduction can be observed in relation to the initial measurements. In the case of rapid decreases, 52 peaks were observed in 1990 and 45 peaks in 2017, with an annual average of 39 peaks.

Water level

Figures 18 and 19 show the number of increasing and decreasing peaking events in relation to water level in the non-regulated stations mentioned above. The intermittent behavior of the peaks is maintained. In the case of increasing peaks (figure 18) there is a transition from 41 events in 1990 to 45 events in 2017, with multiple increases and decreases in the

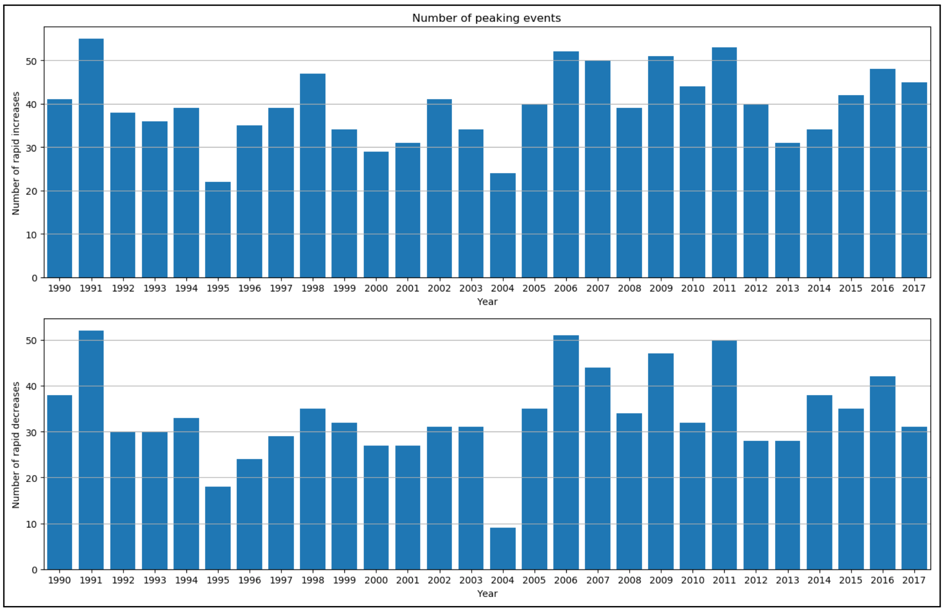


Figure 18: Number of increasing and decreasing water level peaks per year - Hugdal bru Station

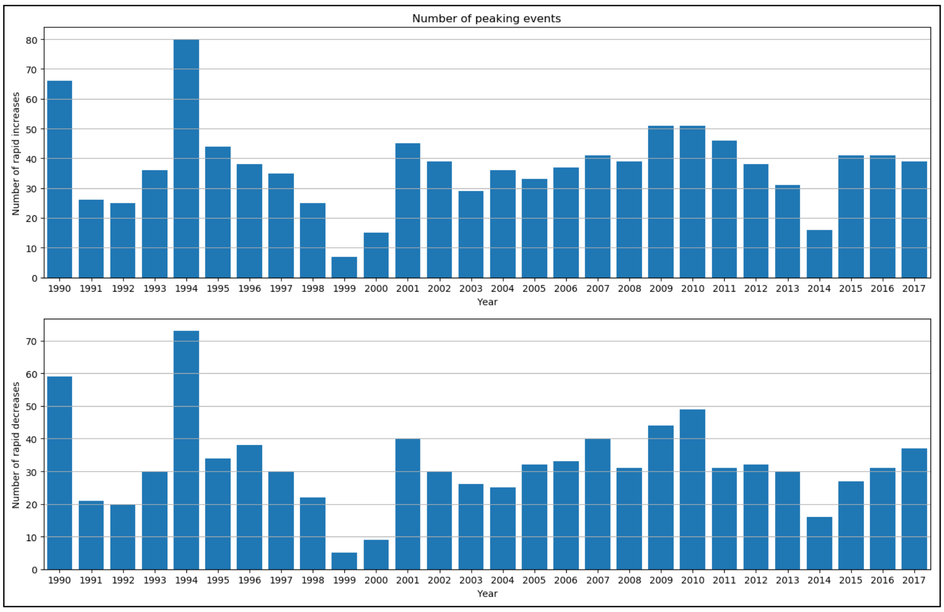


Figure 19: Number of increasing and decreasing water level peaks per year - Bjoreio Station

intermediate. The same happens with the decreasing peaks (figure 19) where 38 events were detected in the first year and 31 events in 2017. There is no clear trend.

4.2 Number of peaks per day

Thanks to COSH Tool, it is possible to quantify the amount of peaks present in a day and also define its frequency since sometimes, more than one daily event can be recorded which is a sign of intense upstream activity that occasionally generates the increase of the peaks.

With the tool it is also possible to get the exact data of each parameter, here the summarized information is presented in graphs, bearing in mind that all the detailed data is found in the excel documents obtained after processing each of the stations with COSH. The results will be classified taking into account their origin (regulated or unregulated rivers) and their type, considering discharge peaks or water level peaks.

4.2.1 Regulated rivers

Discharge

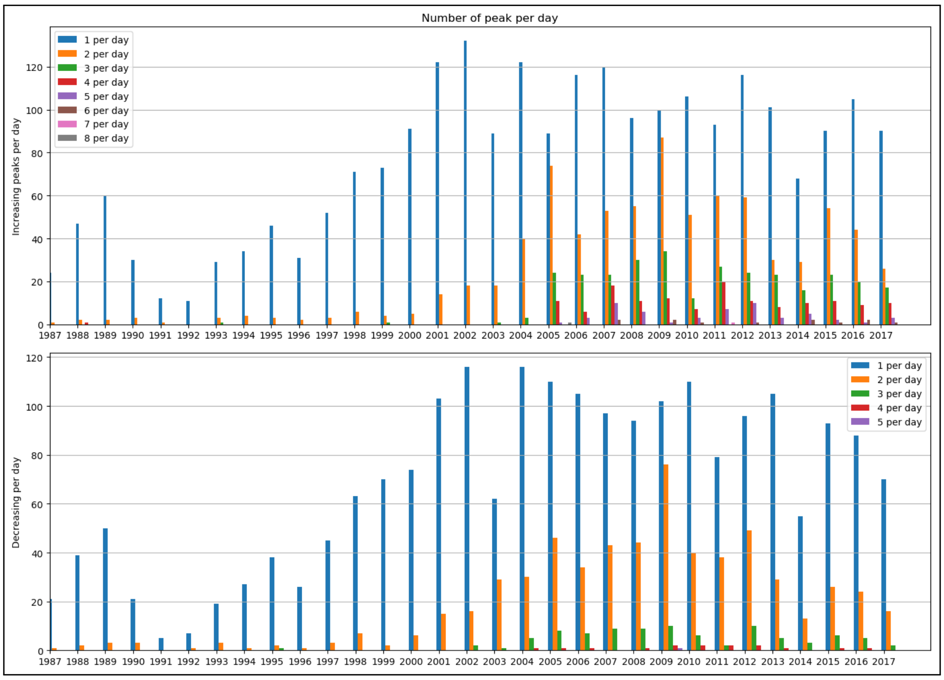


Figure 20: Number of increasing and decreasing discharge peaking events per day - Stuvane Station

Figures 20 and 21 show the frequency with which N amount of peaks is presented per day, with one event being the most predominant feature, followed by two and three daily peaks. Broadly, a tendency to increase can be observed, given that the amount of peaking events registered initially is considerably lower than the final quantity, adding that this

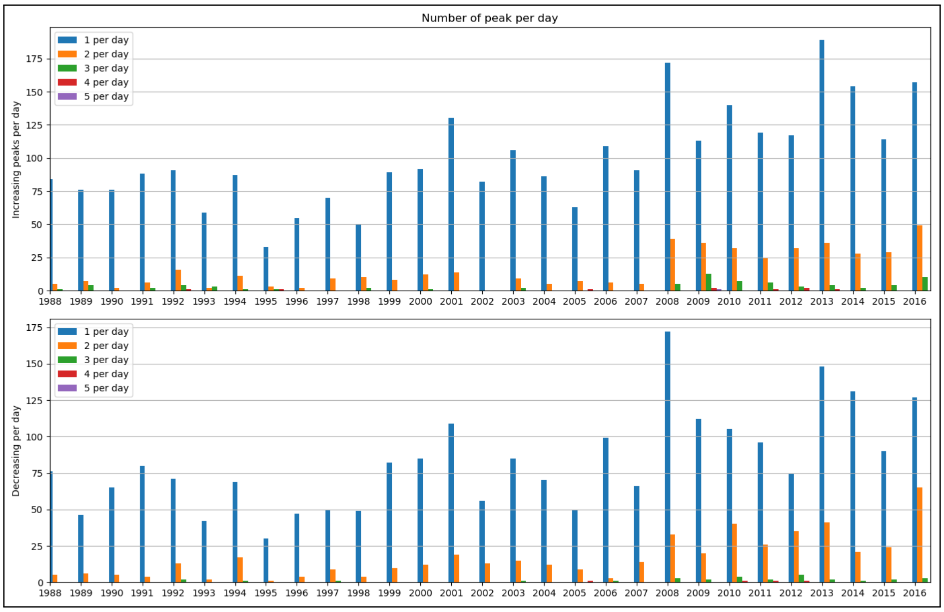


Figure 21: Number of increasing and decreasing discharge peaking events per day - Rate Station

amount increases gradually.

From figure 20 it can be inferred that the peaking events did not occur with a high frequency at the beginning of the measurements. Regarding the upper part (increasing peaks per day), in 1987, when the first record was taken, only 24 days were detected in which one increasing peak took place and just one day registered two increasing peaks, later an increase in both frequency and amount of peaks per day was observed, in the last measure registered in 2017 were detected 90 days in which one peak was detected, 26 days with two peaking events, 17 days with three peaks, 10 days with four peaks, three days with five peaking events and there was even one day that recorded five peaks. A similar behavior is shown for the decreasing peaks. With this pattern it can be inferred in the first place that there is a clear increment in the amount of peaking events and also it can be said that there is a trend, whose significance level will be calculated later with Mann Kendal trend test and the use of R.

Figure 21 shows the amount of peaking events per day in relation to discharge for the Rate Station. The behavior is very similar to the one found in the Stuvane. There is an increase in both the number of peaks per day and their frequency. In 1987, regarding the increasing peaks in the upper part of the plot, 25 days were detected in which only one peaking event took place, three days with two peaks and one day in which three peaks were detected. These quantities increased considerably during the following years until 2009 when there were detected 139, 65 and six days with one, two and three peaks respectively. The same pattern was found for the decreasing peaks shown at the bottom of the graph.

Water Level

In this section, the number of days with N water level peaking events both increasing and decreasing will be shown.

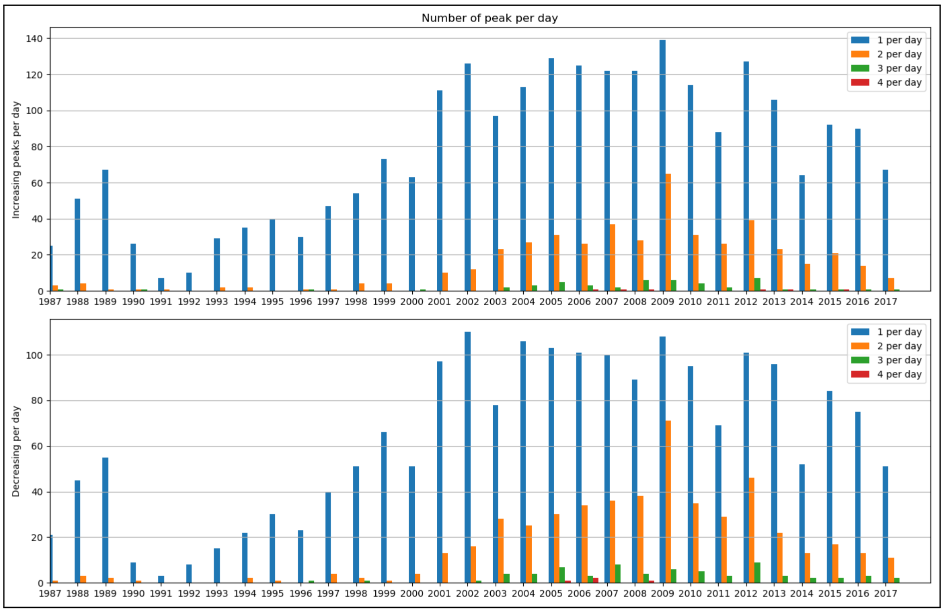


Figure 22: Number of increasing and decreasing water level peaking events per day - Stuvane Station

The behavior of the two measurement stations is quite similar. In the initial part, a very low number of events can be observed for both, increasing and decreasing peaks. Likewise, the result at the end of the measurements reflects a clear increase, reaching up to five increasing and decreasing peaks per day in 2017. The figure 22 corresponds to the frequency of peaking events per day registered by Stuvane station, in 1993 (first record), only two days were detected with one single peak for both criteria, increasing and decreasing peaking events. Thus, it can be inferred that in that year the activity in the river Lærdal was quite stable and did not present major changes. With the passing of the years, the frequency of the peaks rose considerably exceeding 100 days with one peaking event. In the same way, days that showed up to five peaks were recorded at the end of the measurement period.

In the case of Rate (figure 23), the frequency of peaking events is higher, this may be due

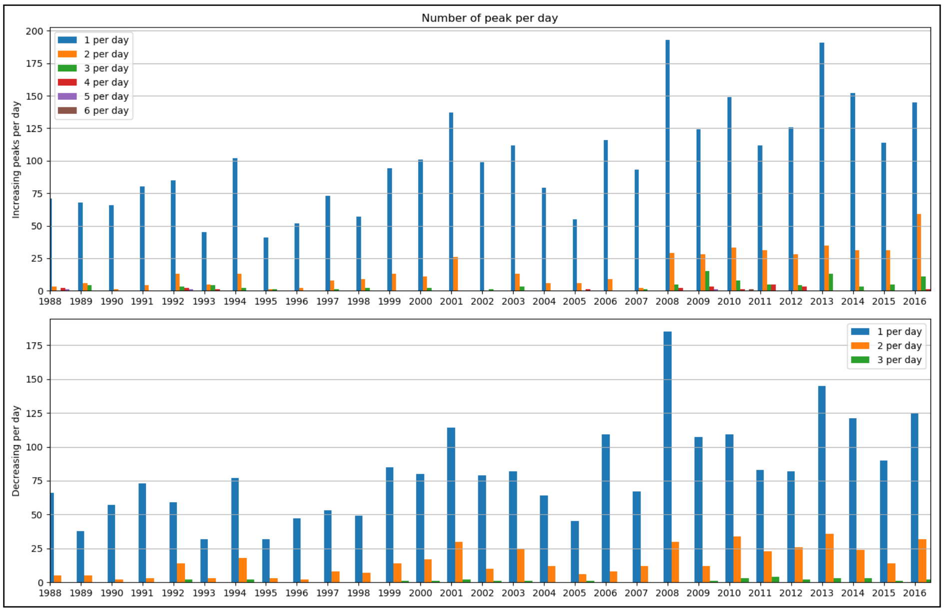


Figure 23: Number of increasing and decreasing water level peaking events per day - Rate Station

to its location and the river that passes through it (Nidelva) which has a lot of activity and is influenced by Leirfossene power plant. In this measuring station, starting in 1998, up to five increasing and three decreasing peaking events per day were detected. In the same way there was an annual increase in the amount of peaks reaching up to four rapid increases and three rapid decreases per day in the last year.

4.2.2 Unregulated rivers

Following, the same analysis will be done for the selected measurement stations that are located in rivers which are not influenced by the presence of a hydroelectric plant.

Discharge

In this case there is an intermittency regarding the number of days with certain peaks and their frequency. Since there is no clearly defined trend and there are no hydroelectric plants that influence the river, it can be suggested that these highs and lows can be caused by weather conditions, excess or lack of rain, change in seasons, floods, etc. Figure 24 corresponds to the Hugdal bru station, in both, the increasing and decreasing peaks per day the intermittency mentioned above can be appreciated. In the case of the increasing peaks (upper graph), 41 days were found at the beginning of the measurements in which one peaking event was presented, while in 2017 this value was 43. For the decreasing peaks per day section, the frequency decreased but the intermittency was conserved, in

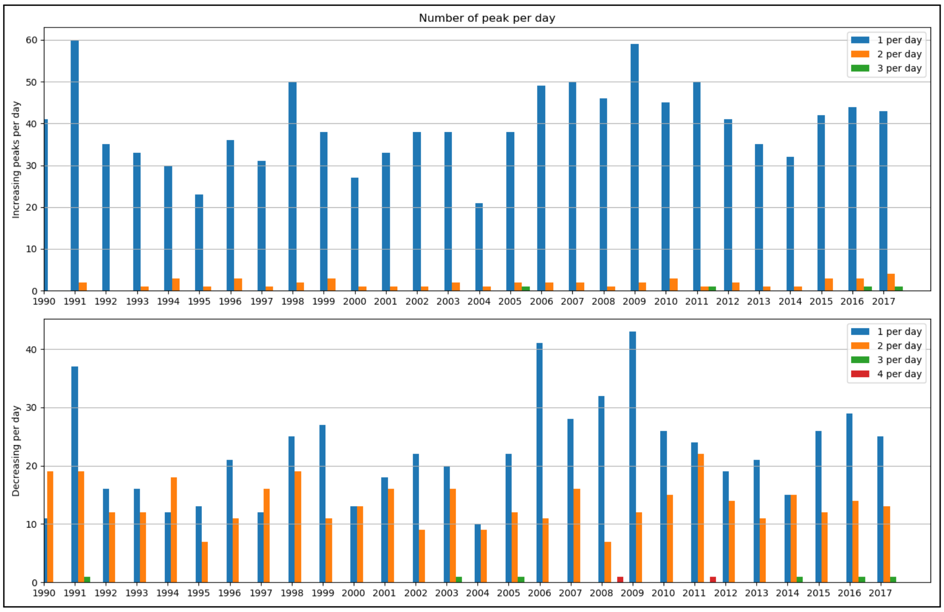


Figure 24: Number of increasing and decreasing discharge peaking events per day - Hugdal bru Station

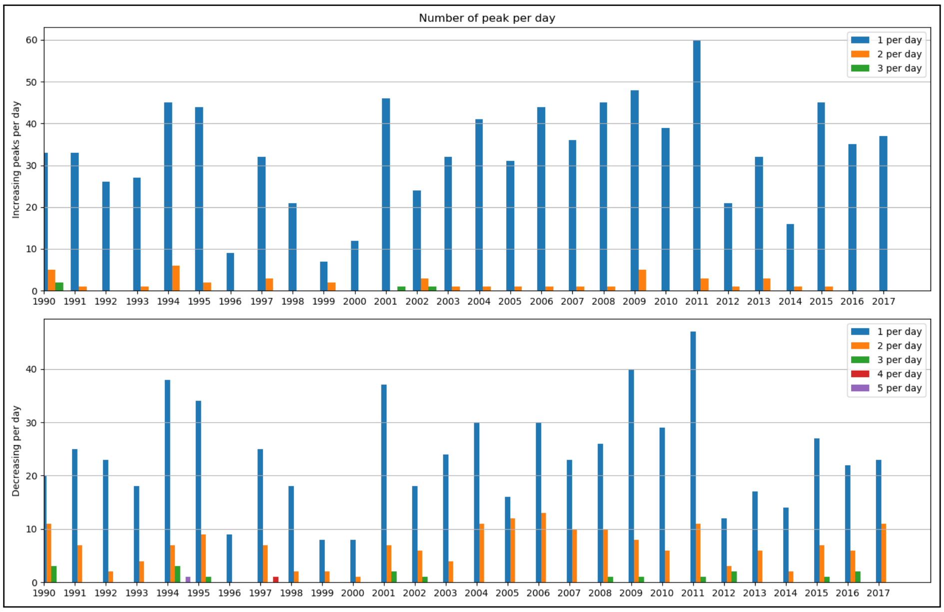


Figure 25: Number of increasing and decreasing discharge peaking events per day - Bjoreio Station

1990 there were counted 11 days in which only one peaking event was presented, while in 2017 this amount was 25. Also the frequency of peaks remained variable with four being the largest amount.

Figure 25 shows the discharge peaking events per day in Bjoreio measurement station.

The behavior is similar to the station described above. The intermittency is conserved, with a higher peak in 2011, when 60 days were detected in which there was one increasing peaking event, in the same year the greatest amount of decreasing peaks was also shown. Regarding the increasing peaks, the maximum number of events was three while in the case of the fast decreases, one day was recorded with four peaking events.

Water level

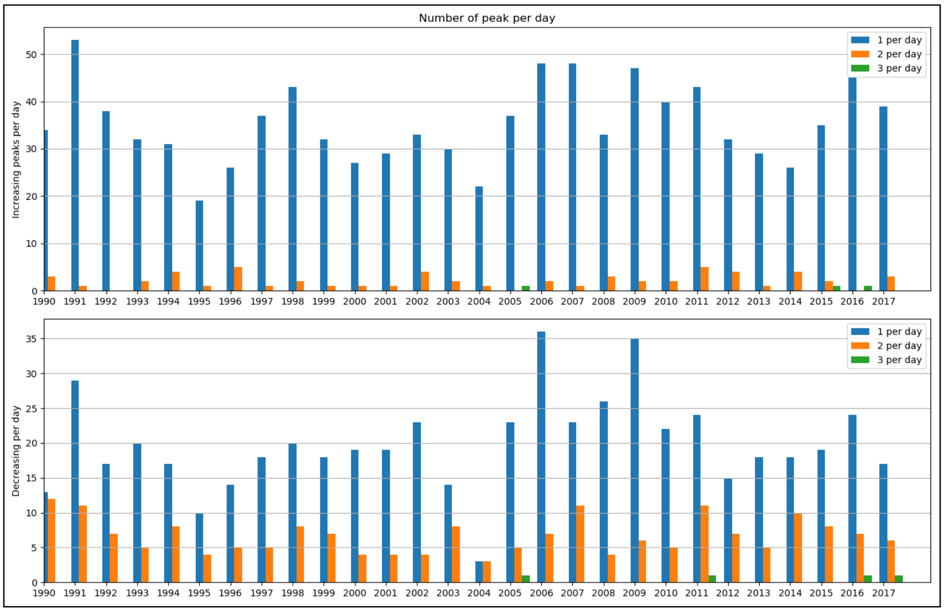


Figure 26: Number of increasing and decreasing water level peaking events per day - Hugdal bru Station

Figures 26 and 27 show the water level behavior for the two stations located in unregulated rivers. The behavior of the water level is quite consistent with what is shown in the discharge section, so it can be said that the intermittence in the number of days with certain peaking events is maintained. In the case of Hugdal bru (Fig 26), the maximum amount detected was three peaks, while in Bjoreio (Fig 27) up to seven peaking events were recorded in the same day.

4.3 Number of peaks per hour

It is considered that the number of peaks per hour can be quite useful since it shows the actual discharge and water level behavior of the rivers throughout the day, in such a way that it is possible to corroborate if there exists a connection between the consumption

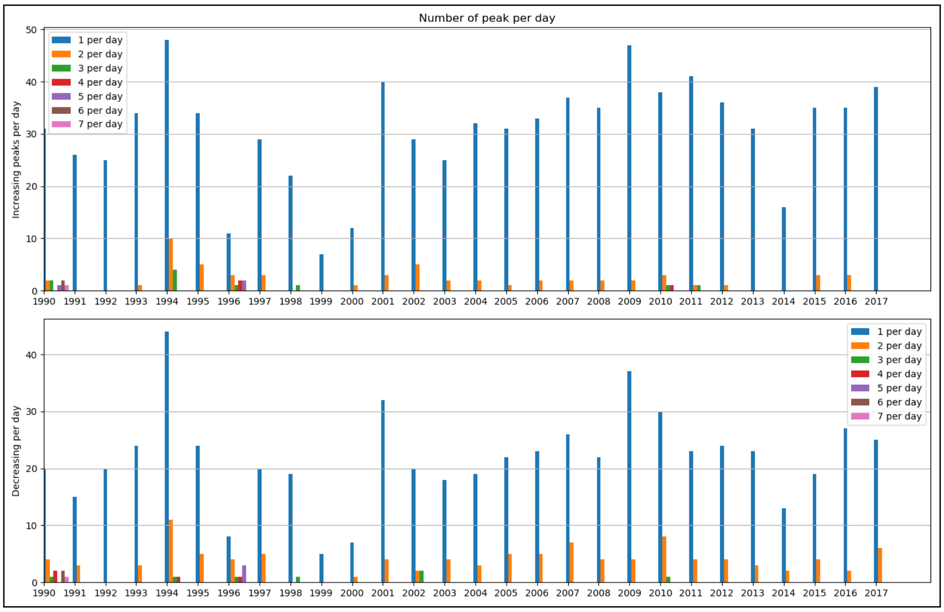


Figure 27: Number of increasing and decreasing water level peaking events per day - Bjoreio Station

trends and the operation of the hydroelectric plants.

In order to have a point of comparison, a plot of the variation of energy prices during the day has been done. The figure 28 shows information provided by Nord Pool according to the day-ahead prices [57]. The values are defined for each bidding area in accordance with the supply and demand of energy, in this case the shown information corresponds to the prices registered on the 02.05.2019 in the city of Trondheim (Norway).

4.3.1 Regulated rivers

Discharge

Figure 29 shows the number of increasing and decreasing peaking events per hour measured at Stuvane station. Regarding the increasing peaks, it can be observed that the greatest number of events happened between 8:00 (562 peaks) and 9:00 (456 peaks), which coincides with the time at which the greatest amount of energy is also required in the homes. Most people are getting ready to go to their respective jobs and daily activities. Then there is another slight increase between 18:00 and 19:00, which corresponds to the return homes of a large part of the population. As expected, the number of rapid decreases presents an opposite behavior. In this case, the greatest number of decreases occurred at midnight, between 00:00 (377 peaks) and 01:00 (373 peaks), which can be explained by the low energy demand during this lapse. The result for the Rate station (figure 30)

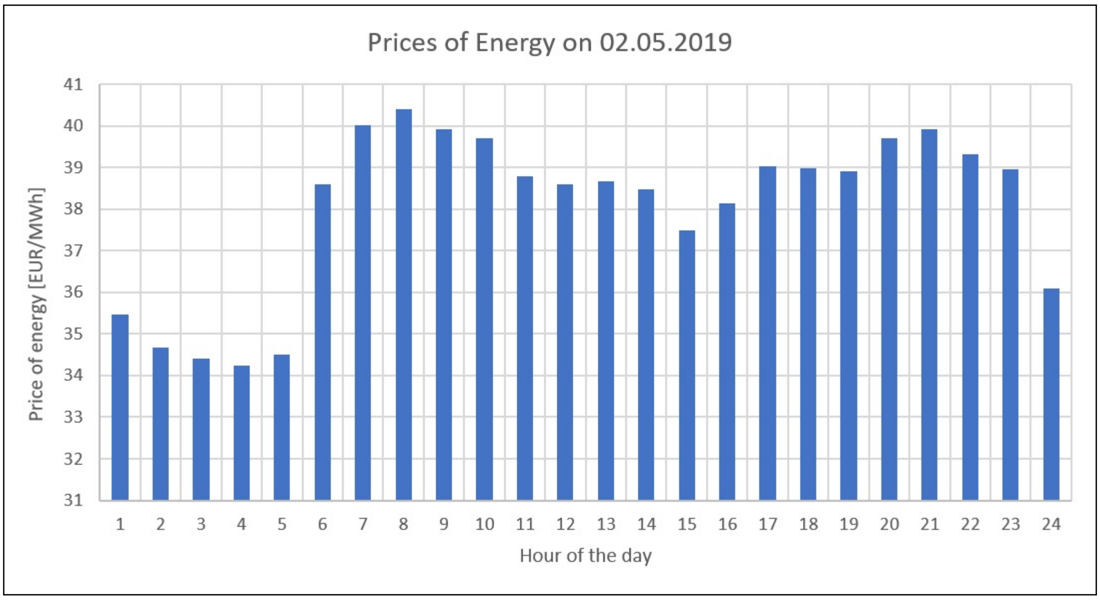


Figure 28: Variation of prices of energy through the day. Taken from [57]

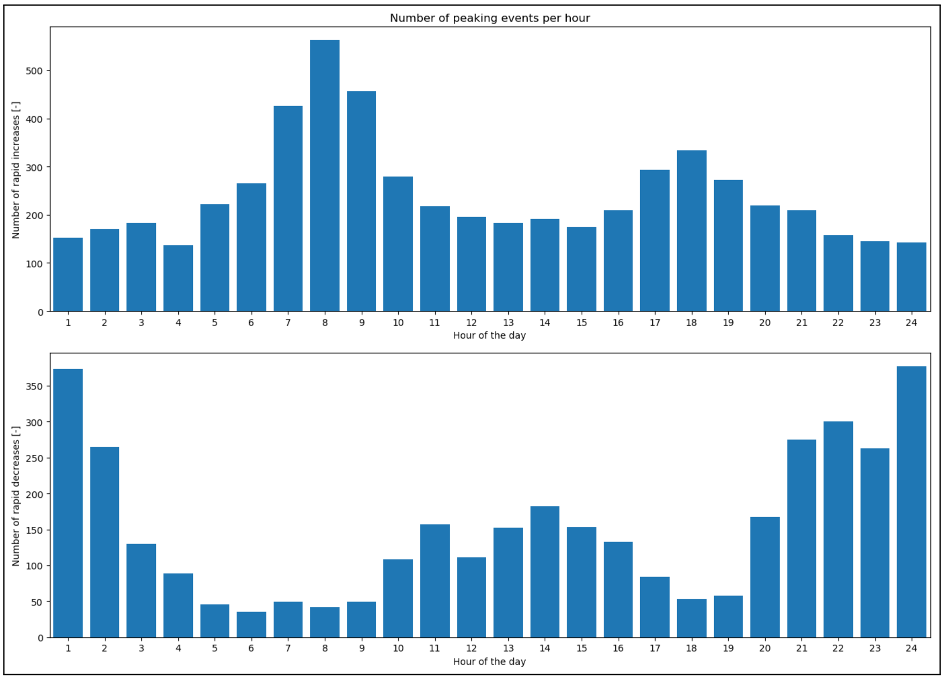


Figure 29: Number of increasing and decreasing discharge peaking events per hour - Stuvane Station

is quite similar, in the case of rapid increases it can be seen that the highest number of peaks occurred between 07:00 and 08:00 with 661 and 512 peaking events respectively. In relation to the decreasing peaks, the greatest number was presented during 23:00 (499 peaks) and 00:00 (551 peaks).

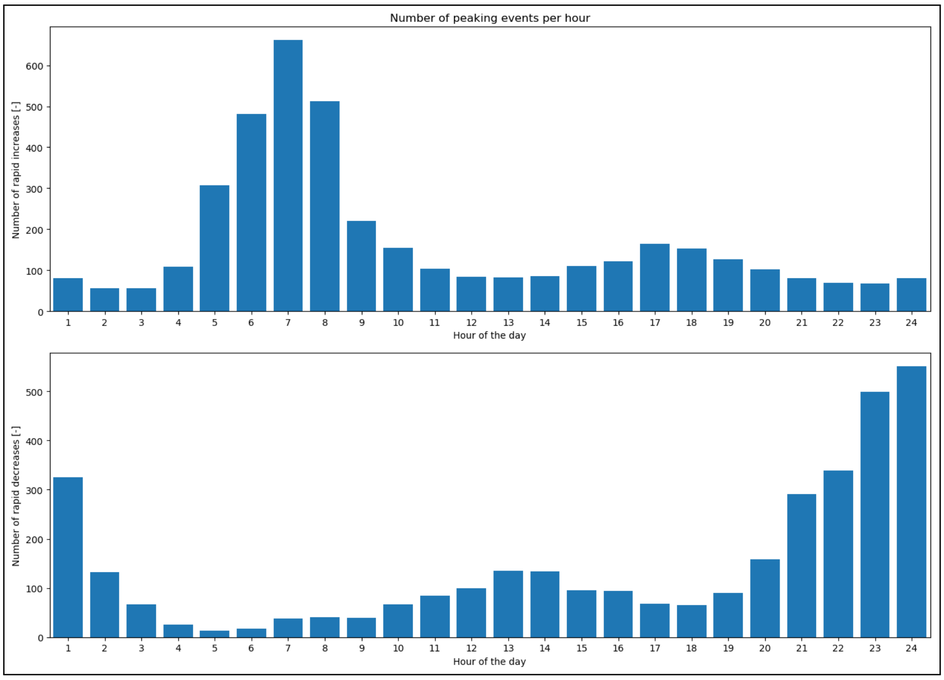


Figure 30: Number of increasing and decreasing discharge peaking events per hour - Rate Station

Water Level

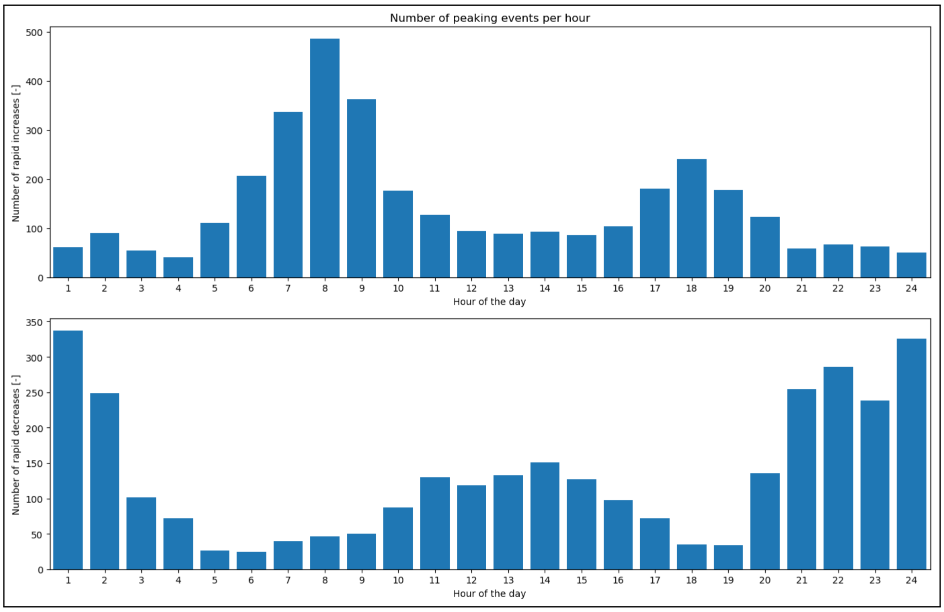


Figure 31: Number of increasing and decreasing water level peaking events per hour - Stuvane Station

The water level behavior coincides with the results obtained when analyzing discharge. Figure 31 shows the amount of increasing a decreasing peaks detected in Stuvane in re-

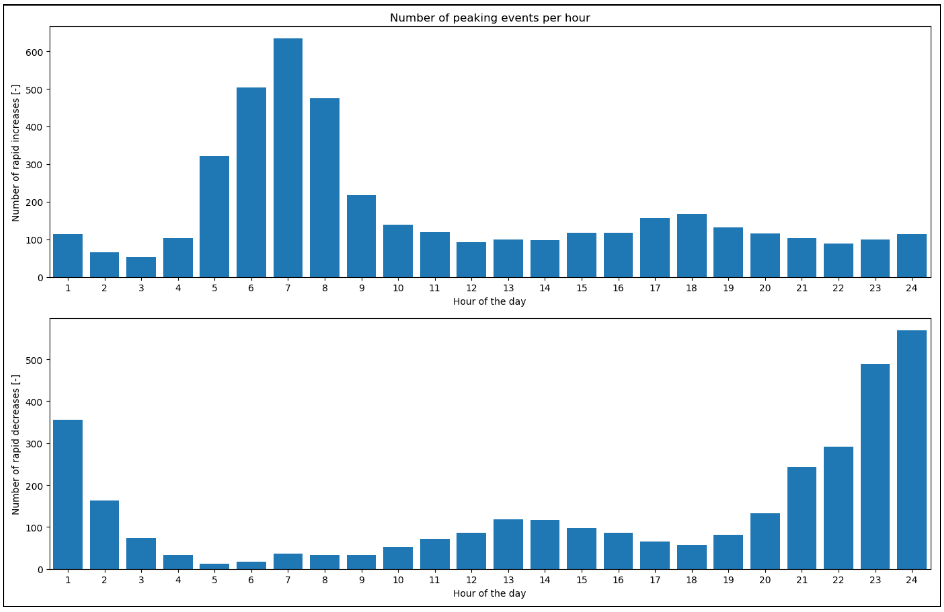


Figure 32: Number of increasing and decreasing water level peaking events per hour - Rate Station

lation to water level. In this case, a perfect correlation with the results obtained in the previous graphs is presented. For the increasing peaks, the highest number of events occurred during 08:00 and 09:00 with 486 and 363 peaks respectively. In relation to the rapid decreases, a considerate amount of events can be observed between 00:00 and 01:00 with 326 and 337 decreasing peaks, respectively.

Figure 32 presents the results obtained in the Rate station, in this case, as it happened with discharge, the largest increment in increasing peaking events between 07:00 and 08:00 was evidenced with 634 and 435 peaks respectively. In the case of the rapid decreases, a predominance is observed towards 23:00 when there were 489 peaks and 00:00 when that amount increased to 569 peaks.

4.3.2 Unregulated rivers

Discharge

Following, the results obtained for the unregulated stations will be shown. In this case the pattern observed in the previous section is not observed and the increases occur at different periods of the day. Figure 33 shows the number of peaking events in relation to discharge for the Hugdal bru station. Here, the highest frequency of increasing peaks was recorded between 18:00 and 19:00 with 100 events. Regarding the rapid decreases, a maximum point was presented at 05:00 with 131 peaks. It can also be added that the

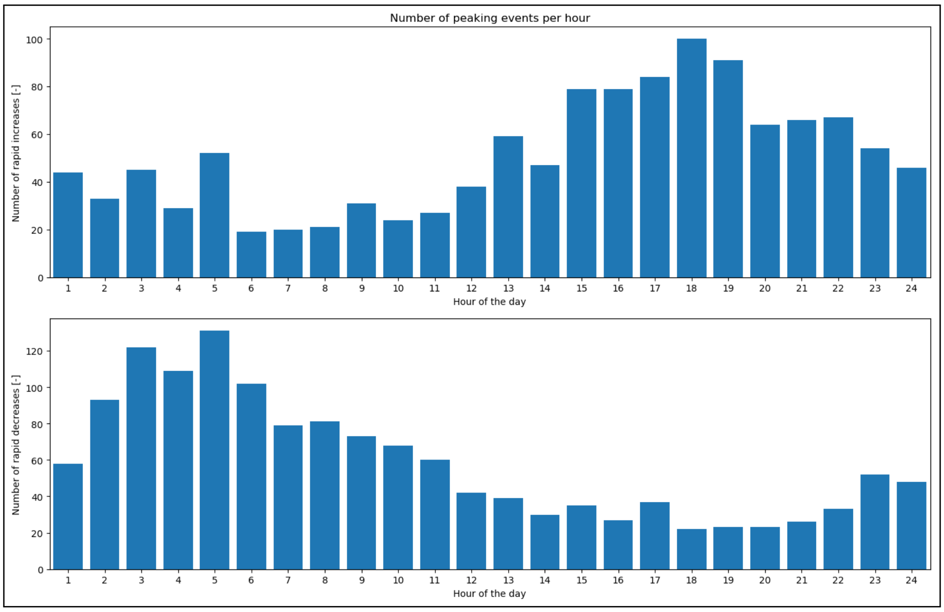


Figure 33: Number of increasing and decreasing discharge peaking events per hour - Hugdal bru Station

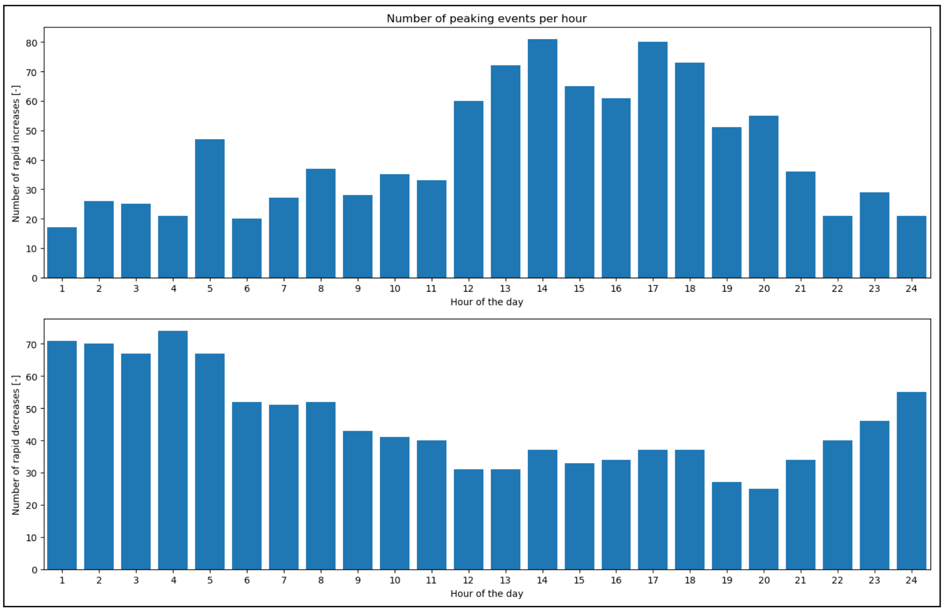


Figure 34: Number of increasing and decreasing discharge peaking events per hour - Bjoreio Station

total amount of peaking events is considerably lower than that presented in the stations that are under the influence of hydroelectric plants.

Figure 34, on the other hand, shows the data for the Bjoreio station. In this case, the highest frequency of increasing peaks occurred at 14:00 with 81 events, while the highest number of rapid decreases occurred at 04:00 with a frequency of 74 peaks. As it can be observed,there is no specific pattern when it comes to the times with more peaks during the day, in the same way the amount of events is quiet reduced.

Water level

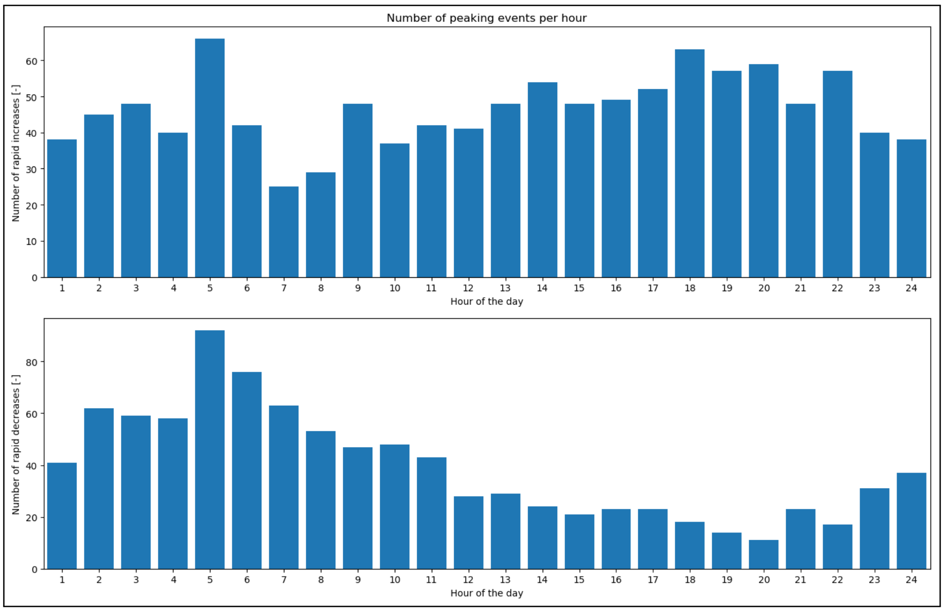


Figure 35: Number of increasing and decreasing water level peaking events per hour - Hugdal bru Station

Figure 35 shows the number of peaking events per hour at Hugdal bru station, in relation to water level. Contrary to what happened with the regulated rivers, where the increasing and decreasing peaks presented an opposite behavior, here the biggest frequency for both, rapid increases and rapid decreases took place at 05:00. At that time there were 66 increasing and 92 decreasing peaking events.

In the case of the Bjoreio station (figure 36), the highest frequency of increasing peaks occurred at 1:00 PM with 78 events and, for its part, the greatest number of decreasing peaks occurred at 01:00 and 10:00, both with 47 events.

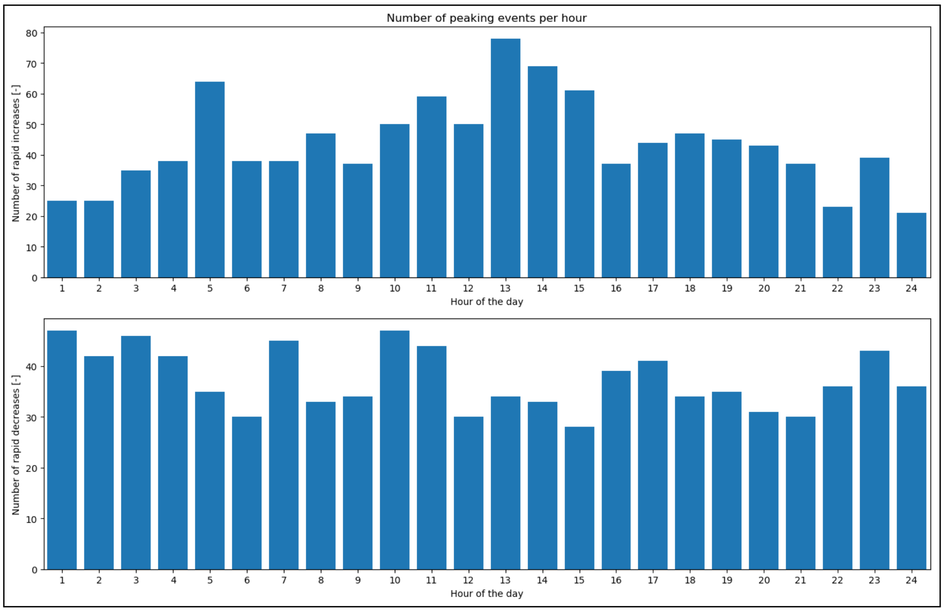


Figure 36: Number of increasing and decreasing water level peaking events per hour - Bjoreio Station

4.4 Trend Analysis

A general compilation of the results made with R will be shown below. It is important to have a complete view of the different stations and the processed data both in discharge and water level, in order to have a better understanding of the dynamics of the various parameters and the effect of the hydroelectric plants on the water courses.

4.4.1 Comparison of the increasing and decreasing peaks per year

Regulated rivers

Figure 37 and 38 show both the number of increasing and decreasing peaks for all stations located on regulated rivers. Figure 37 shows the trends for water level, most of the graphs show a tendency to increase the number of peaking events over the years, with the exception of Tørrisdal, which is located on the Namsen River, where the opposite phenomenon occurs. It is also remarked that, with exception of three stations, (Hegra, Låvis and Bertnem) the amount of increasing peaks is above the decreasing peaks.

In the case of fig 38 the same information is shown but related to water level. Here, only one station (Ruud) shows more decreasing than increasing peaks. As an interesting fact, in the Skjermo station two trends can be observed that, despite having the same direction, are separated one each other, they show considerably more increasing peaks

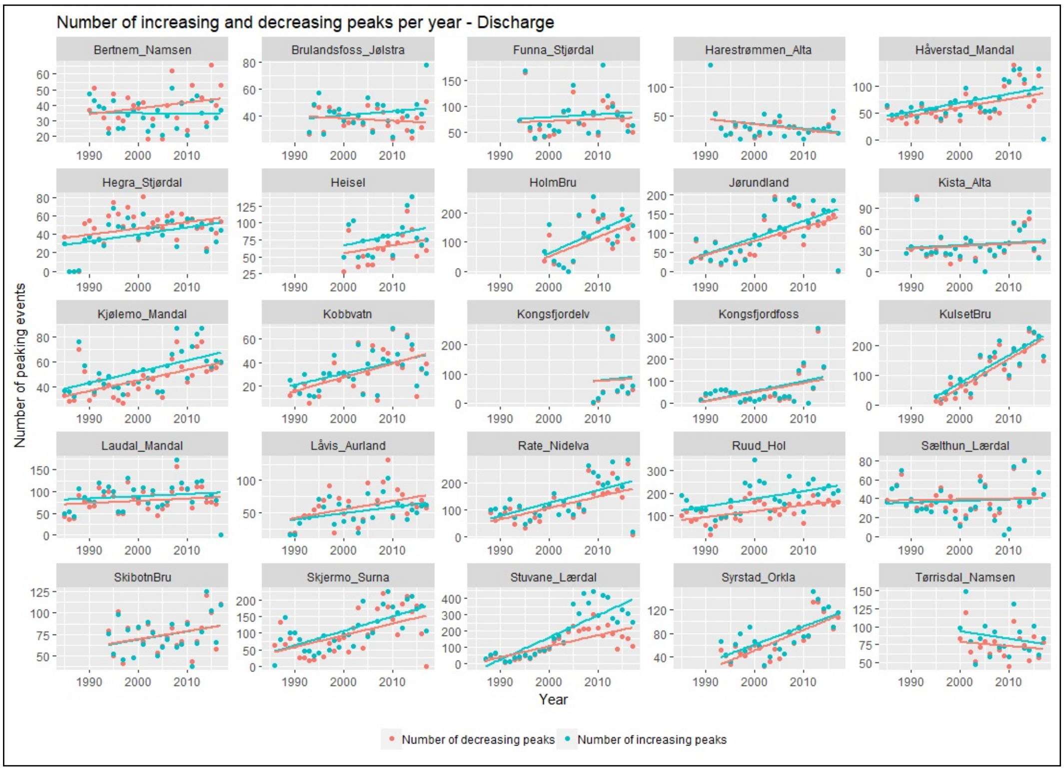


Figure 37: Comparison of the increasing and decreasing discharge peaks per year

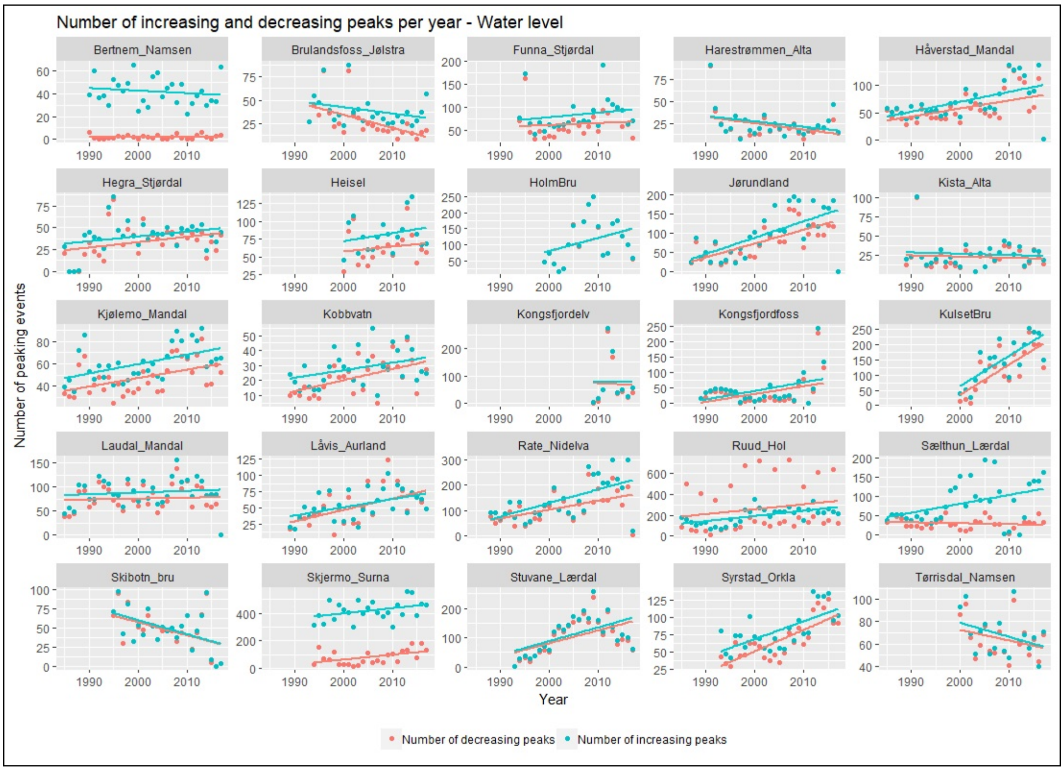


Figure 38: Comparison of the increasing and decreasing water level peaks per year

than decreasing peaks, this type of behavior can indicate that in the power plant that is located upstream, the gates are opened quickly but later the turbines are turned off slowly, therefore the fast decreases are less than fast increases.

Unregulated rivers

Figure 39: Comparison of the increasing and decreasing discharge peaks per year

In the figure 39, rapid decreases over rapid increases predominate (with respect to discharge), contrary to what happened with the regulated rivers. In all the stations a very similar behavior can be observed between the two types of peaks, with the exception of Hugdal bru where there is a predominance of decreasing peaking events. Since these stations are not influenced by hydropower plants, it can be suggested that changes in the climatic conditions generated decreases in the discharge of the river in which the measuring station is located, but a more thorough investigation is needed to determine the exact reason for these decreases.

On the other hand, figure 40 shows the frequency of increasing and decreasing peaks per year in relation to water level, here, a predominance of increasing peaks in all seasons is observed.

Figure 40: Comparison of the increasing and decreasing water level peaks per year

4.4.2 Number of increasing peaking events per day

Regulated rivers

Figures 41 and 42 show the number of days with one, two and three increasing peaks for the regulated rivers. In the figure 41 the statistics referring to discharge are shown. As expected, a large predominance of days with one increasing peak is observed, followed by two and three peaking events per day respectively. The upwards trend remains.

The same case is presented in figure 42 where the data corresponding to water level is shown.

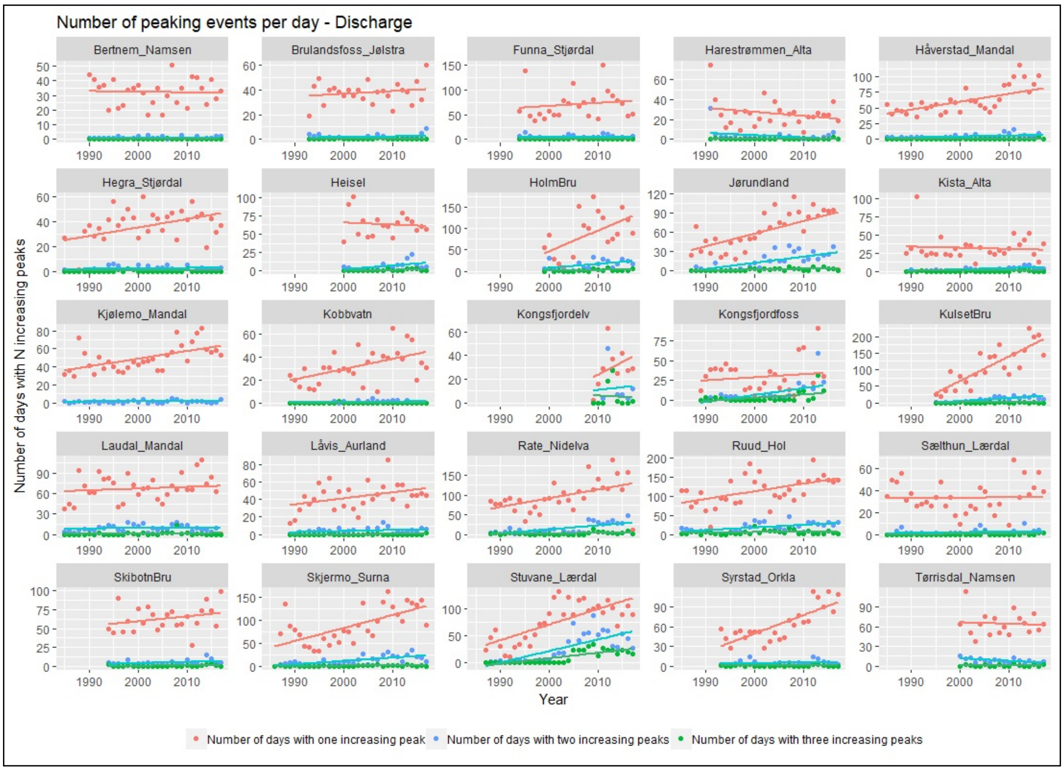


Figure 41: Number of days with one, two and three increasing discharge peaks

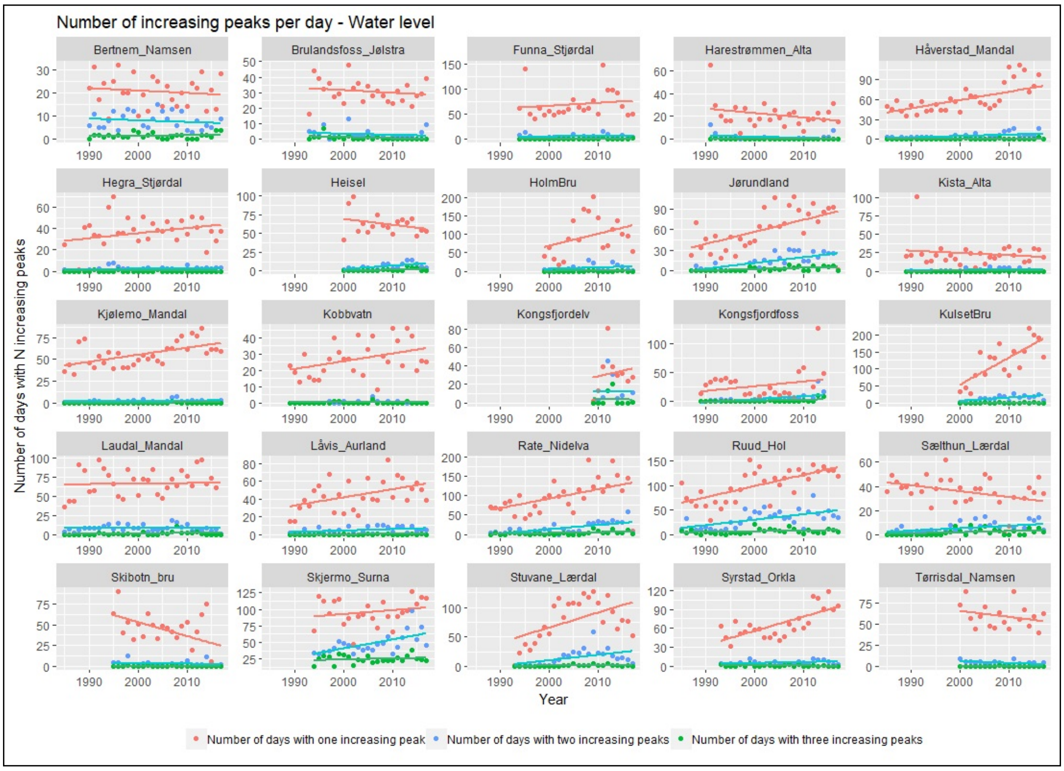


Figure 42: Number of days with one, two and three increasing water level peaks

Unregulated rivers

Figure 43: Number of days with one, two and three increasing discharge peaks

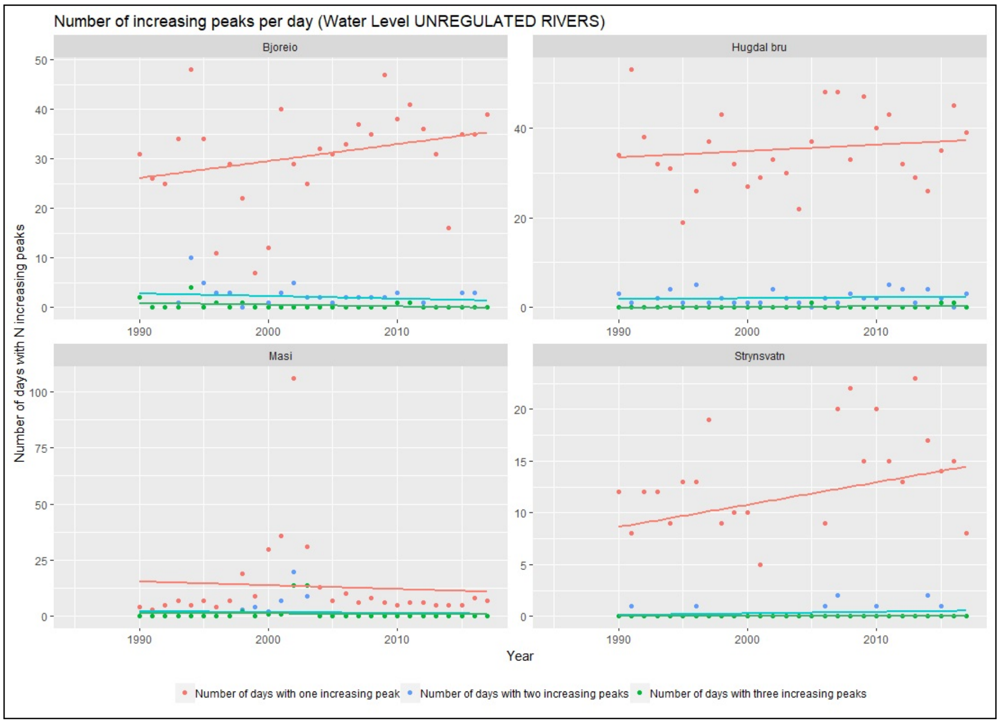


Figure 44: Number of days with one, two and three increasing water level peaks

4.4.3 Comparison of maximum rate of change per year

The data collected from maximum rate of change per year in relation to discharge and water level in regulated rivers will be shown below. Figure 45 shows the comparison between rate of increase and decrease respectively. In almost all stations, a corresponding behavior can be observed between these two parameters, that is, the amount of increasing and decreasing peaks increased or decreased following the same pattern, with the exception of Stuvane and Tørrisdal, where an indirect relationship is observed, which indicates that, when there was an increment in the increase rate of change, a reduction in the decrease rate of change was also observed.

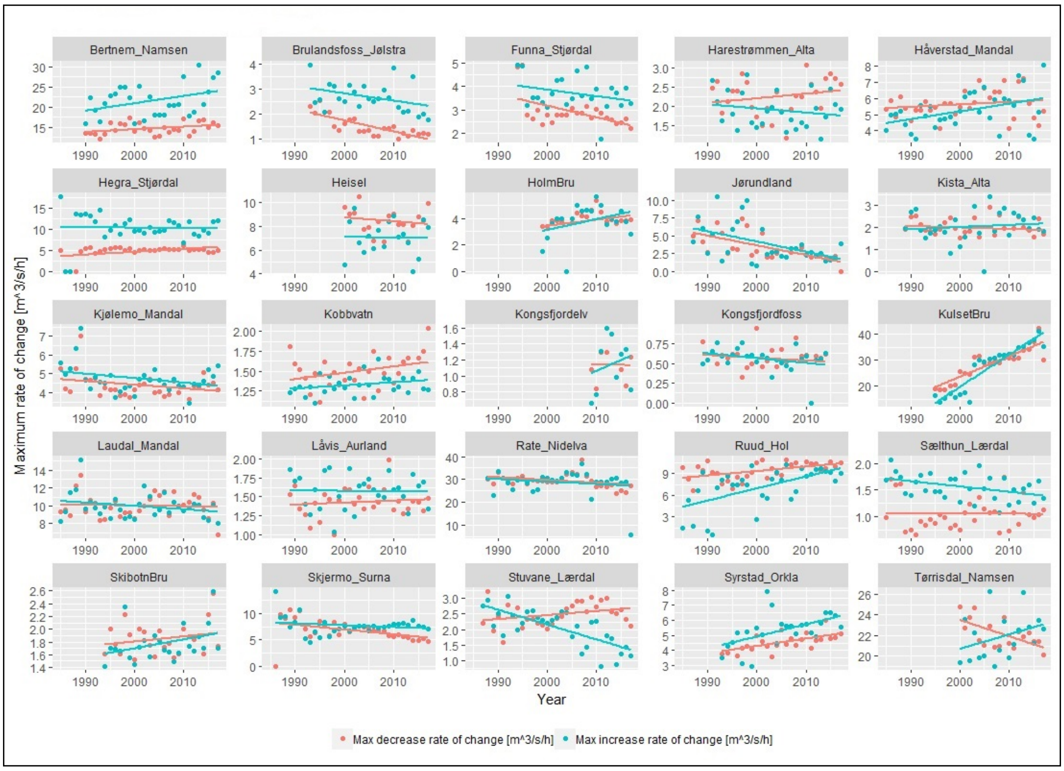


Figure 45: Comparison of maximum rate of change per year - Discharge

Figure 46 shows the analysis of the same parameters for water level. In general, most stations show a similar behavior with reference to the value of the rate of change as well as the trend. As an interesting fact, in the Skjermo station located in the Surna river, there is a considerable difference in the value of rates of change as well as in the trend direction.

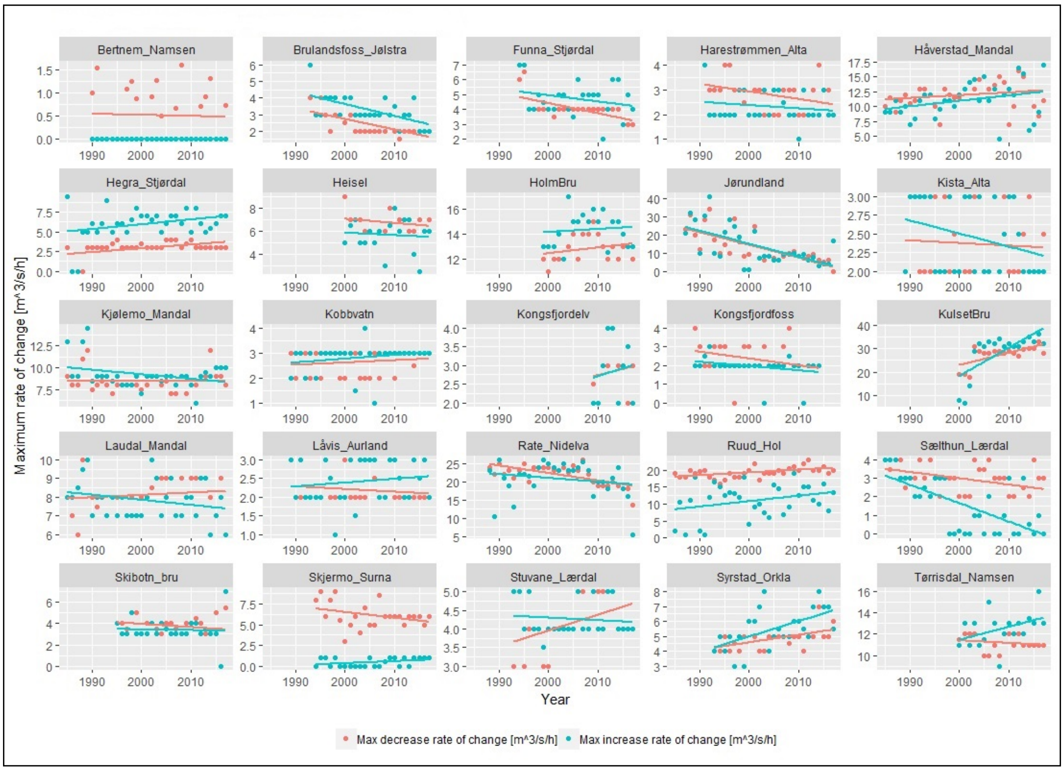


Figure 46: Comparison of maximum rate of change per year - Water level

4.4.4 Mann Kendall trend test

The results obtained from the Mann Kendall trend test will be shown below. The purpose of this analysis is to evaluate the presence of possible significant trends and in this way quantify the results observed previously by means of graphs. In this case, a categorization of the data was carried out in such a way that it was possible to make a classification in 3 different ranges. Taking into account that a trend is considered significant when its p-value is less than 0.05, the first group was defined, which will be marked with blue. Likewise, the results located between 0.05 and 0.1, although they are not highly significant like the first ones, also present a degree of relevance, which is greater the closer they are to the main criterion (0.05). This intermediate group will be marked with light red. Finally, the results that are greater than 0.1 will be considered as excluded, therefore an indicative of the absence of trends and will be marked with dark red.

Table 2 shows the results of the Mann Kendall and Sen's slope trend tests. In the case of the increasing discharge peaks per year, twelve stations have a p-value below the level of significance (0.05) therefore the null hypothesis is rejected and the alternate hypothesis of acceptance of trend in the time-series data is confirmed. These trends are considered significant and are represented by blue. Additionally, as mentioned before, the sign of the tau value represents the direction of each trend, in this case all values are positive so it can be determined that all detected cases show an upwards tendency. One of the stations (HolmBru) is marked with light red because it is very close to the level of significance. The other values are above this level and therefore H0 is confirmed what implies the non-existence of a trend.

Regarding the decreasing peaks per year, a behavior very similar to the first parameter is observed, all the trends are repeated, with the exception of Hegra, which exceeds the level of significance given that its p-value is 0.306 which is greater than 0.05. Thus, it can be affirmed that in the case of the decreasing peaks per year 11 trends were confirmed, all of them positive, which is determined due to the positive sign on the Tau values.

Table 3 shows the result of the trend tests with respect to the number of days with one, two and three increasing peaks. In a general way it can be seen that 4 stations present trends along the three parameters, which indicates that there was a very active hydropeaking in the rivers where these measurement stations are located (Håverstad, Skjermo, Stuvane and Jørundland). Likewise, some gauges presented trends in the first two parameters, such as Rate, Ruud and KulsetBru. The mentioned trends are shown in blue. It can also be indicated that all of them show an upwards tendency given the sign of the Sen's slope. On the other hand, two stations were very close to being defined as trend, but they exceed the level of significance by a small difference, therefore they could not be signaled as significant, nevertheless it is important to take them into account. These are indicated in light red.

Table 4 shows the trends obtained after evaluating the data corresponding to the number of increasing and decreasing peaks per year in relation to water level. In this case, more than the double of trends detected, if a comparison is made with the results obtained for discharge. Ten stations gave a positive result to the trend test, which implies that the p-value was below the level of significance (0.05). These stations were: Håverstad, Kjølemo, Låvis, Rate, Ruud, Sælthun, Skibotn, Stuvane, Syrstad, Jørundland and KulsetBru. Regarding the direction of the trends, all of them, except of three show an upwards tendency. The three stations that show a trend with a downwards inclination are Skibotn with respect to both, increasing and decreasing peaks per year and Brulandfoss only with the decreasing peaking events. Additionally three stations were very close to the limit to be classified as significant trends for both parameters, these stations were Funna, Hegra and Kobbvatn.

Table 2: Number of increasing and decreasing discharge peaks per year

Station	**Inc peaks per year**			**Dec peaks per year**		
	tau	***p-value***	***Sen's slope***	***tau***	***p-value***	***Sen's slope***
Bertnem	-0.051	0.721	-0.054	0.158	0.251	0.341
Brulandsfoss	0.037	0.815	0.024	-0.145	0.326	-0.268
Funna	0.098	0.519	0.702	0.159	0.286	0.905
Håverstad	0.440	0.000	1.733	0.382	0.002	1.354
Hegra	0.255	0.039	0.631	0.128	0.306	0.333
Kjølemo	0.431	0.001	0.900	0.470	0.000	0.905
Laudal	0.166	0.182	0.796	0.171	0.168	0.886
Låvis	0.288	0.031	0.974	0.323	0.015	1.356
Rate	0.398	0.002	4.778	0.460	0.000	4.545
Ruud	0.314	0.011	3.184	0.395	0.001	2.704
Sælthun	0.004	0.988	0.000	-0.036	0.780	-0.180
Skjermo	0.498	0.000	4.606	0.406	0.001	3.700
Stuvane	0.656	0.000	12.231	0.596	0.000	7.571
Syrstad	0.464	0.001	2.933	0.544	0.000	3.146
Tørrisdal	-0.132	0.471	-1.000	-0.085	0.649	-0.571
Harestrømmen	-0.049	0.738	-0.111	-0.026	0.867	-0.100
Heisel	0.238	0.184	1.455	0.264	0.139	1.833
HolmBru	0.322	0.059	7.375	0.275	0.108	5.923
Jørundland	0.482	0.000	5.000	0.431	0.001	4.143
Kista	0.139	0.301	0.400	0.180	0.177	0.556
Kobbvatn	0.361	0.007	1.000	0.389	0.003	1.217
Kongsfjordelv	0.333	0.251	5.375	0.222	0.466	4.589
Kongsfjordfoss	0.161	0.261	1.333	0.084	0.566	0.667
KulsetBru	0.665	0.000	9.444	0.692	0.000	10.111
SkibotnBru	0.218	0.143	1.000	0.188	0.213	1.000

It is interesting to note that three stations maintained their constant behavior in both parameters, discharge and water level, and presented significant trends for both increasing and decreasing peaks per year, these stations were: Håverstad, Stuvane and Jørundland.

Table 3: Number of days with one, two and three increasing peaks - Discharge

Station	**1 inc peak per day**		**2 inc peaks per day**		**3 inc peaks per day**	
	p-value	***Sen's slope***	***p-value***	***Sen's slope***	***p-value***	***Sen's slope***
Bertnem	0.634	-0.091	0.983	0.000	0.804	0.000
Brulandsfoss	1.000	0.000	1.000	0.000	0.967	0.000
Funna	0.309	0.732	0.920	0.000	0.680	0.000
Håverstad	0.000	1.359	0.033	0.100	0.026	0.000
Hegra	0.023	0.526	0.145	0.000	1.000	0.000
Kjølemo	0.000	0.857	0.409	0.000	1.000	0.000
Laudal	0.329	0.500	0.744	0.000	0.186	0.000
Låvis	0.051	0.692	0.058	0.123	0.344	0.000
Rate	0.001	2.444	0.006	1.000	0.175	0.000
Ruud	0.003	2.000	0.005	0.667	0.553	0.000
Sælthun	0.852	0.000	0.164	0.000	0.013	0.000
Skjermo	0.000	3.198	0.000	0.696	0.028	0.000
Stuvane	0.000	2.875	0.000	1.750	0.000	0.000
Syrstad	0.000	2.667	0.300	0.095	0.762	0.000
Tørrisdal	0.820	0.222	0.018	-0.400	0.800	0.000
Harestrømmen	0.646	-0.125	0.221	0.000	0.610	0.000
Heisel	0.970	-0.100	0.024	0.364	0.025	0.000
HolmBru	0.069	5.111	0.080	1.000	0.027	0.000
Jørundland	0.000	2.464	0.000	1.000	0.000	0.000
Kista	0.486	0.143	0.000	0.143	0.156	0.000
Kobbvatn	0.011	0.882	0.058	0.000	0.676	0.000
Kongsfjordelv	0.295	2.125	0.289	1.083	0.643	0.000
Kongsfjordfoss	0.947	0.000	0.034	0.333	0.117	0.000
KulsetBru	0.000	7.500	0.000	0.944	0.171	0.000
SkibotnBru	0.143	0.757	0.158	0.077	0.150	0.000

Table 5 shows the results corresponding to the trend evaluation performed for the amount of days that presented 1, 2 and 3 repetitions of increasing water level peaks. In this case

Table 4: Number of increasing and decreasing water level peaks per year

Station	**Inc peaks per year**			**Dec peaks per year**		
	tau	***p-value***	***Sen's slope***	***tau***	***p-value***	***Sen's slope***
Bertnem	-0.125	0.363	-0.279	0.098	0.505	0.000
Brulandsfoss	-0.189	0.198	-0.437	-0.576	0.000	-1.000
Funna	0.289	0.053	1.194	0.277	0.062	1.321
Håverstad	0.452	0.000	1.805	0.336	0.007	1.000
Hegra	0.213	0.088	0.406	0.207	0.097	0.556
Kjølemo	0.416	0.001	0.846	0.384	0.002	0.750
Laudal	0.160	0.198	0.555	0.091	0.466	0.327
Låvis	0.327	0.014	1.179	0.419	0.002	1.575
Rate	0.438	0.001	6.077	0.443	0.001	4.000
Ruud	0.383	0.002	4.670	0.254	0.039	3.599
Sælthun	0.317	0.010	3.000	-0.084	0.505	-0.239
Skibotn	-0.306	0.045	-2.000	-0.303	0.047	-1.857
Skjermo	0.207	0.165	3.629	0.356	0.016	3.655
Stuvane	0.415	0.004	5.793	0.419	0.004	5.310
Syrstad	0.424	0.003	2.283	0.586	0.000	3.118
Tørrisdal	-0.198	0.271	-1.100	-0.203	0.256	-1.000
Harestrømmen	-0.106	0.452	-0.182	-0.107	0.452	-0.182
Heisel	0.186	0.304	1.000	0.223	0.211	1.500
HolmBru	0.246	0.151	5.000	0.240	0.162	5.000
Jørundland	0.511	0.000	5.000	0.520	0.000	3.429
Kista	0.101	0.453	0.226	0.109	0.419	0.190
Kobbvatn	0.229	0.087	0.458	0.402	0.003	0.821
Kongsfjordelv	0.222	0.466	5.083	0.111	0.754	2.524
Kongsfjordfoss	0.127	0.378	0.800	0.034	0.825	0.167
KulsetBru	0.529	0.002	11.000	0.564	0.001	9.500

four stations maintained a constant behavior along all the studied parameters showing significant trends (blue). These stations were Håverstad, Rate, Stuvane and Jørundland, all showing an upwards tendency, which could be determined by the positive sign of the

Table 5: Number of days with one, two and three peaks - Water level

Station	**1 inc peak**		**2 inc peaks**		**3 inc peaks**	
	p-value	***Sen's slope***	***p-value***	***Sen's slope***	***p-value***	***Sen's slope***
Bertnem	0.539	-0.131	0.414	-0.053	0.837	0.000
Brulandsfoss	0.325	-0.261	0.231	-0.061	0.008	0.000
Funna	0.172	0.743	0.468	0.063	0.108	0.000
Håverstad	0.001	1.314	0.014	0.150	0.096	0.000
Hegra	0.167	0.323	0.029	0.059	0.471	0.000
Kjølemo	0.000	0.867	0.190	0.000	0.366	0.000
Laudal	0.438	0.333	0.790	0.000	0.075	0.000
Låvis	0.031	0.886	0.032	0.140	0.212	0.000
Rate	0.001	2.786	0.000	1.059	0.016	0.125
Ruud	0.000	2.236	0.001	1.095	0.078	0.129
Sælthun	0.077	-0.333	0.021	0.196	0.004	0.068
Skibotn	0.050	-1.688	0.451	0.000	0.338	0.000
Skjermo	0.285	0.700	0.001	1.077	0.708	0.056
Stuvane	0.009	2.649	0.005	0.911	0.025	0.044
Syrstad	0.001	2.056	0.107	0.111	0.454	0.000
Tørrisdal	0.343	-0.667	0.066	-0.200	1.000	0.000
Harestrømmen	0.531	-0.143	0.152	0.000	0.087	0.000
Heisel	0.622	-0.571	0.022	0.400	0.071	0.059
HolmBru	0.208	3.235	0.458	0.111	0.196	0.000
Jørundland	0.000	2.214	0.001	0.867	0.000	0.176
Kista	0.612	0.125	0.132	0.000	0.237	0.000
Kobbvatn	0.051	0.432	0.560	0.000	0.801	0.000
Kongsfjordelv	1.000	0.917	0.529	0.917	0.616	0.000
Kongsfjordfoss	0.860	0.111	0.009	0.227	0.059	0.000
KulsetBru	0.002	8.000	0.004	1.067	0.490	0.000

Sen's slope. Additionally two stations presented trends in the first two parameters and were very close to the threshold of significance (light red) in the third parameter, these stations were Håverstad and Ruud. In general, 9, 12 and 5 trends were established with days that registered one, two and three increasing peaks respectively.

To corroborate the hypothesis that states the fact that the hydropeaking is highly influenced by the power plants, it was decided to apply the trend tests for the stations located in unregulated rivers in such a way that it will be possible to establish the differences between the two regimes.

Table 6 shows the results of the trend analysis of the increasing and decreasing peaks per year for both discharge (flow) and water level (stage). As it can be observed, only the station located in Strynsvatn registered a positive trend (blue) and solely with respect to discharge. All the other stations exceed the significance level (0.05) in its p-value, therefore H0 was confirmed and the non-existence of a trend was defined.

On the other hand, table 7 records the trend evaluation for the days that registered one, two and three increasing peaks. In this case two stations showed a trend with reference to discharge (Hugdal bru and Strynsvatn), while only one station presented a trend with respect to water level (Bjoreio). Given that these results do not show a constant behavior, it could be inferred that these increases were influenced by sporadic events typical of the natural behavior of the rivers in response to climate and other factors that are not of anthropogenic origin.

Table 6: Increasing and decreasing peaks per year - Unregulated rivers

Station		**Inc peaks per year**			**Dec peaks per year**		
		tau	***p-value***	***Sen's slope***	***tau***	***p-value***	***Sen's slope***
Bjoreio	**Flow**	0.088	0.526	0.236	0.072	0.607	0.220
Hugdal bru		0.263	0.055	0.560	0.234	0.088	0.410
Masi		0.122	0.382	0.085	0.092	0.513	0.078
Strynsvatn		0.407	0.003	0.378	0.407	0.003	0.400
Bjoreio	**Stage**	0.107	0.440	0.167	0.056	0.692	0.071
Hugdal bru		0.153	0.268	0.240	0.142	0.303	0.188
Masi		0.073	0.616	0.000	-0.151	0.283	-0.074
Strynsvatn		0.172	0.217	0.167	0.106	0.450	0.070

Likewise, the correlation between the distance from each measuring station to the power plant outlet and the Sen's slope was made, which showed a direct relation between the

Table 7: Number of days with one two and three increasing peaks - Unregulated rivers

Station		**1 peak per day**		**2 peaks per day**		**3 peaks per day**	
		p-value	***Sen's slope***	***p-value***	***Sen's slope***	***p-value***	***Sen's slope***
Bjoreio	**Flow**	0.220	0.360	0.455	0.000	0.182	0.000
Hugdal bru		0.148	0.333	0.055	0.000	0.024	0.000
Masi		0.340	0.118	0.598	0.000	0.592	0.000
Strynsvatn		0.009	0.333	0.027	0.000	1.000	0.000
Bjoreio	**Stage**	0.043	0.382	0.584	0.000	0.165	0.000
Hugdal bru		0.526	0.154	0.451	0.000	0.063	0.000
Masi		0.936	0.000	0.960	0.000	0.512	0.000
Strynsvatn		0.164	0.167	0.400	0.000	1.000	0.000

magnitude of the trends and their proximity to the outlets of each power plant.

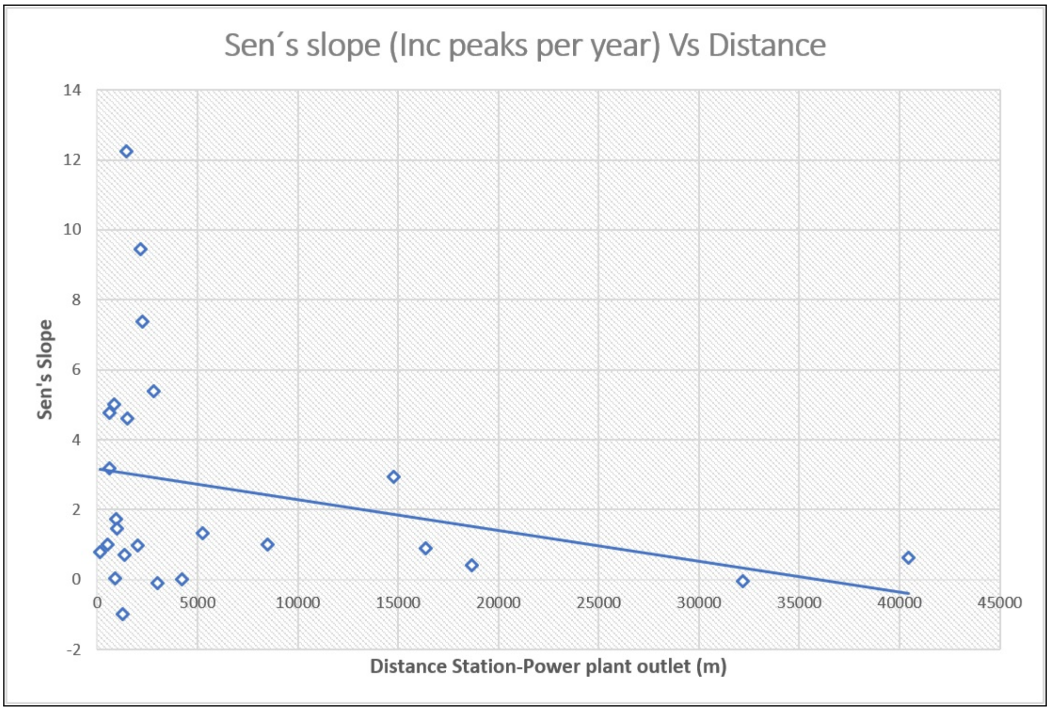


Figure 47: Relation Sen's slope Vs Distance (Inc peaks per year) - Discharge

Figures 47 and 48 confirm the influence of hydropower projects on key kydrological indicators of the behavior of the rivers, such as stage and flow. In both cases it has been found out that the magnitude of the trends is greater as the stations are closer to the power

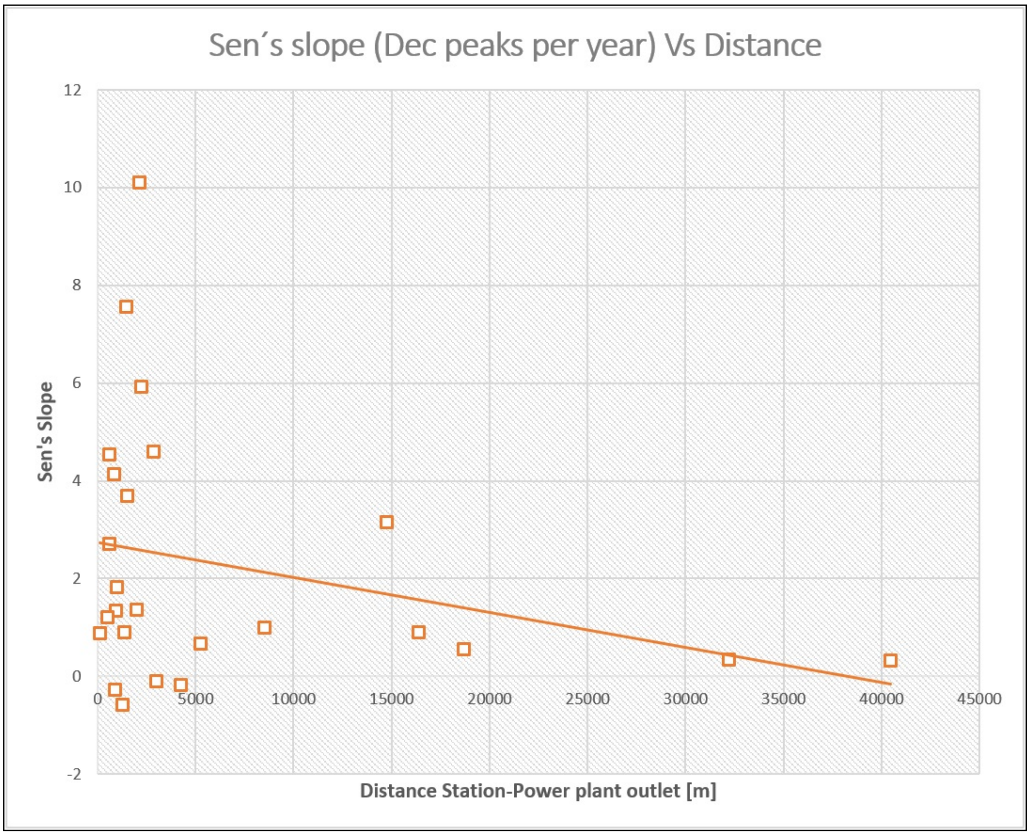


Figure 48: Relation Sen's slope Vs Distance (Dec peaks per year) - Discharge

plant outlet which makes sense taking into account that at this initial point there is a combination of the normal flow of the river plus the turbined water that is discontinuously released depending on the peaks of energy demand.

The figures 47 and 48 show the relation Distance vs Sen's Slope both for increasing and decreasing peaks per year. It can be seen how the stations that are closer to the power plant outlet register a greater magnitude of Sen's slope in comparison to those that are located at a greater distance.

5 Discussion

In the beginning of this study it has been pointed out that the change in the environmental law and the liberalization of the market has generated considerable consequences in the rivers that are influenced by hydroelectric plants. It has also been indicated that the increase of incentives and the market orientation to meet energy demand, both in Norway and in other countries, has contributed to a considerable increase in the production strategies of the hydropower plants, which represents an intermittent operation of the dams, this due to the fact the energy requirement does not occur continuously but presents increases and decreases depending on the time of the day or even the season of the year.

According to the energy consumption rates provided by Nord Pool (e.g fig 28), it is known that in Norway, on average, there is an increase in electricity demand in the mornings, between 07:00 and 09:00, when people leave for their jobs or studies and in the afternoons between 18:00 p.m. and 20:00, when the work and school hours are over and everyone arrives at their homes (which means high peaks of consumption and therefore high prices). This variation also depends on the seasons given that the demand of energy is considerably higher in the winter, when the constant use of heating and electricity is required due to the low temperatures and the few hours of light, in the same way in the summer this consumption decreases significantly because there is an increment in temperatures and additionally there are many more hours of sun.

All these factors have been taken into account to verify the influence of the dynamics of the energy market on the behavior of the rivers, assess the operational changes over time for part of the Norwegian hydropower system and the trends on the hydrological indicators downstream of the power plant outlets.

In the first place, an evaluation of the number of increasing and decreasing peaks per year in both, regulated and unregulates rivers was done in order to define if a considerable increase has taken place after the Energy Act. Likewise the available unregulated stations were chosen, in this way it was possible to establish a point of comparison and observe if a different trend occurs when there is no hydroelectric plant that influences the behavior of the river.

Regarding the regulated rivers, a considerable rise in the amount of increasing and decreasing peaks per year can be observed for all the stations, both for discharge and water level. This increase began to be evident in the 90's and has remained constant over the years. The two parameters, increasing and decreasing peaks, keep the same pattern since they have a directly proportional relationship. Sometimes it shows how the plants are rumped up fast and shut down slowly, as it is the case of the station Bertnem and Skjermo in Figure 38.

On the other hand, unregulated rivers do not present this pronounced increase or even a clear trend. Both water level and discharge show an intermittent behavior, which is understandable given that these rivers are governed by the dynamics of nature. These variations can be originated, for example, by random events such as rainfall or rapid snow melt. In this case there are no significant peaks given that such natural events occur sporadically and have a short duration, sometimes limited to a few days in the case of precipitations or some months as it can be the case of snow and ice-related events. In contrast anthropogenic releases of water can happen on a daily basis during the whole year [24].

Regarding the number of peaks per day, in the regulated rivers, in discharge and water level, a clear tendency can be observed to increase both, the number of peaks per day and the frequency with which there were multiple peaking events during a day. As a general trend in all the stations, at the beginning of the measures (in some cases since 1985) there were very few peaks and therefore few days with multiple repetitions. On the contrary, the amount of peaks at the end of the measurements (2016-2017) registered much higher amounts, having cases of even seven peaks per day, which reflects a considerable increase if a comparison is made with the initial part of the data. As expected, the trends representing the days with one peaking event are higher, followed by two and three peaks respectively.

On the contrary, in the unregulated rivers, intermittent amounts of peaks could be observed, showing even high frequencies at the beginning of the measurements and subsequently constant increases and decreases. The abrupt increments that occurred in the middle of years with moderate or small amounts of peaks could be due to periods with high rainfall rates, or even very strong winters, all of them, natural events.

Similarly, the number of peaks per hour has been analyzed, in which interesting results regarding the trend of peaks and consumption patterns have been found. In the case of the regulated rivers, both in discharge and water level, the peaking events coincide with the energy consumption trends reported by the Nord Pool, as mentioned above, the hours in which people arrive or leave their homes match with the increase of hydropeaking events, on the other hand, the more quiet times which are around midnight, reflect a decrease of the increasing peaks and on the contrary it is where the largest amount of decreasing peaks occurs since it is the time when the power plants stop operating or reduce their production to the minimum allowed. This parameter is a clear example of the influence of hydropower plants on rivers and also reflects the change that has occurred in the Norwegian system after the implementation of the new environmental law.

Subsequently, a trend analysis was performed using the R statistical software together with Mann Kendall and Sen's slope trend tests to determine the significance of the trends observed in the graphs. These results were classified according to the most important parameters being the increasing and decreasing peaks per year, the center of attention. Regarding the unregulated rivers, in the discharge and water level, about half of the peaking events were classified as positive significant trends. In addition there were other results that were very close to the significance limit, which shows that the data had a clear tendency and showed a gradual increase through the years.

On the other hand, in the case of the unregulated rivers, only one significant trend was detected in one of the discharge gauges. With regard to water level, no trend was recorded. Therefore it is inferred that when there are stations which are not influenced by hydroelectric plants, it is less likely that the phenomenon of hydropeaking takes place.

Likewise, the trends corresponding to the number of days with one, two and three increasing peaks were analyzed. This parameter was considered important since it can determine if there was an increase in the frequency of the peaks that occur per day.

Regarding the regulated rivers, in the discharge part there were eleven, eleven and seven significant trends with 1, 2 and 3 peaking events per day respectively. In relation to water level, nine, twelve and five significant trends were detected respectively. A higher amount of significant trends was recorded in the case of discharge. Still, the number of trends is considerable for both parameters and indicates that there was an increase in the frequency of peaking events per day. On the other hand, the unregulated rivers showed maximum one trend per parameter both for discharge and water level, which makes sense given that the fluctuations presented in these rivers are not influenced by hydroelectric plants and take place mainly due to natural events whose daily variations in the flow does not exceed 10% of the daily mean flow [24].

6 Conclusions

The deregulation of the energy market in Norway marked a turning point in the operation of hydropower plants in the country. Before the new law, publicly owned regional hydropower companies were in charge of guaranteeing the energy supply in their respective concession areas and the prices that consumers had to pay were defined annually based on average costs. After the energy act came into force in 1991, the duty of the power companies to provide sufficient electricity for the consumers of a specific area was abolished, and a commercial dynamic was defined in which profitability started to be the primary criterion for the supply of energy by producers. Likewise, energy prices are now determined by the Nordic Power Exchange Nord Pool and are based on supply and demand criteria in which consumers establish how much they are willing to pay for energy and suppliers define how much energy they are willing to sell for certain prices.[58]

This change in the commercial dynamics of energy has also been reflected in changes in the management of hydropower plants. The purpose of this work was to assess the operational changes over time for part of the Norwegian hydropower system by evaluating trends on key hydrological indicators downstream of the power plant outlets. A qualitative and quantitative analysis was carried out to determine the presence of possible trends in the discharge and water level of the rivers and thus define if there was a relationship between the increase in hydropeaking and the liberalization of the energy market. Graphically, the majority of measurement stations located in regulated rivers showed a clear positive trend in the number of peaking events per year and per day, likewise a correspondence was found between the time in which the highest number of peaks were registered and the time of more energy consumption which represents a direct relation between the production of energy and the abrupt changes in the flow of the water courses. The same parameters were analyzed in a group of unregulated rivers in which no similar relation or hydropeaking was found. Likewise, the Mann Kendall and Sen's slope trend tests corroborated the presence of significant trends in more than half of the regulated stations and the almost no presence of trends in the unregulated rivers.

With these results it can be concluded that the modification in the environmental law has generated impacts in the rivers that are influenced by hydropower plants, which at the same time represents consequences in the riverine ecosystems. One of the reasons for hydropeaking is based on the fact that the operation of the plants is controlled by the demand for energy in real time, which creates a high ramping in the times of more consumption. This can serve as a starting point to demand more clarity when defining the legal concessions of each contract and to establish clear rules and numbers in order to define for example the frequency and intensity with which the hydroelectric plants must establish their operation, which should be done slower in order to avoid the hydropeaking phenomenon that is occurring at the moment.

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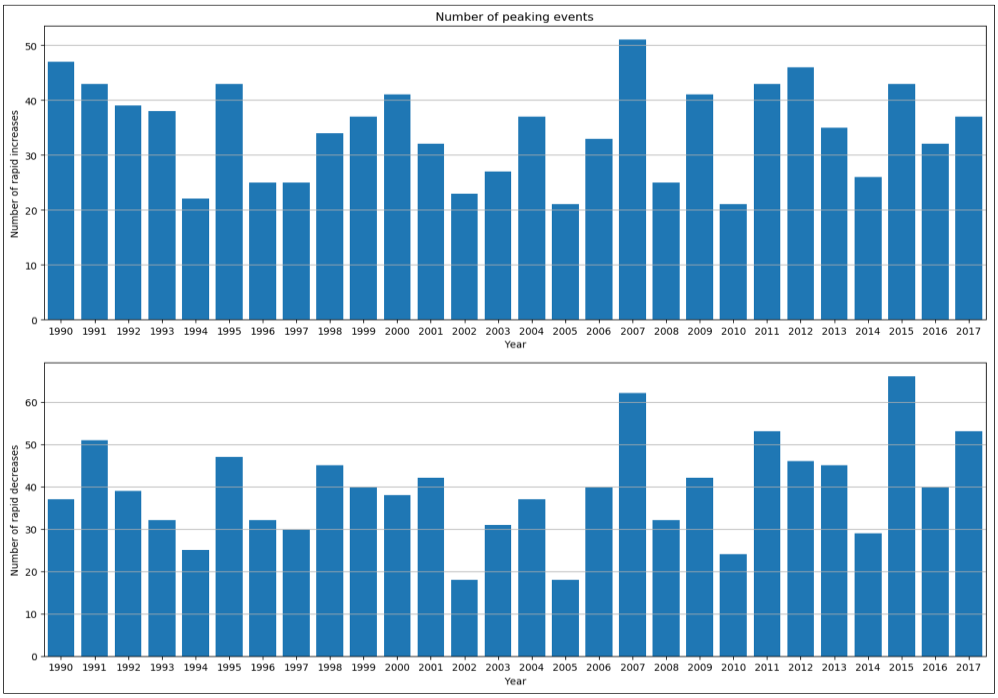

Figure 1. Bertnem. Number of peaks per year - Discharge

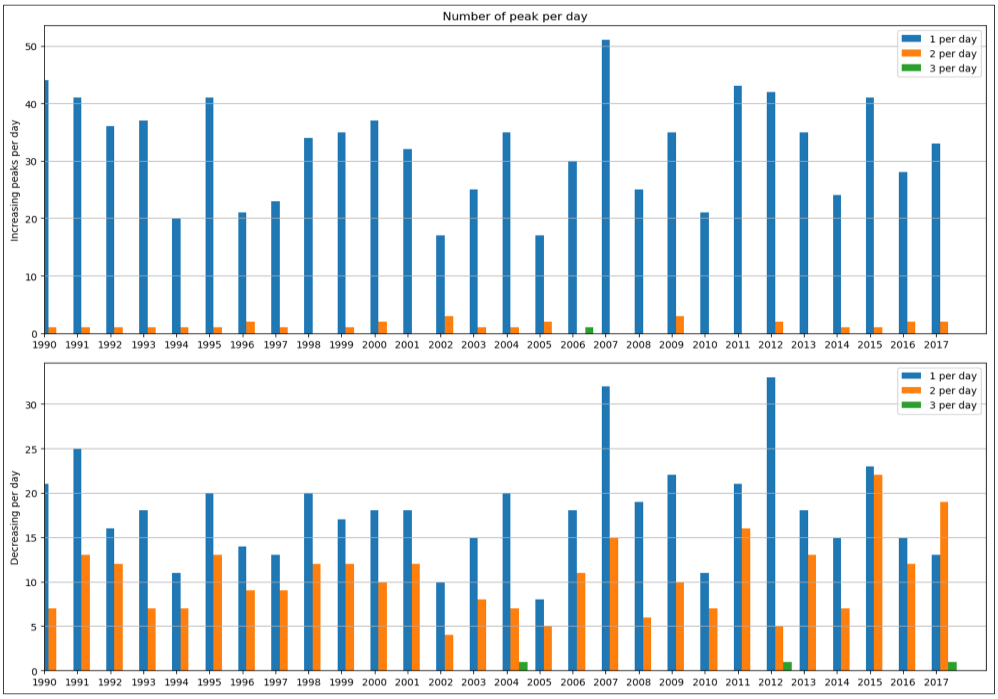

Figure 2. Bertnem. Number of peaks per day - Discharge

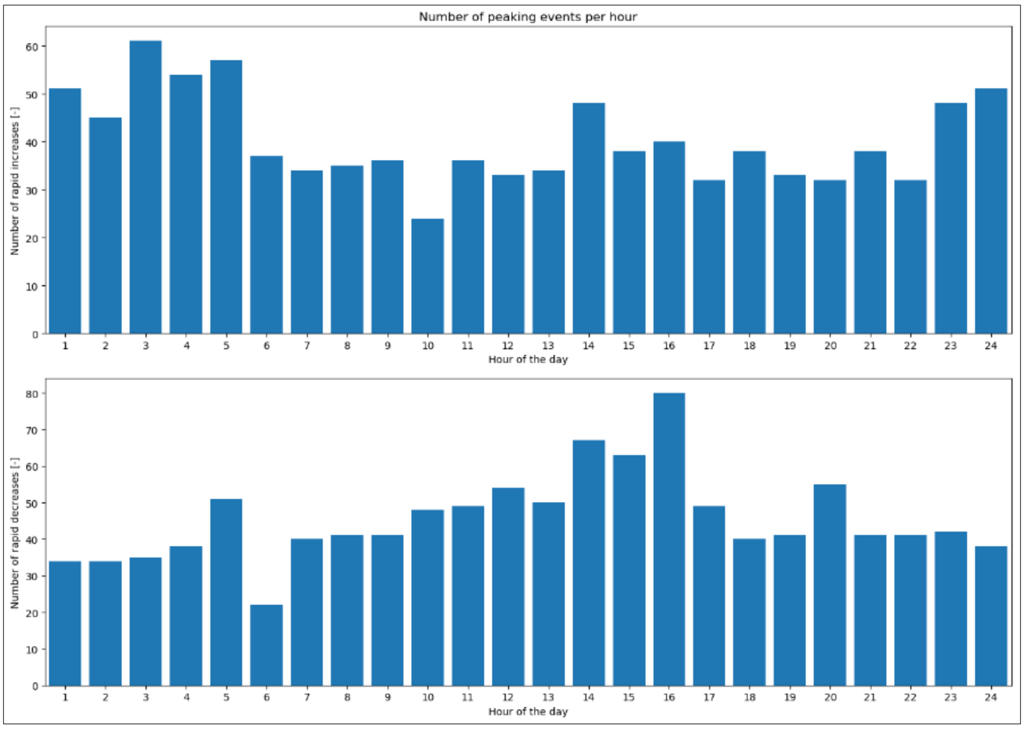

Figure 3. Bertnem. Number of peaks per hour - Discharge

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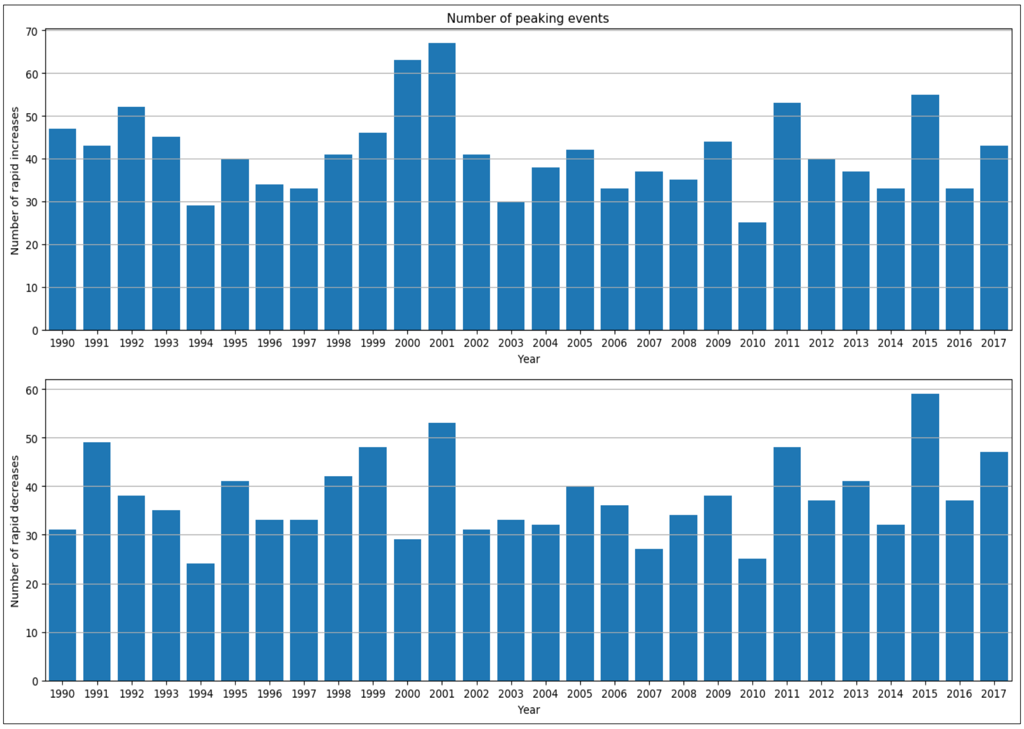

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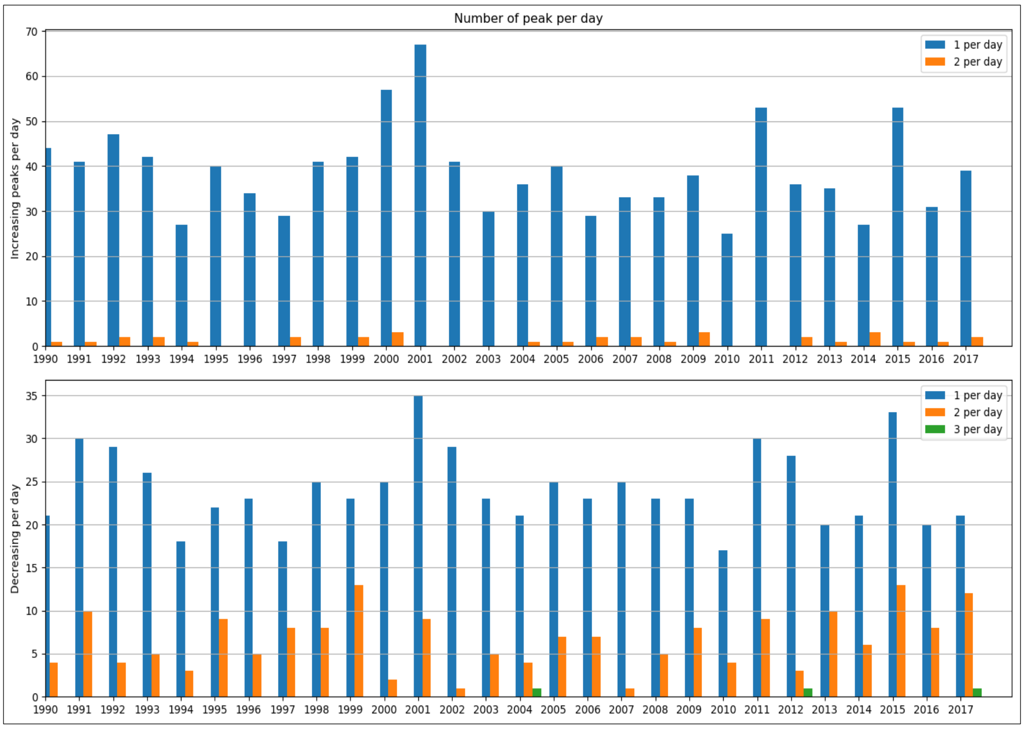


Figure 5. Bertnem. Number of peaks per day - Water level

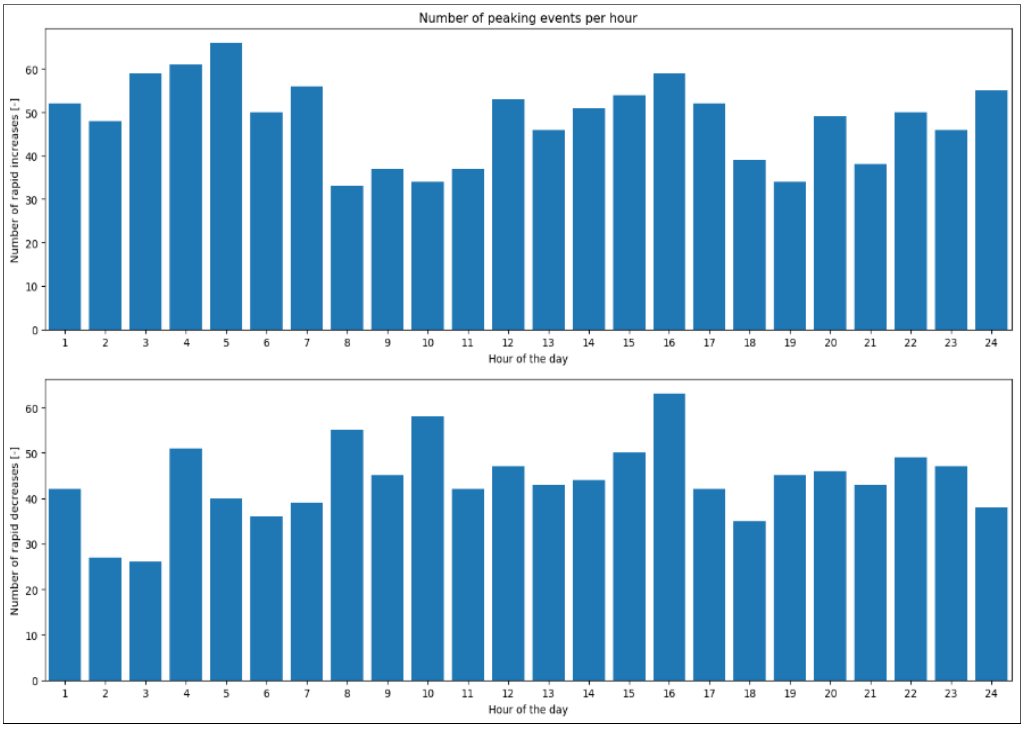


Figure 6. Bertnem. Number of peaks per hour - Water level

1.2 BRULANDSFOSS ND

1.2.1 Discharge

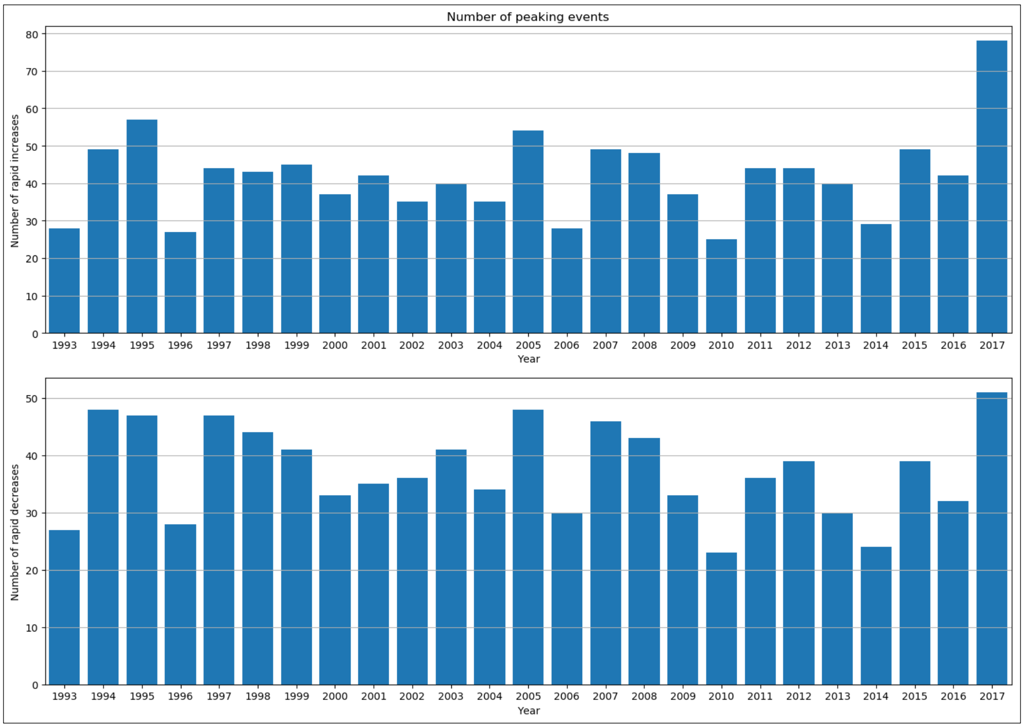
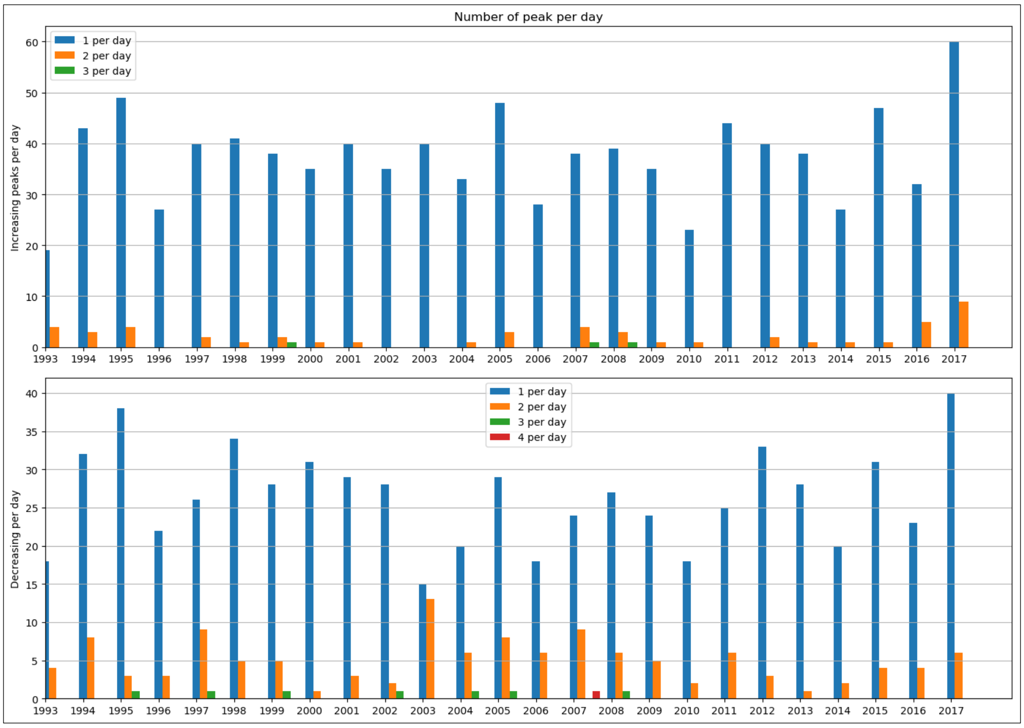


Figure 7. Brulandsfoss. Number of peaks per year - Discharge



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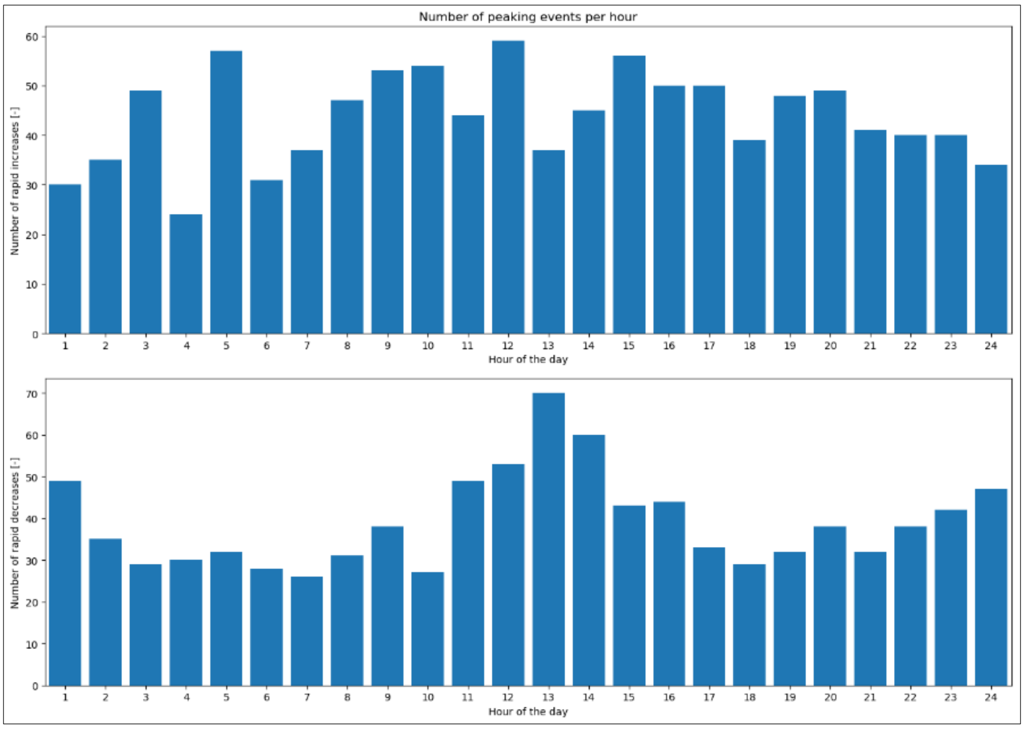
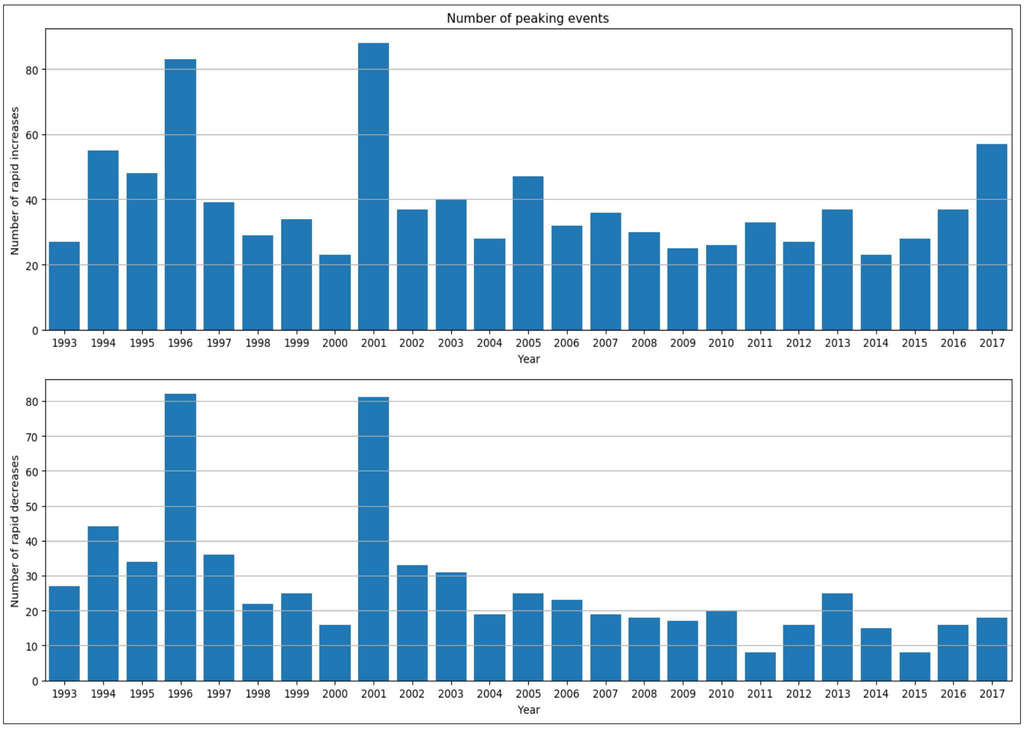


Figure 9. Brulandsfoss. Number of peaks per hour - Discharge

1.2.2 Water level



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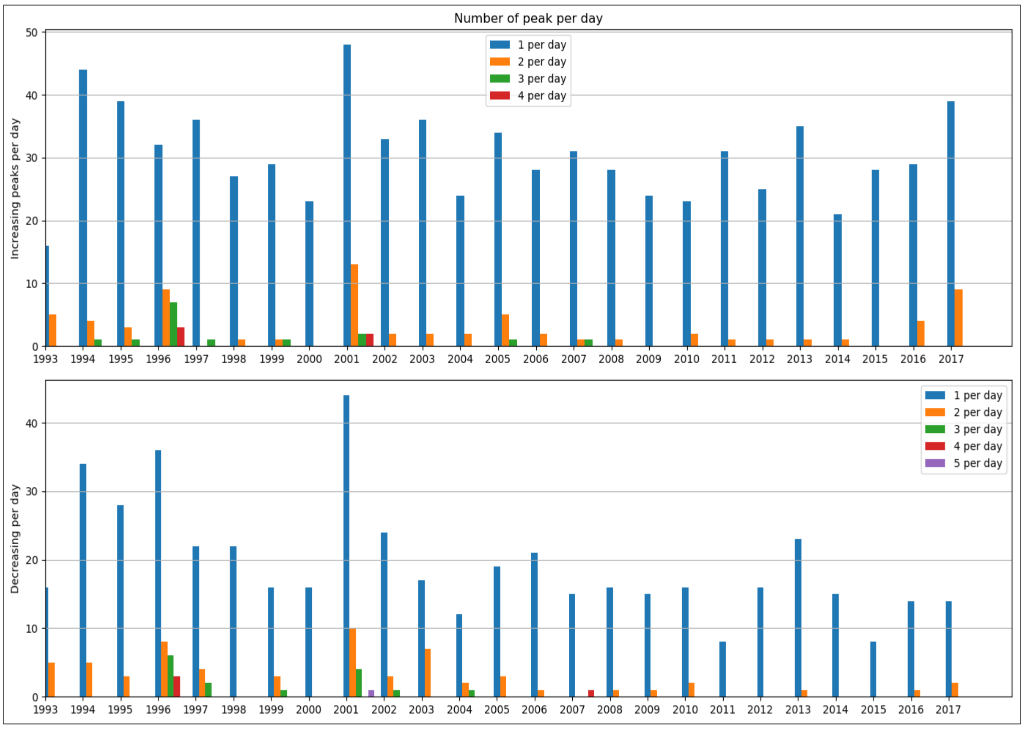

Figure 11. Brulandsfoss. Number of peaks per day - Water level

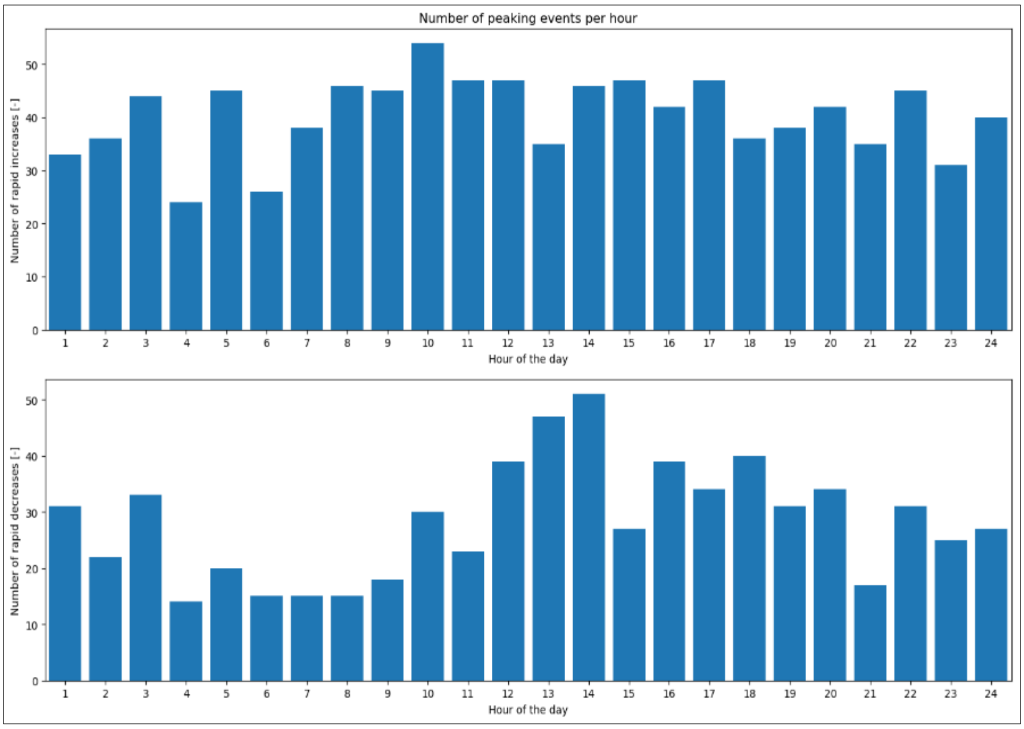

Figure 12. Brulandsfoss. Number of peaks per hour - Water level

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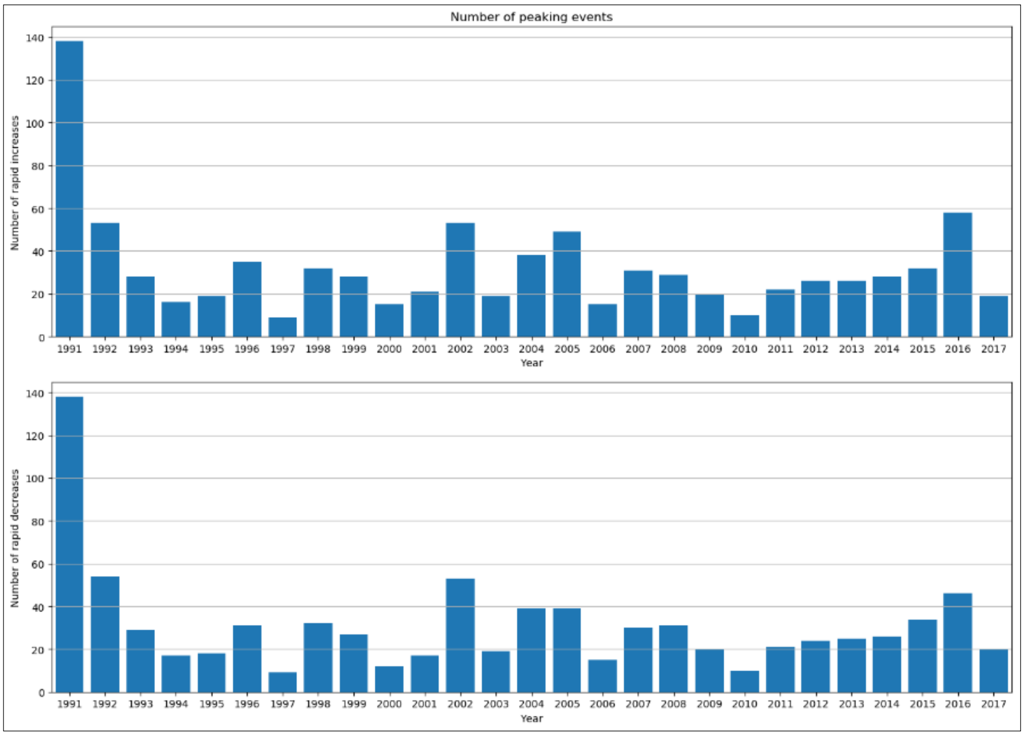
1.3.1 Discharge



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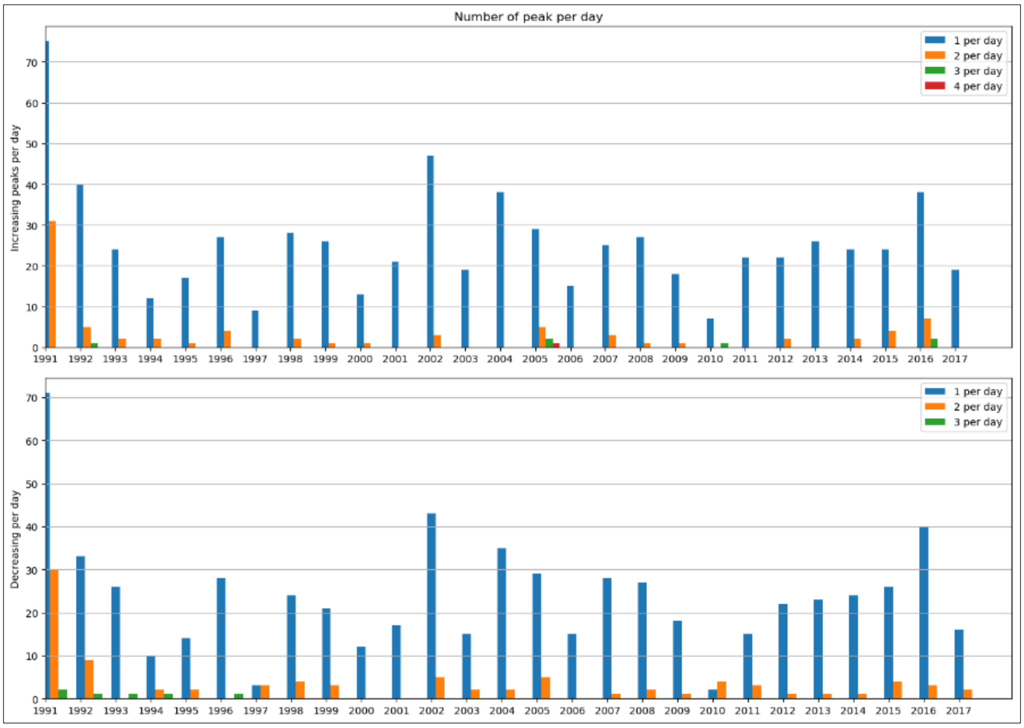


Figure 14. Harestrømmen. Number of peaks per day - Discharge

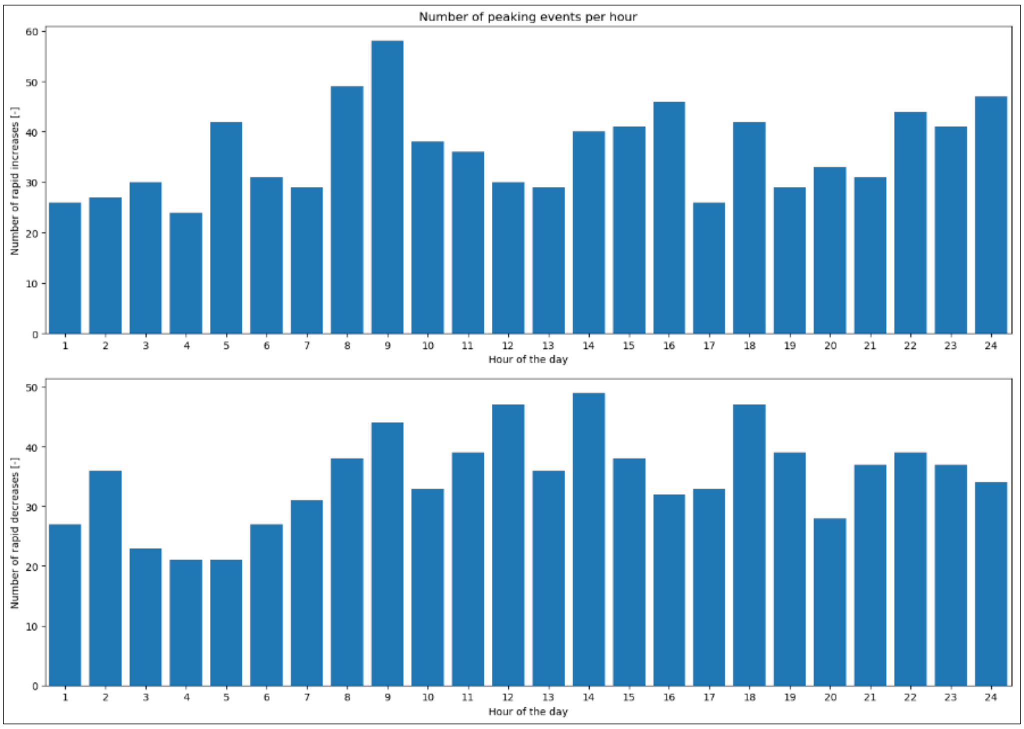
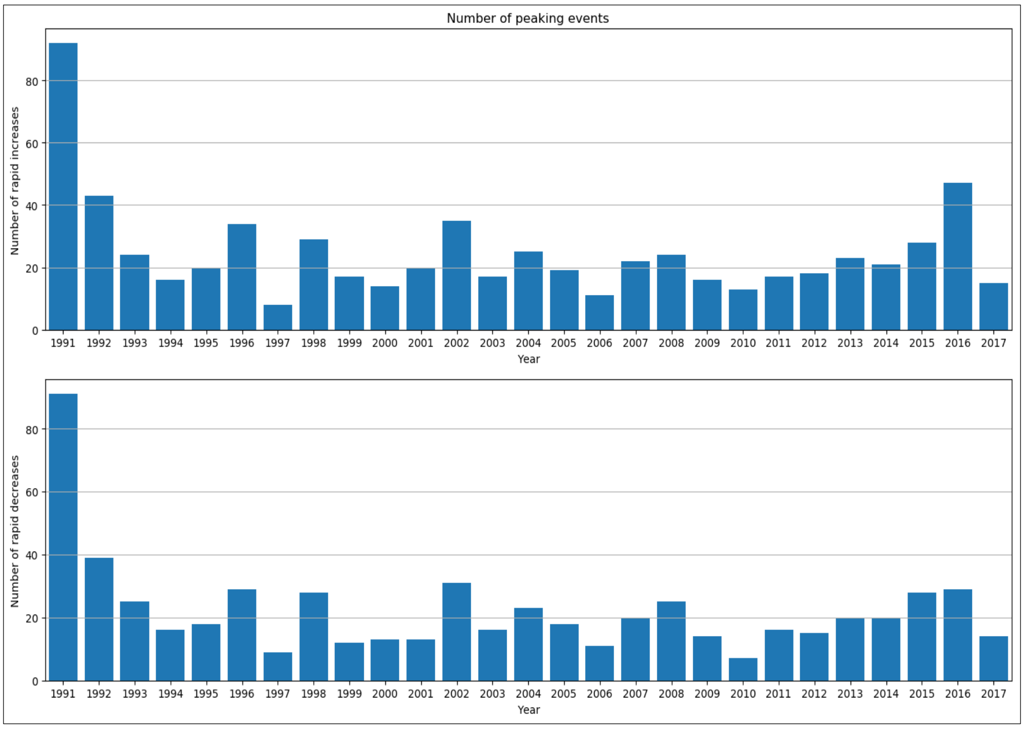


Figure 15. Harestrømmen. Number of peaks per hour – Discharge

1.3.2 Water level



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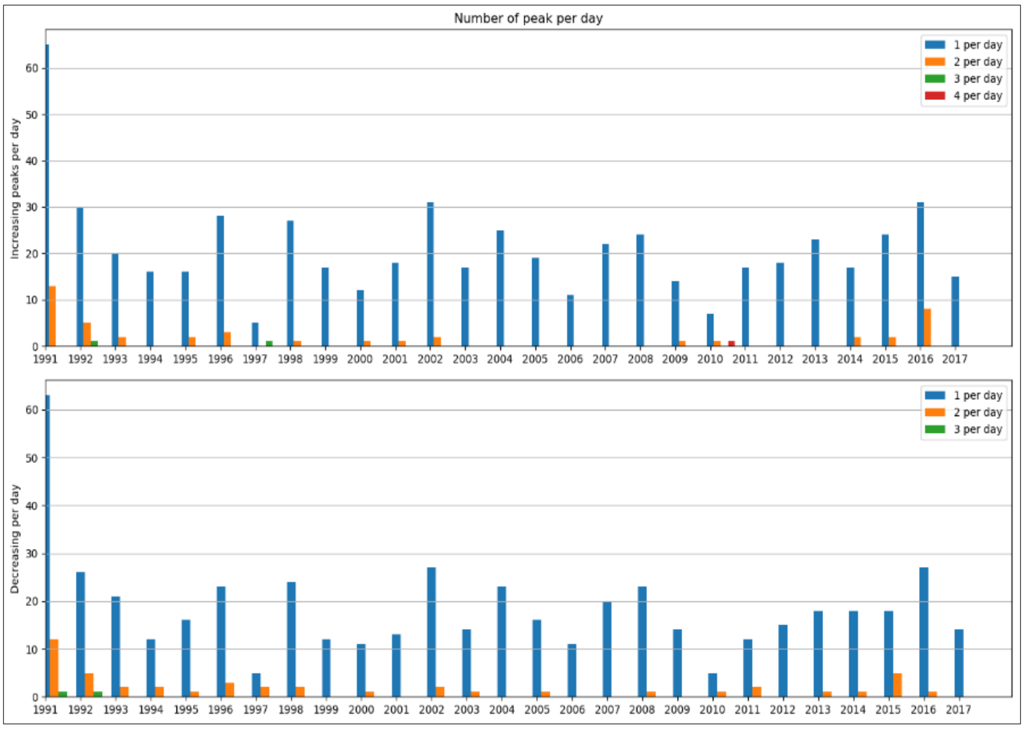
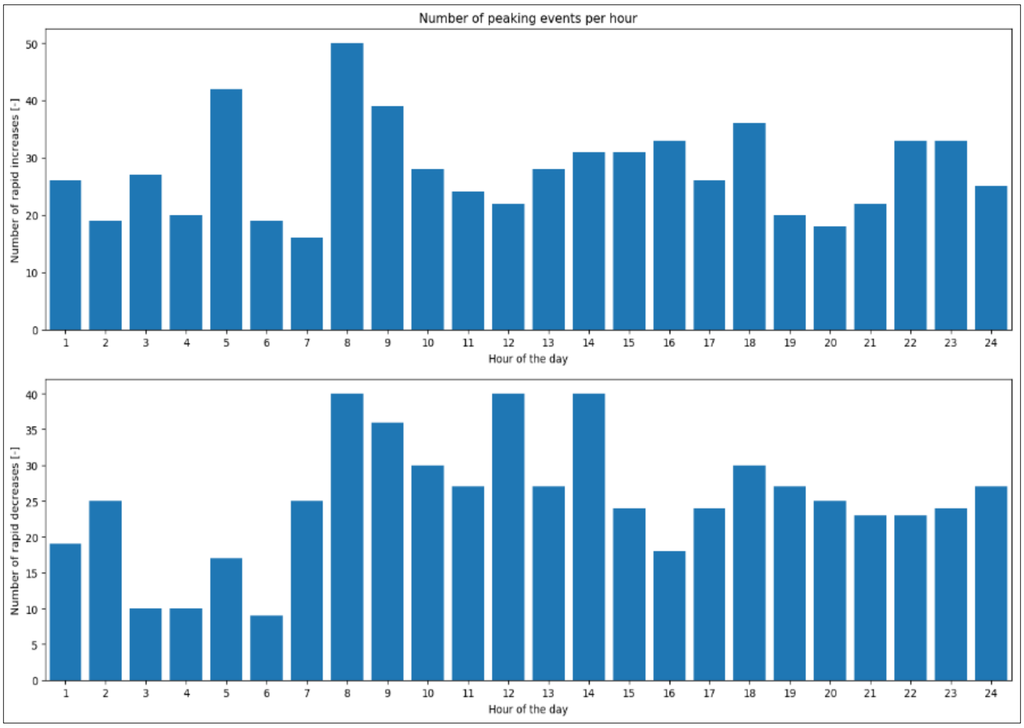


Figure 17. . Harestrømmen. Number of peaks per day – Water level



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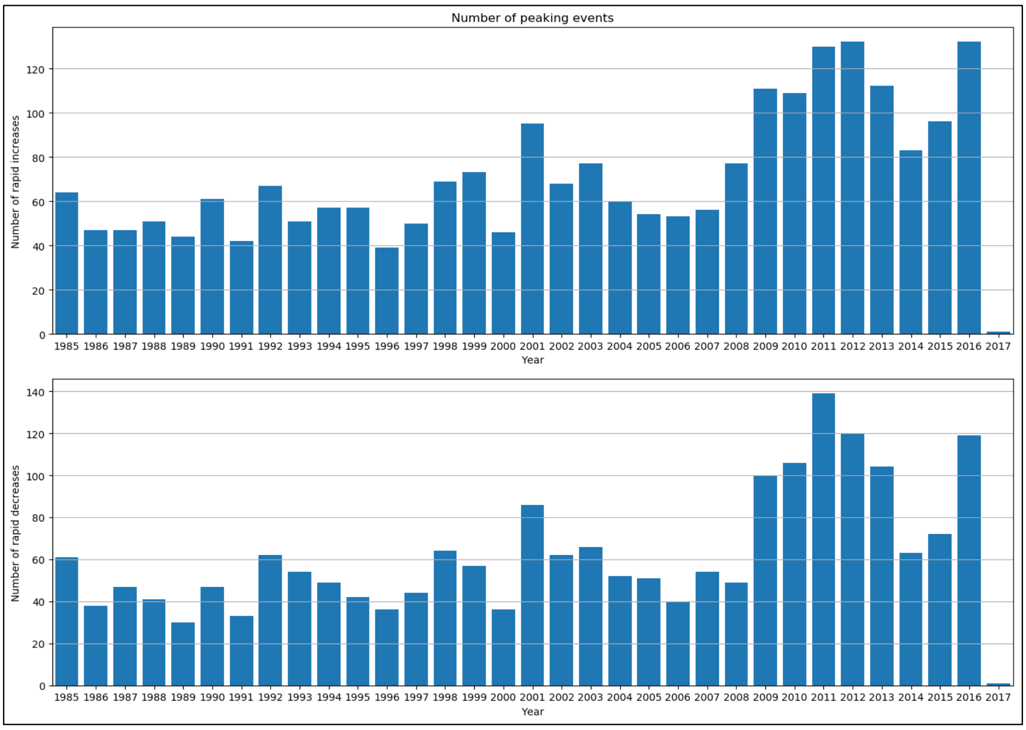
1.4 *HÅVERSTAD*

1.4.1 Discharge



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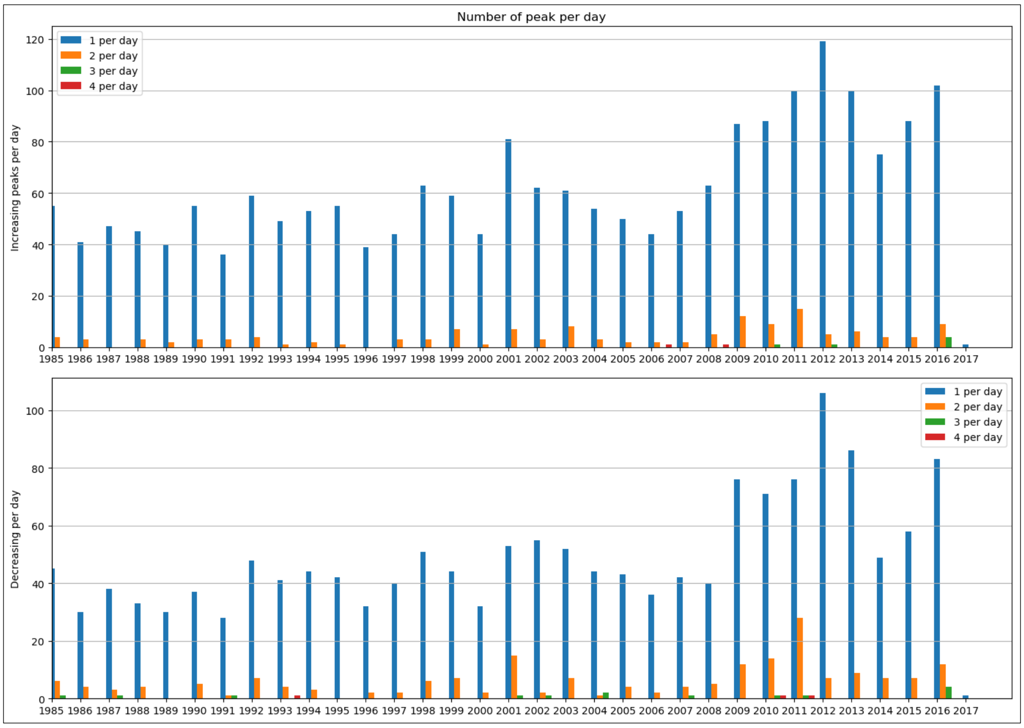

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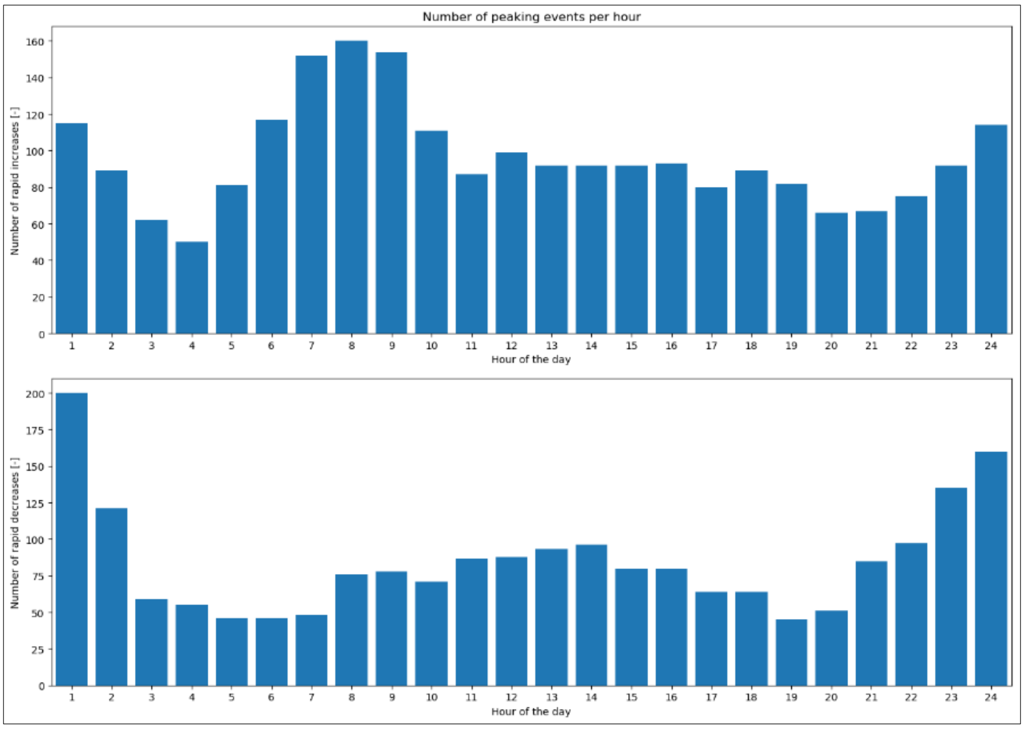

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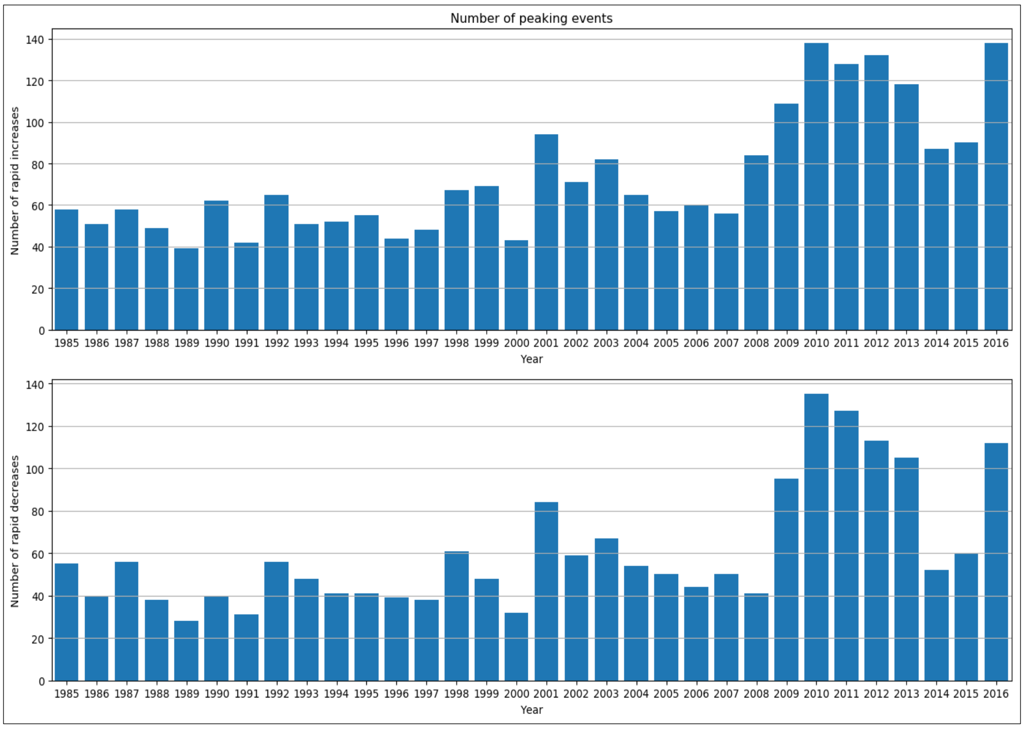


Figure 22. Håverstad. Number of peaks per year – Water level

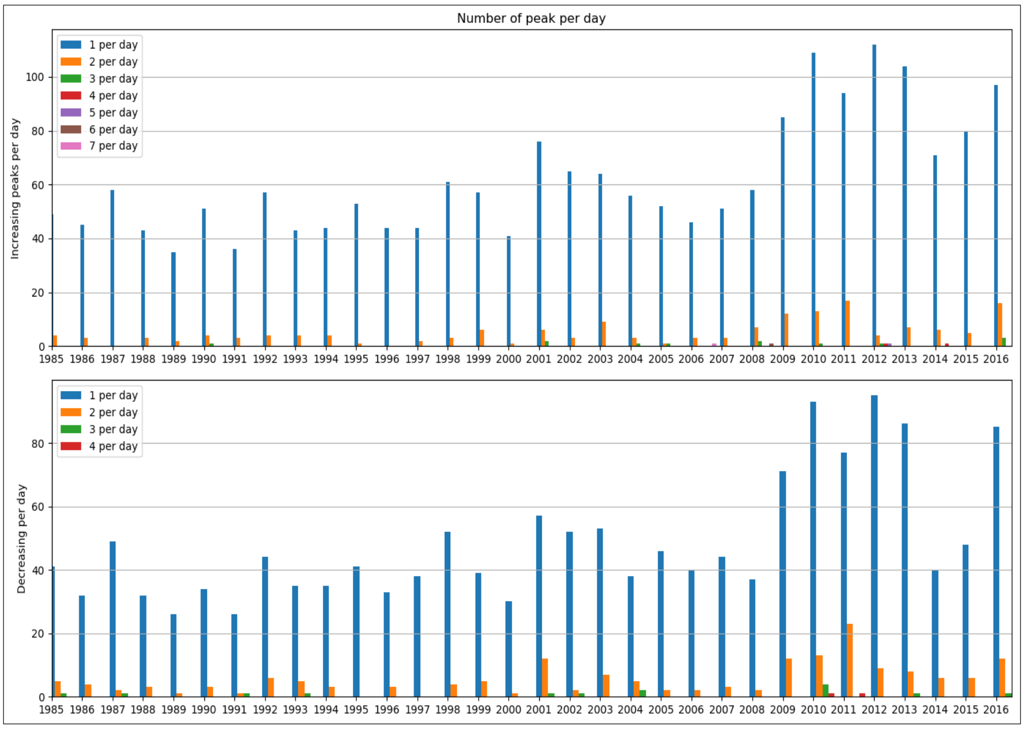


Figure 23. Håverstad. Number of peaks per day – Water level

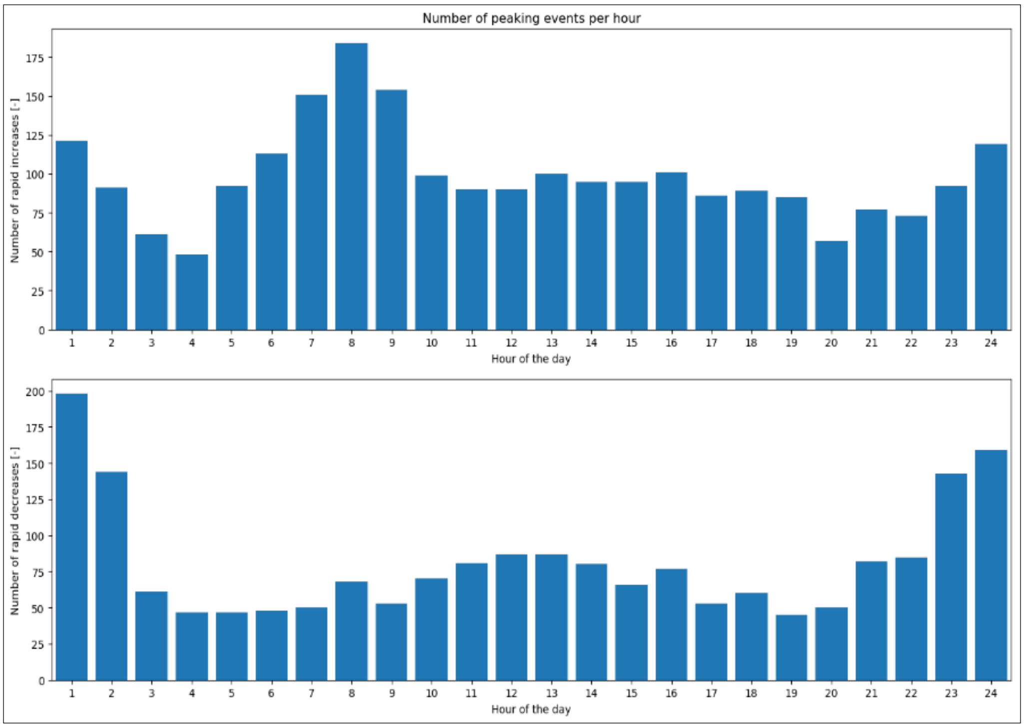


Figure 24. Håverstad. Number of peaks per hour – Water level

1.5 HEGRA BRU

1.5.1 Discharge

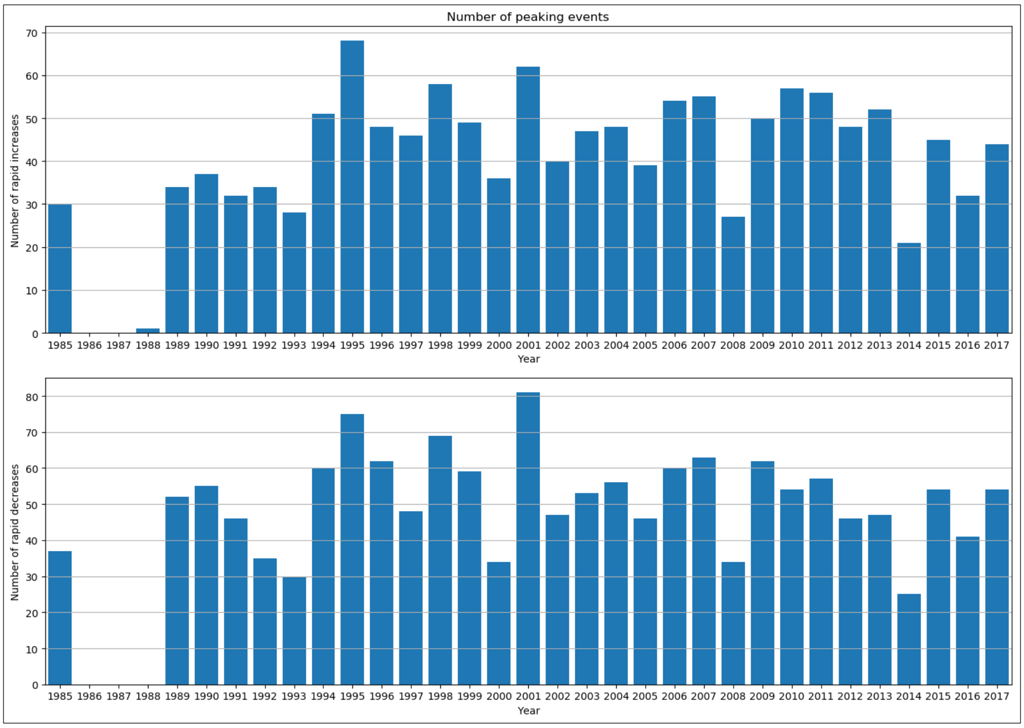
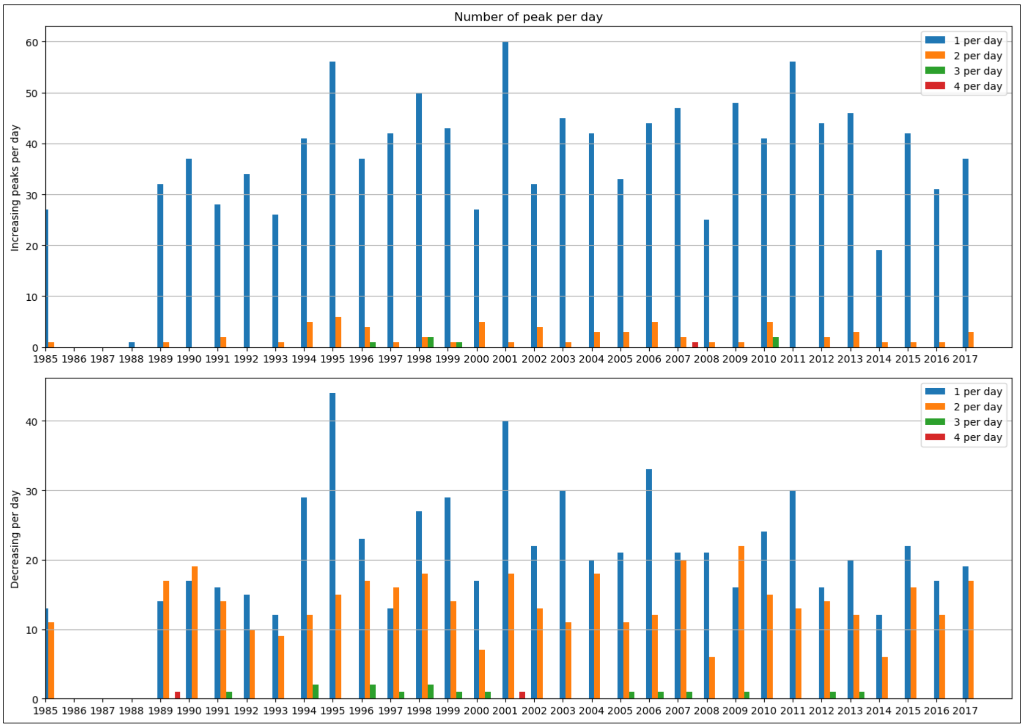


Figure 25. Hegra bru. Number of peaks per year – Discharge



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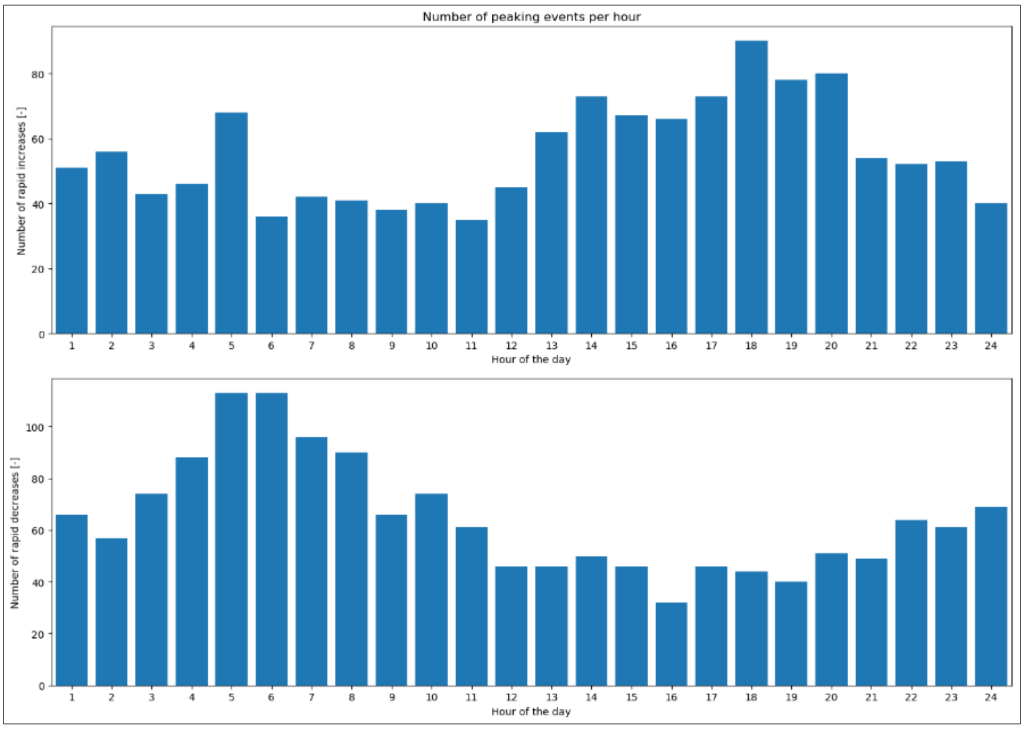

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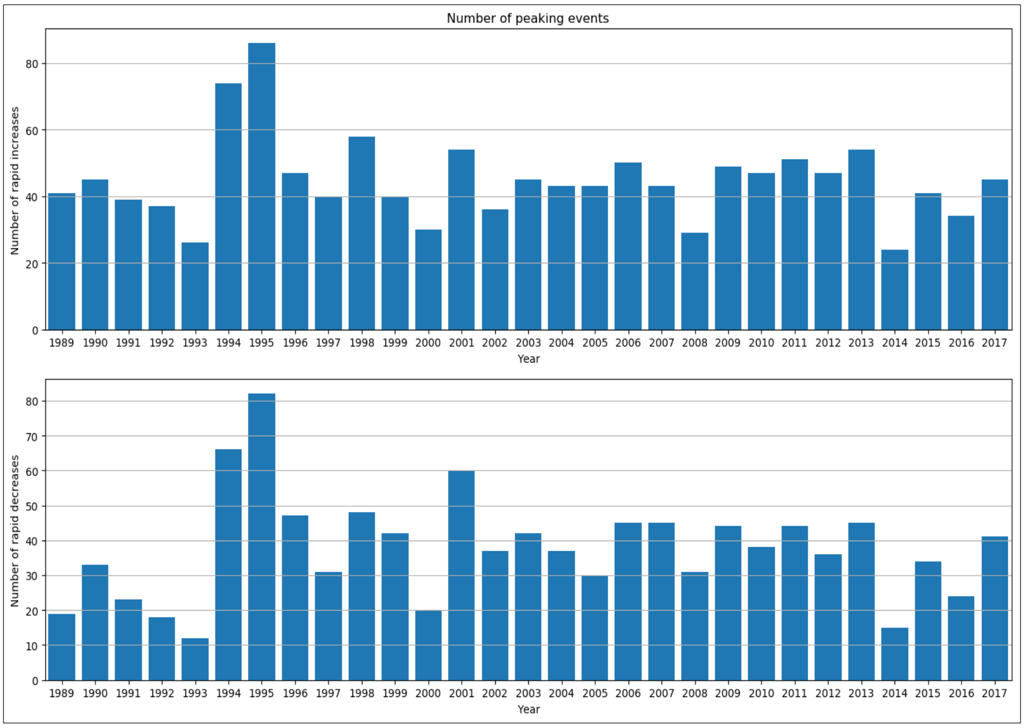
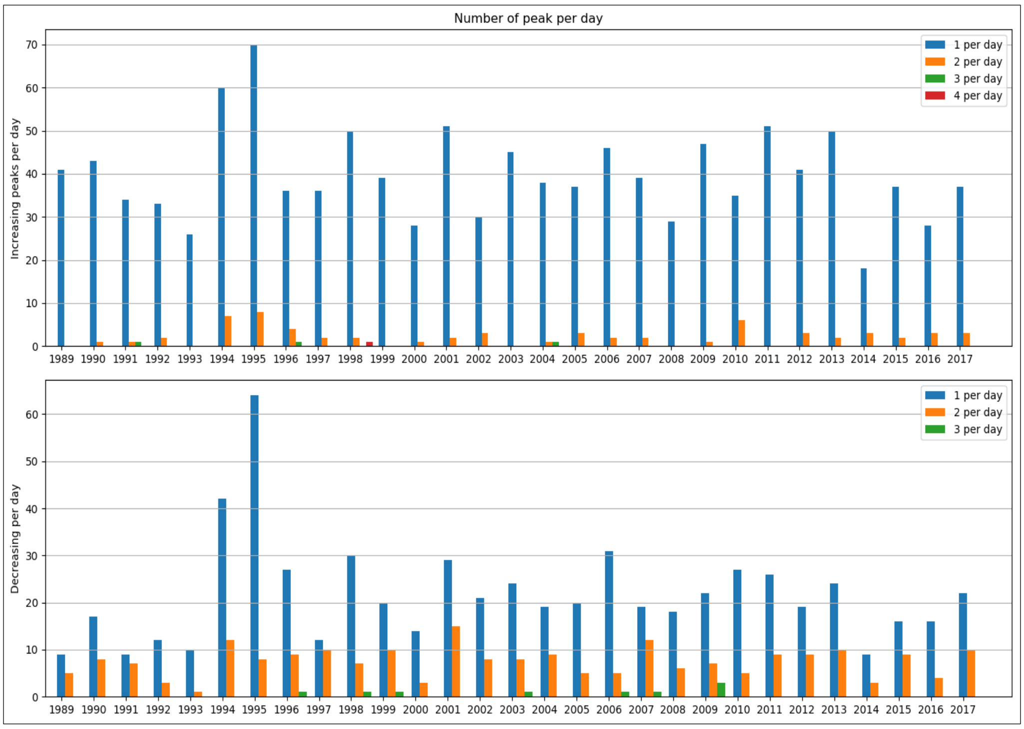


Figure 28. Hegra bru. Number of peaks per year – Water level.



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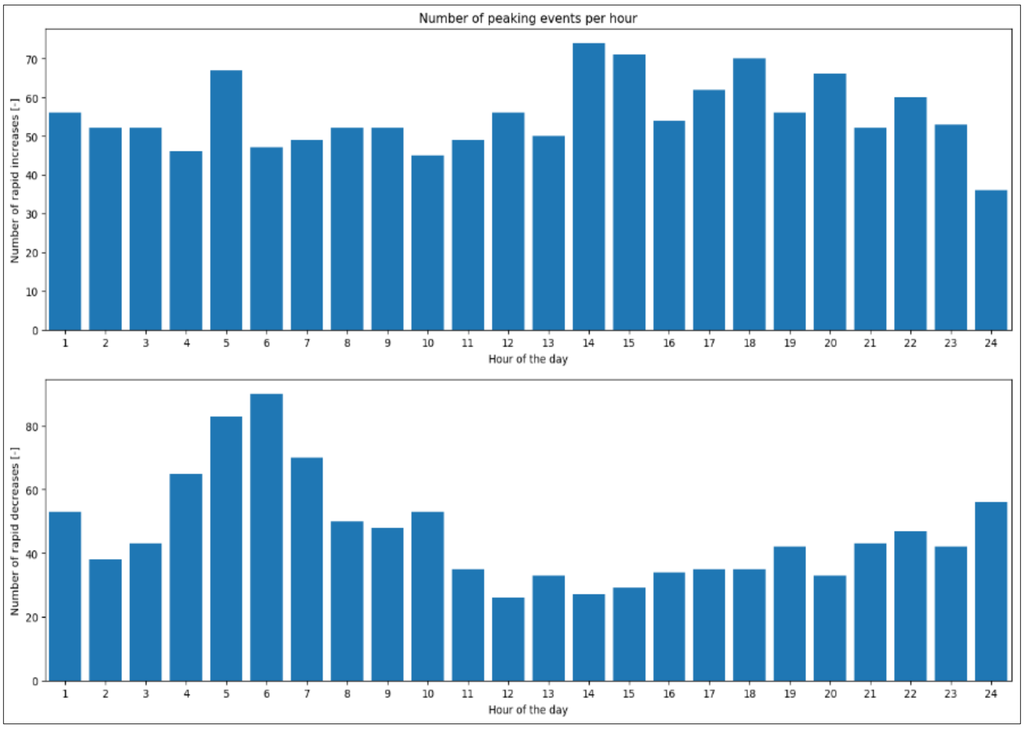
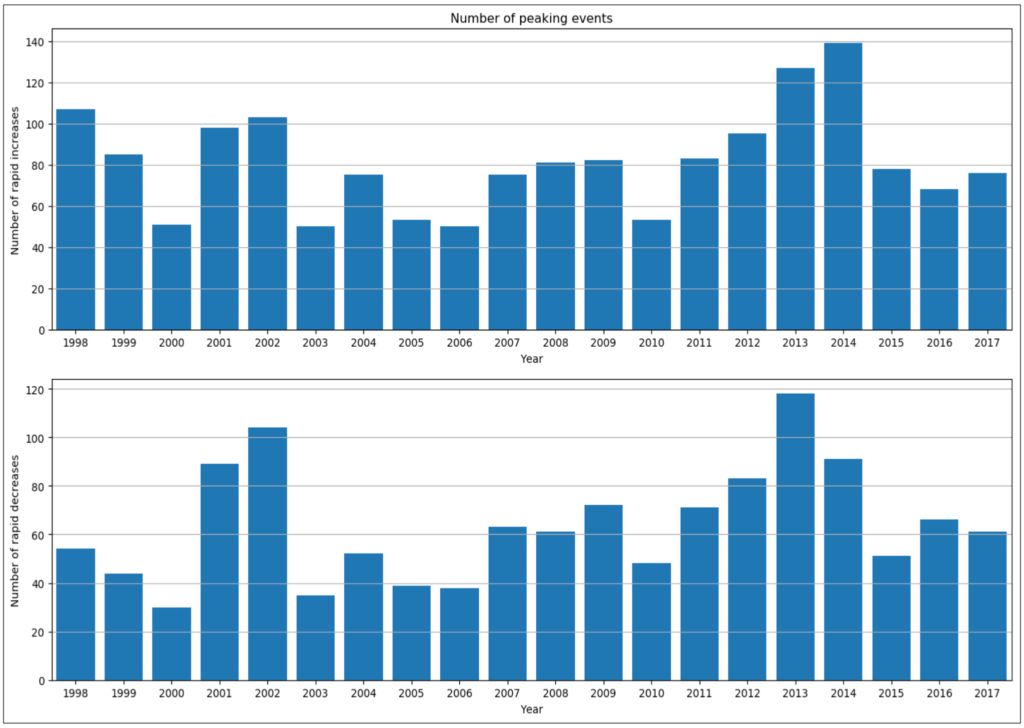


Figure 30. Hegra bru. Number of peaks per hour – Water level

1.6 *HEISEL*

1.6.1 Discharge



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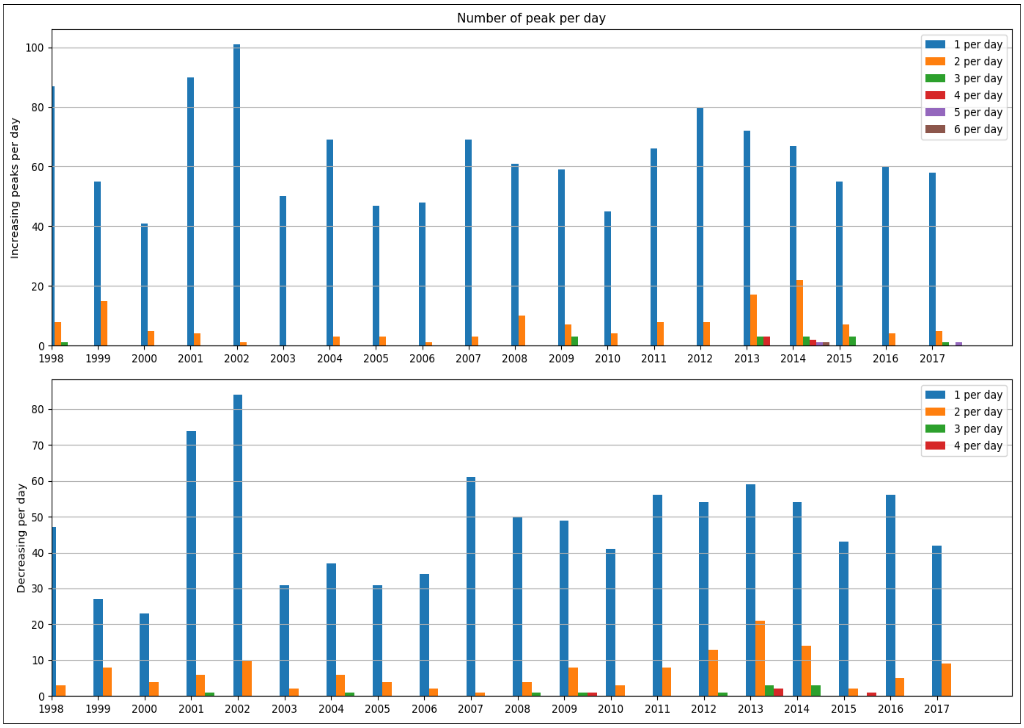

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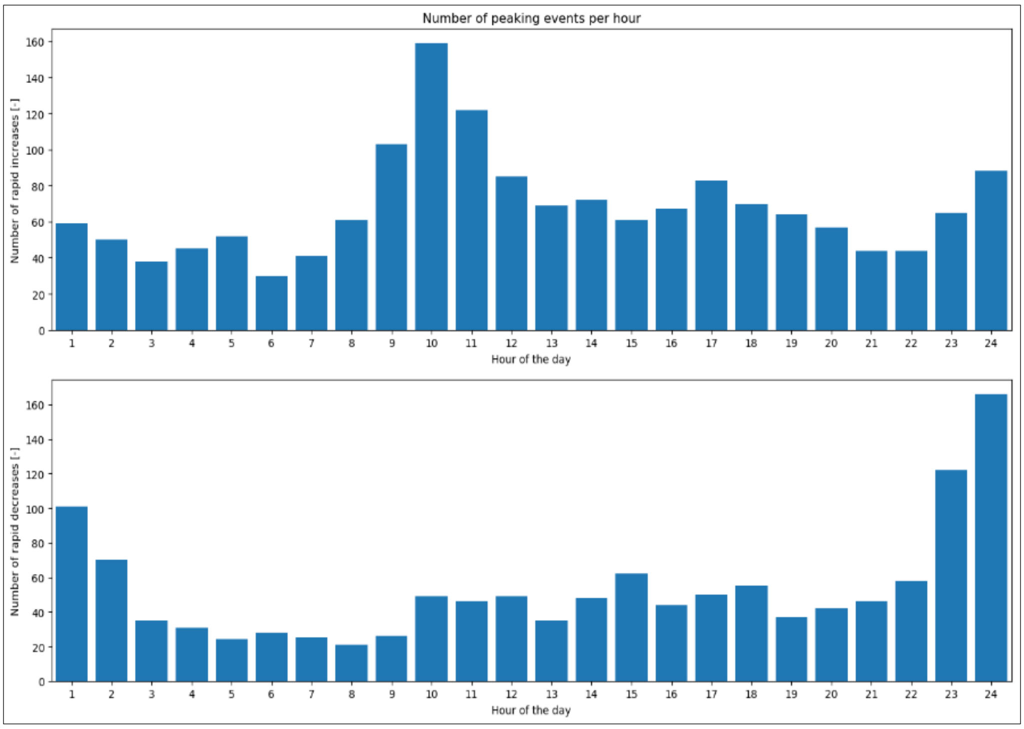

Figure 33. Heisel. Number of peaks per hour– Discharge

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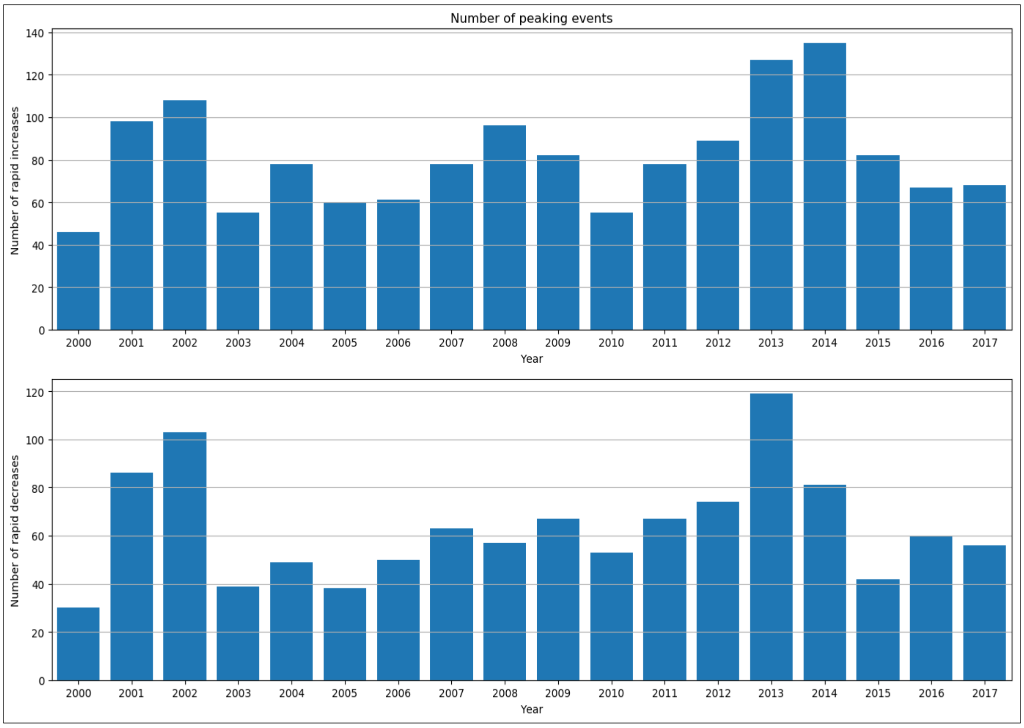

Figure 34. Heisel. Number of peaks per year– Water level

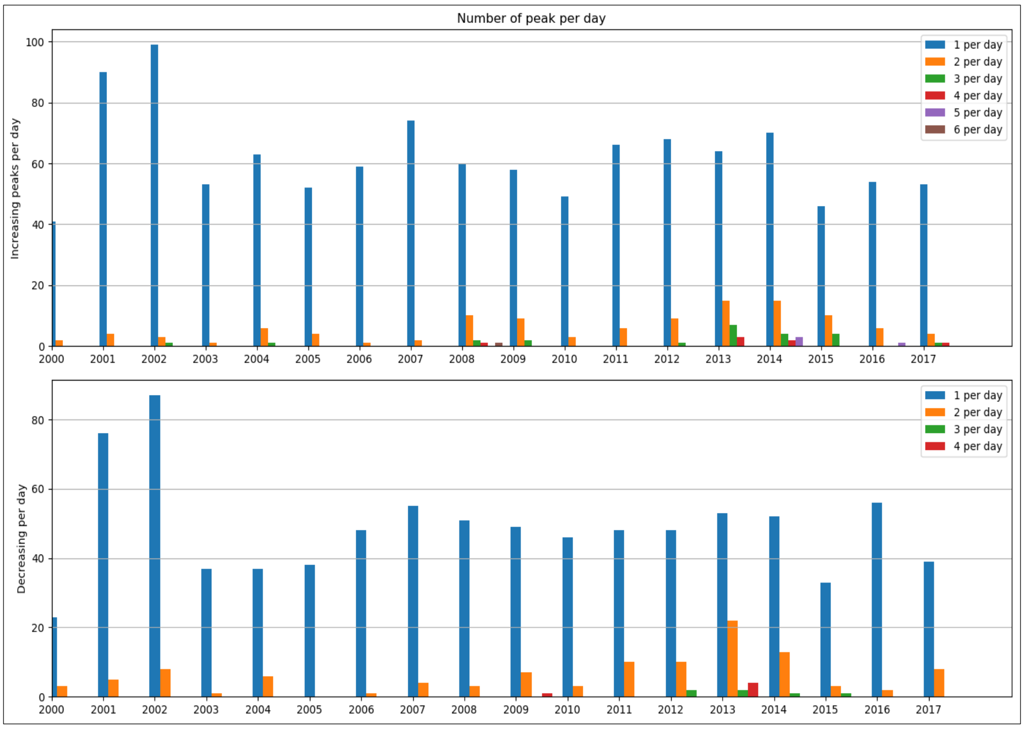

Figure 35. Heisel. Number of peaks per day– Water level

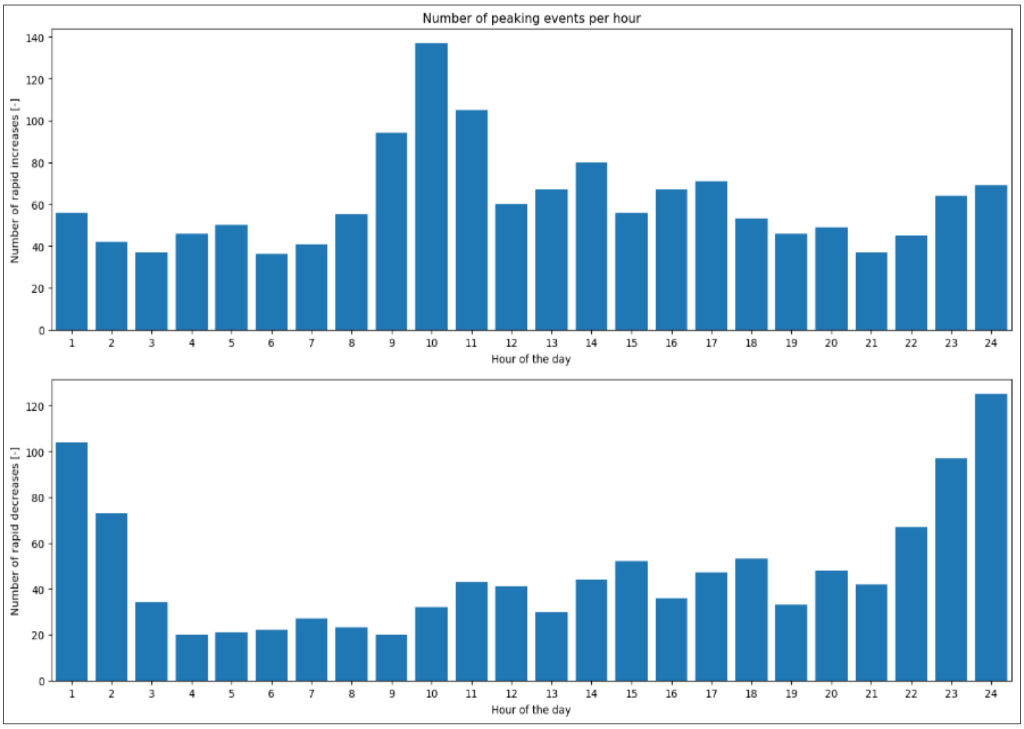

Figure 36. Heisel. Number of peaks per hour– Water level

1.7 *HOLM BRU*

1.7.1 Discharge

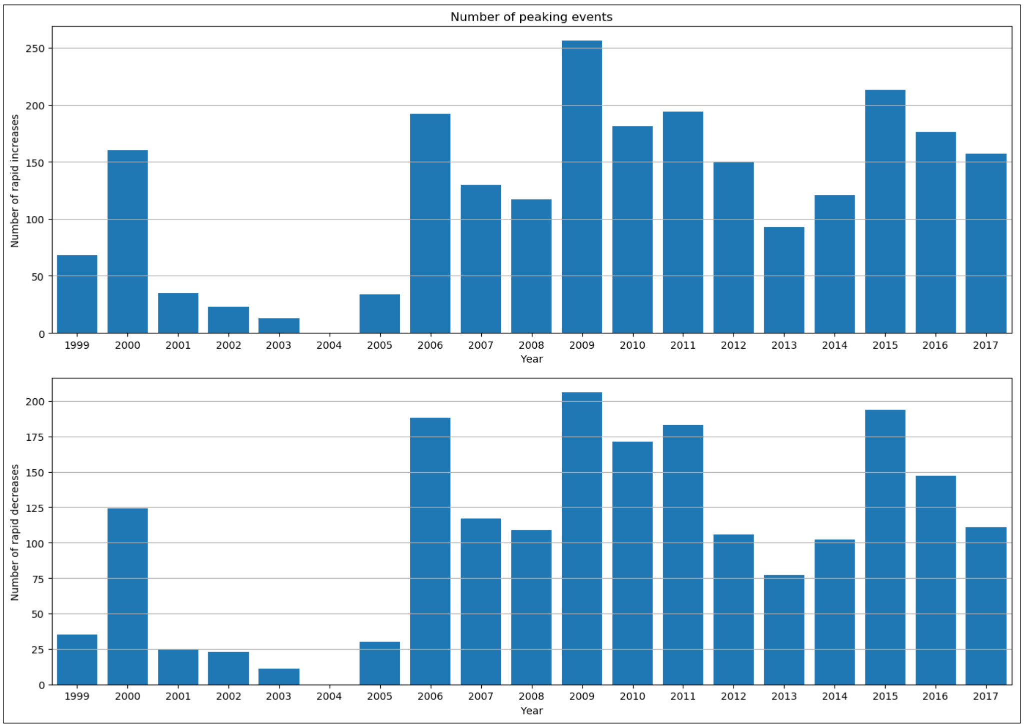

Figure 37. Holm Bru. Number of peaks per year– Discharge

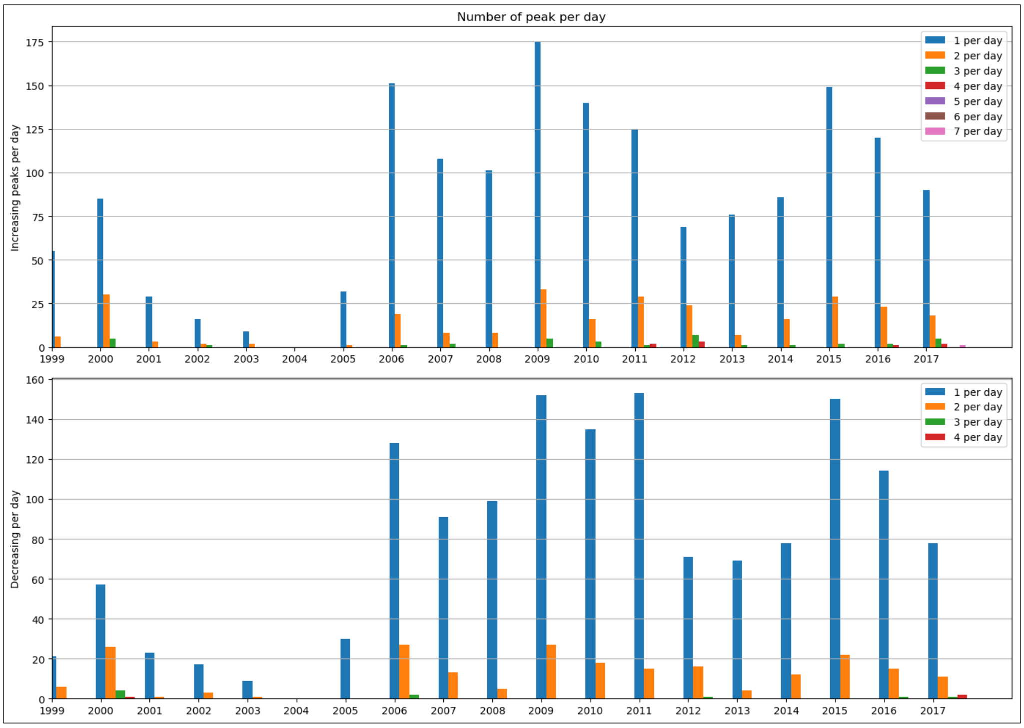

Figure 38. Holm Bru. Number of peaks per day– Discharge

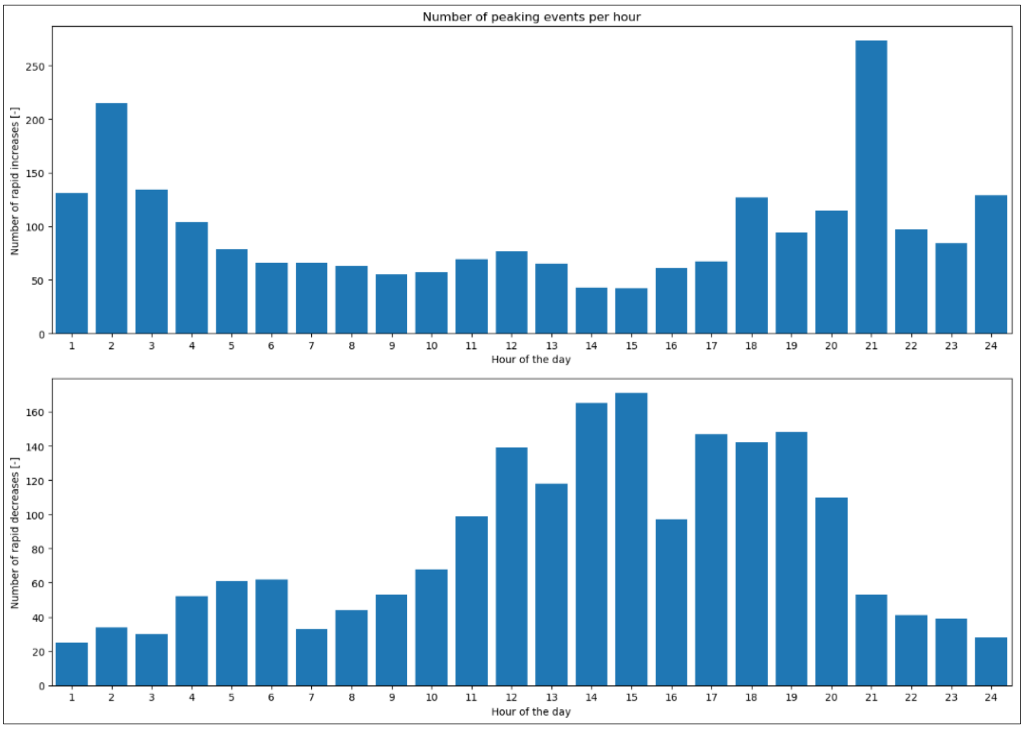

Figure 39. Holm Bru. Number of peaks per hour– Discharge

1.7.2 Water level

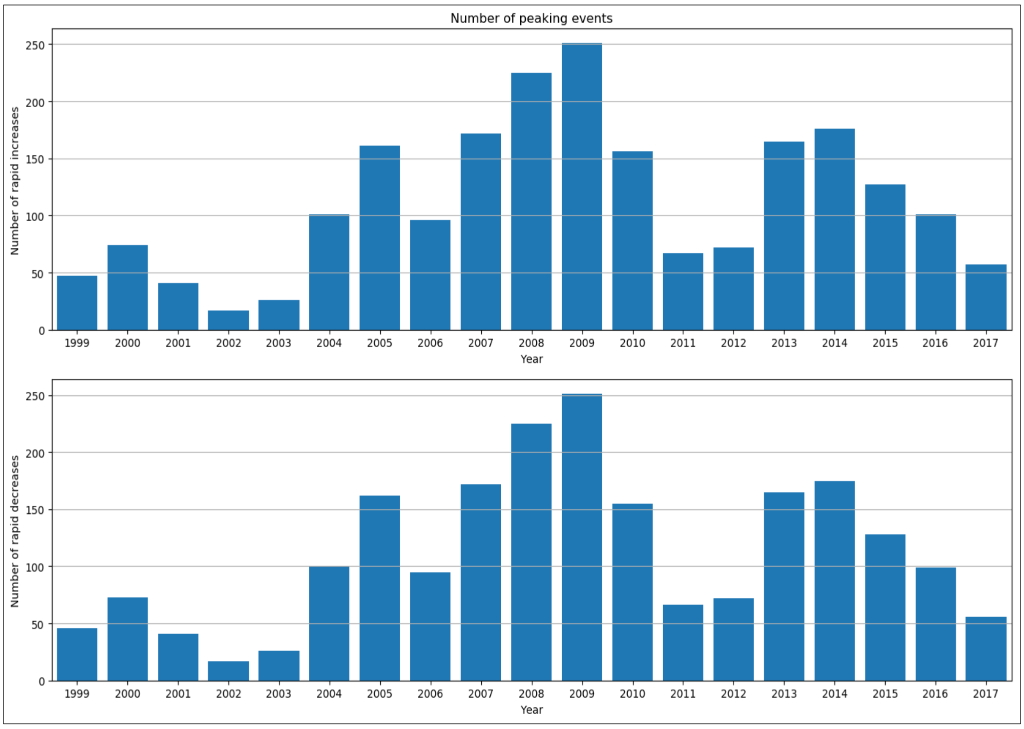

Figure 40. Holm Bru. Number of peaks per year– Water level

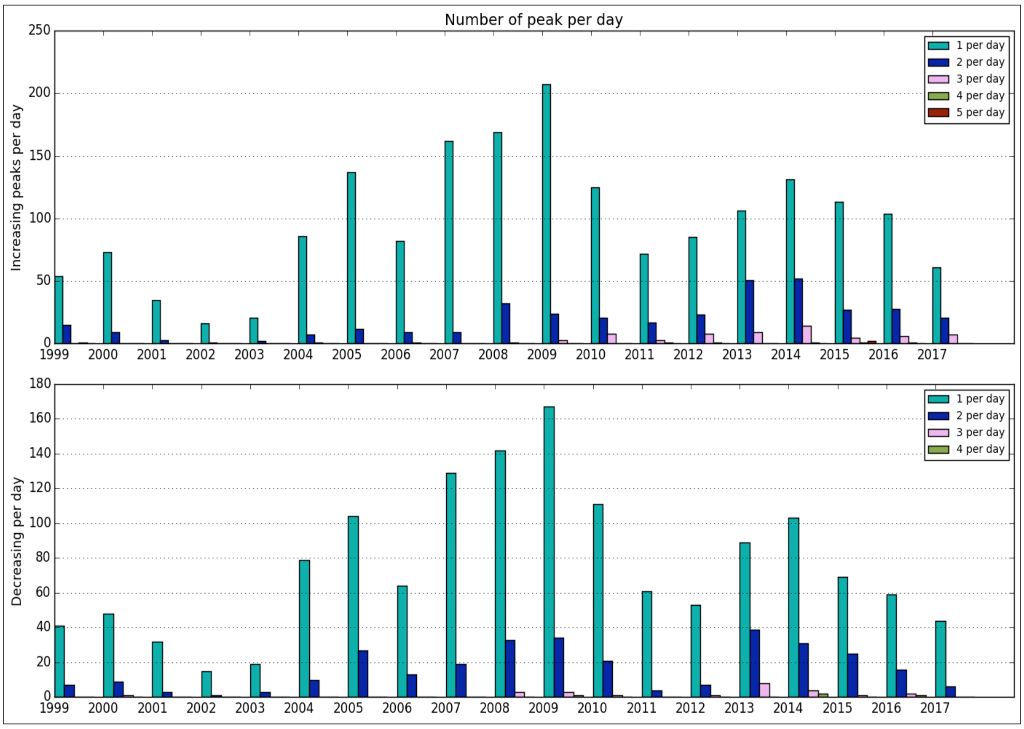

Figure 41. . Holm Bru. Number of peaks per day– Water level

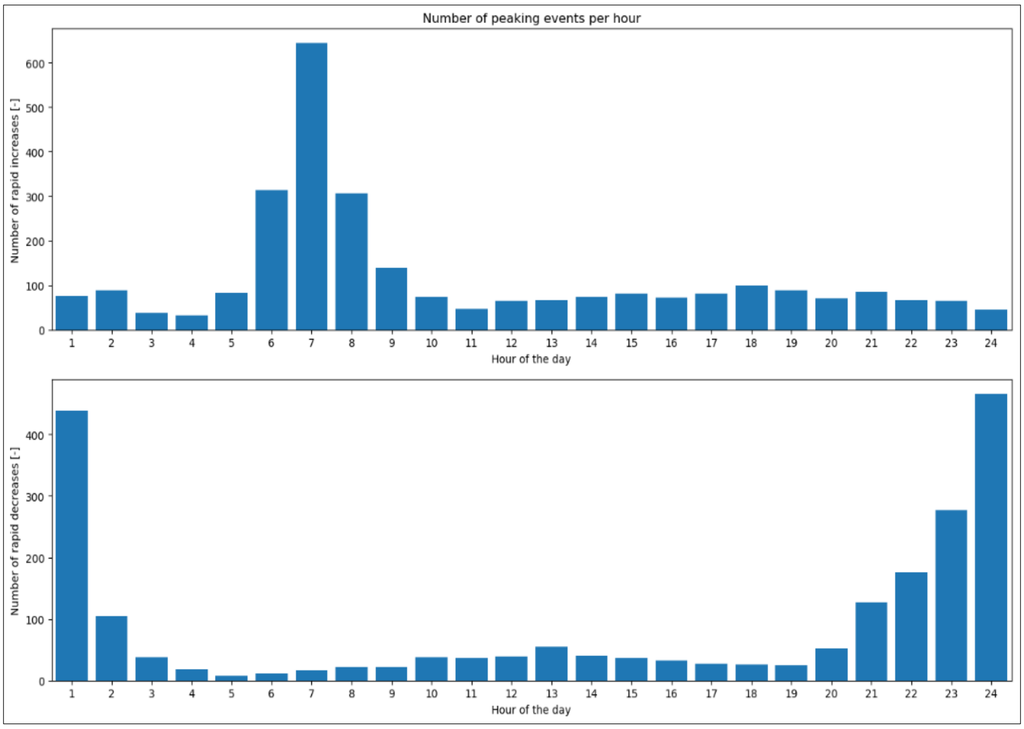

Figure 42. Holm Bru. Number of peaks per hour– Water level

1.8 *JØRUNDLAND*

1.8.1 Discharge

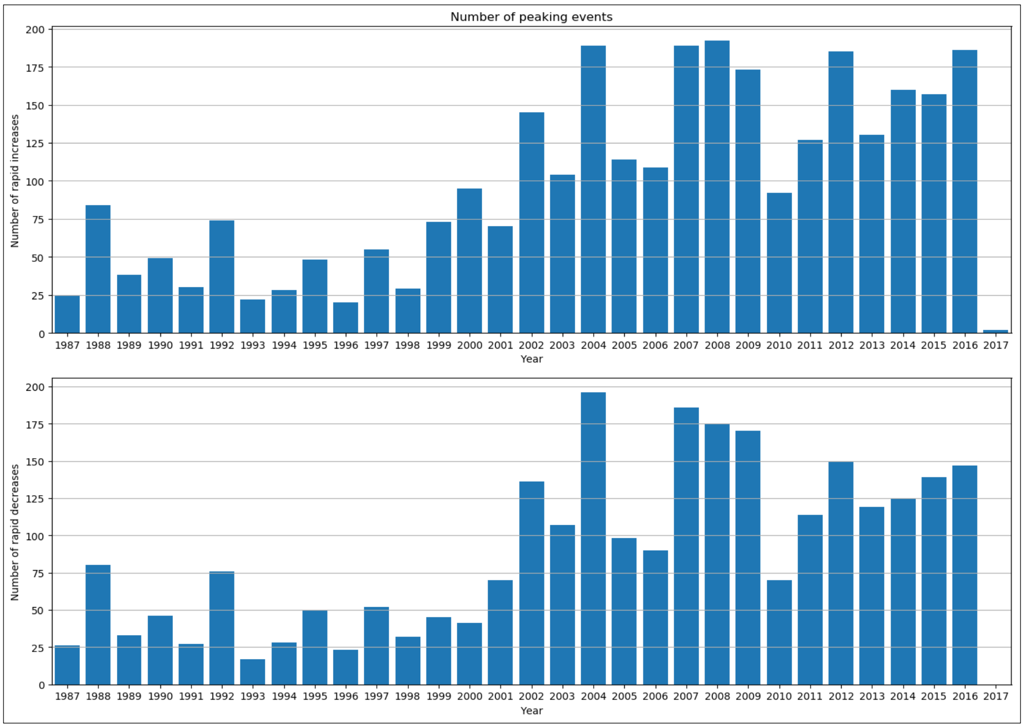

Figure 43. Jørundland. Number of peaks per year– Discharge

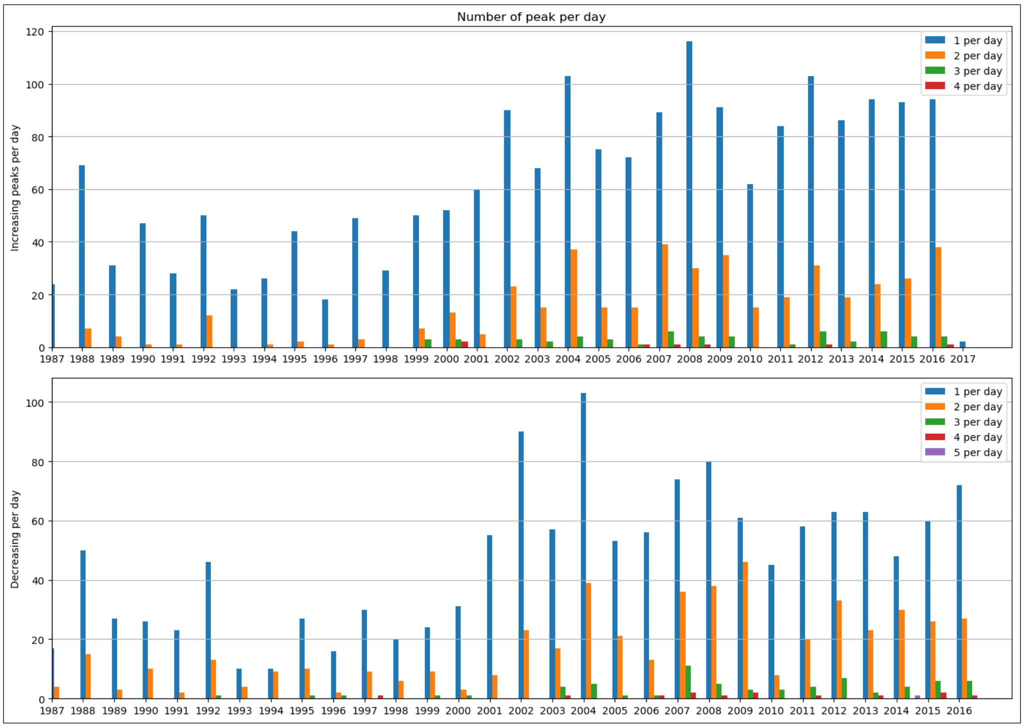

Figure 44. Jørundland. Number of peaks per day– Discharge

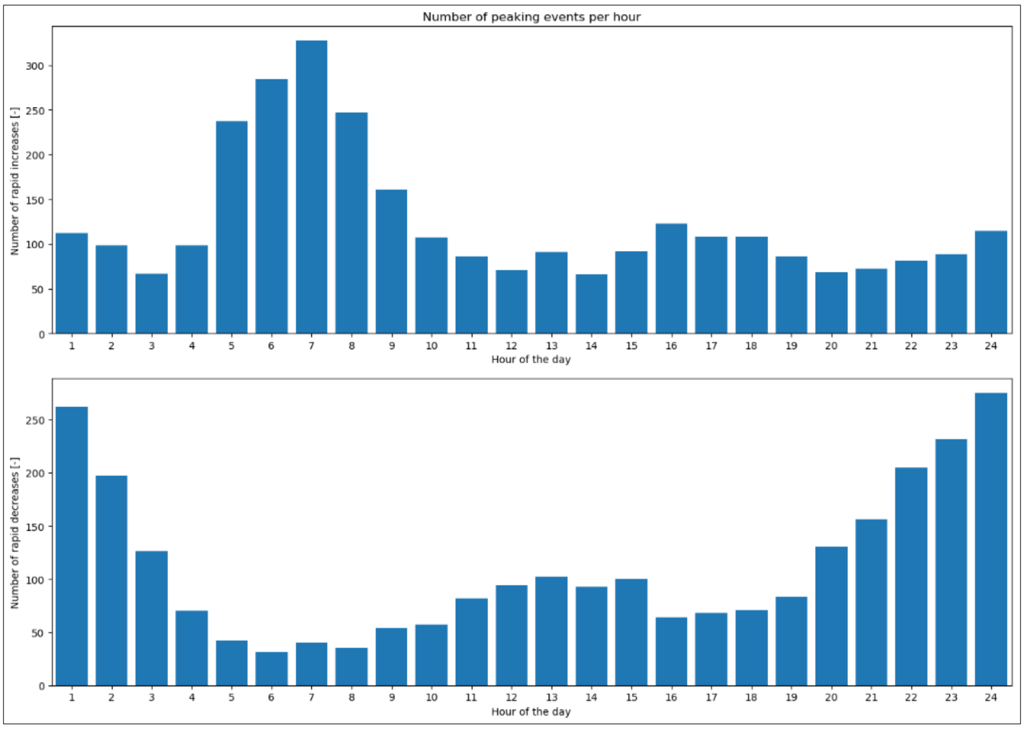

Figure 45. Jørundland. Number of peaks per hour– Discharge

1.8.2 Water level

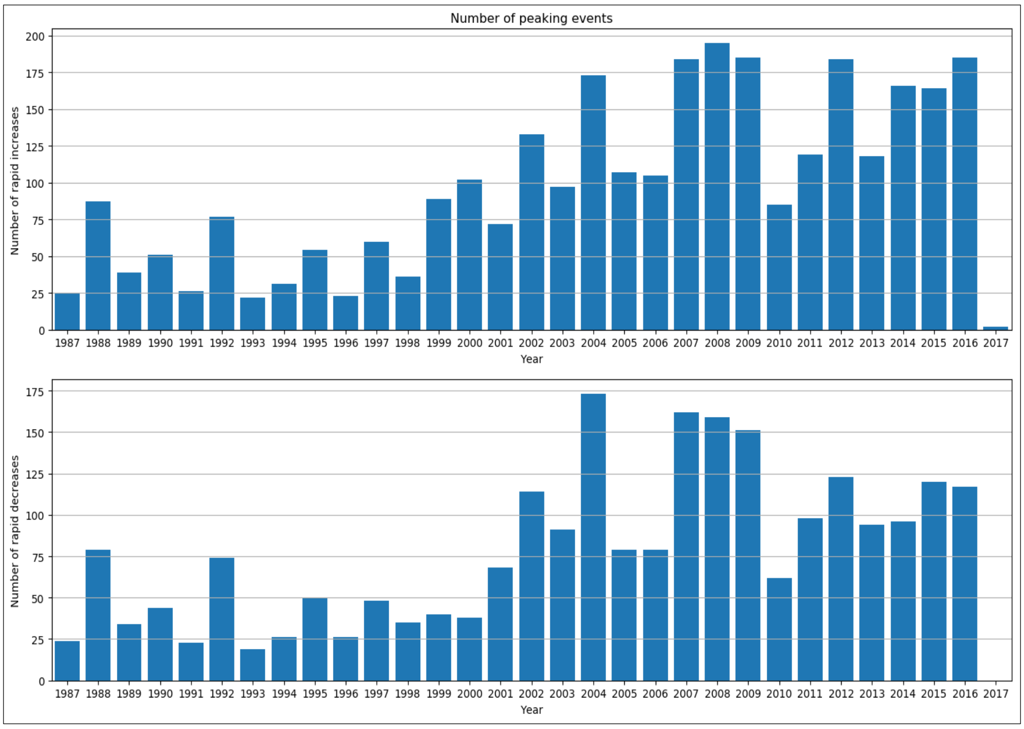

Figure 46. Jørundland. Number of peaks per year– Water level

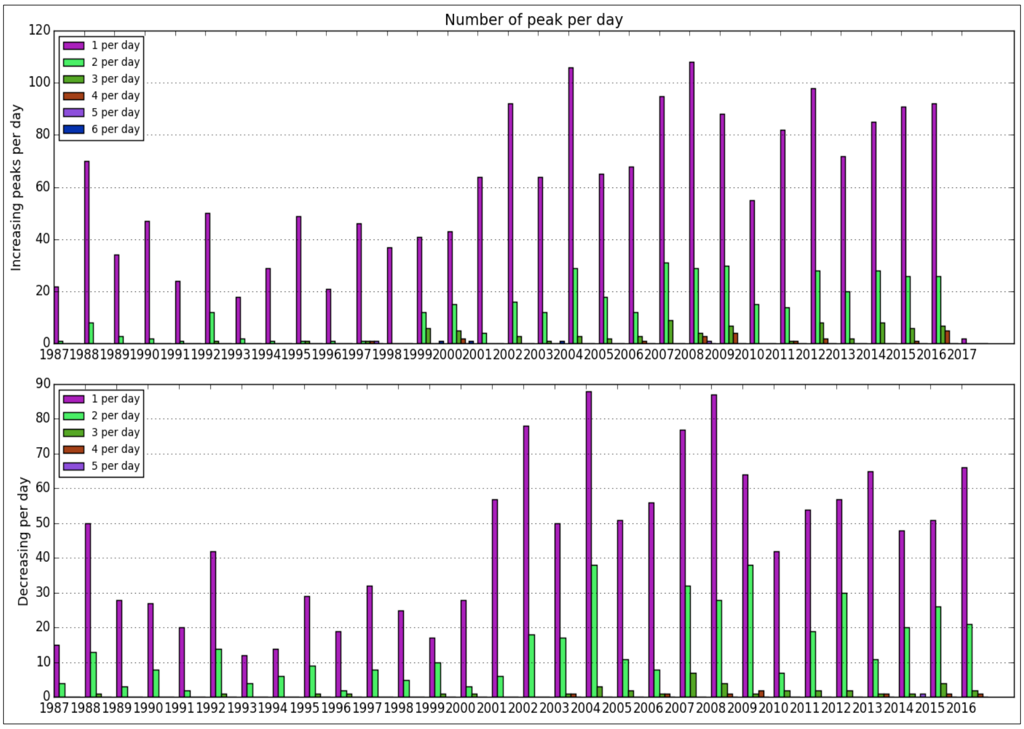

Figure 47. Jørundland. Number of peaks per day– Water level

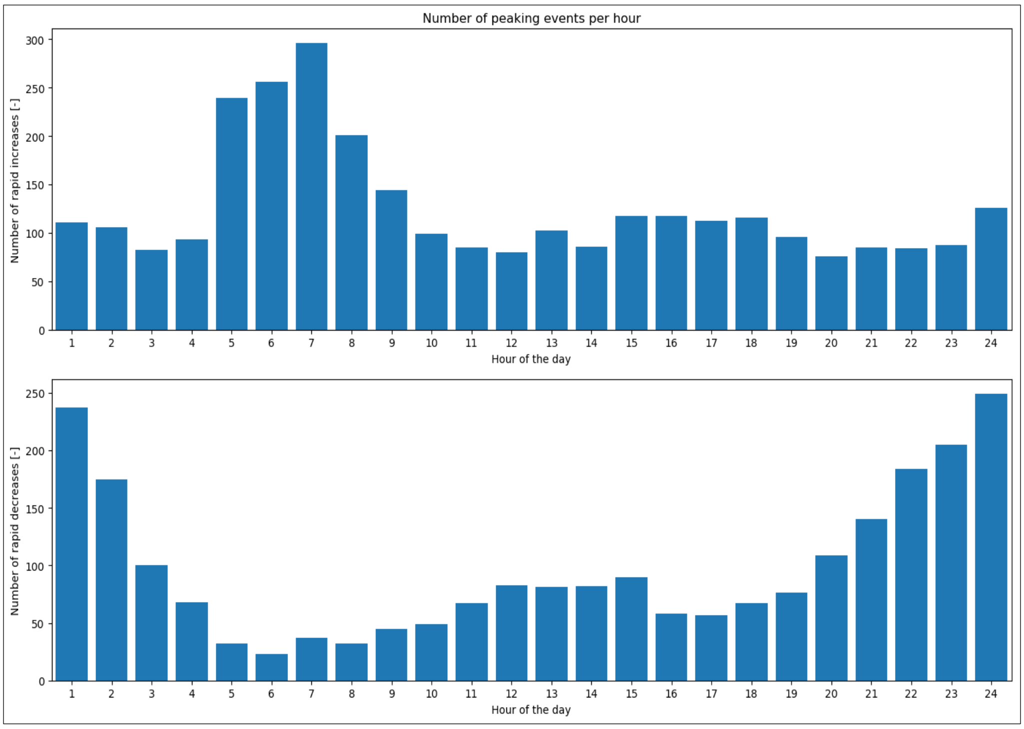

Figure 48. Jørundland. Number of peaks per hour– Water level

1.9 KISTA / CYST

1.9.1 Discharge

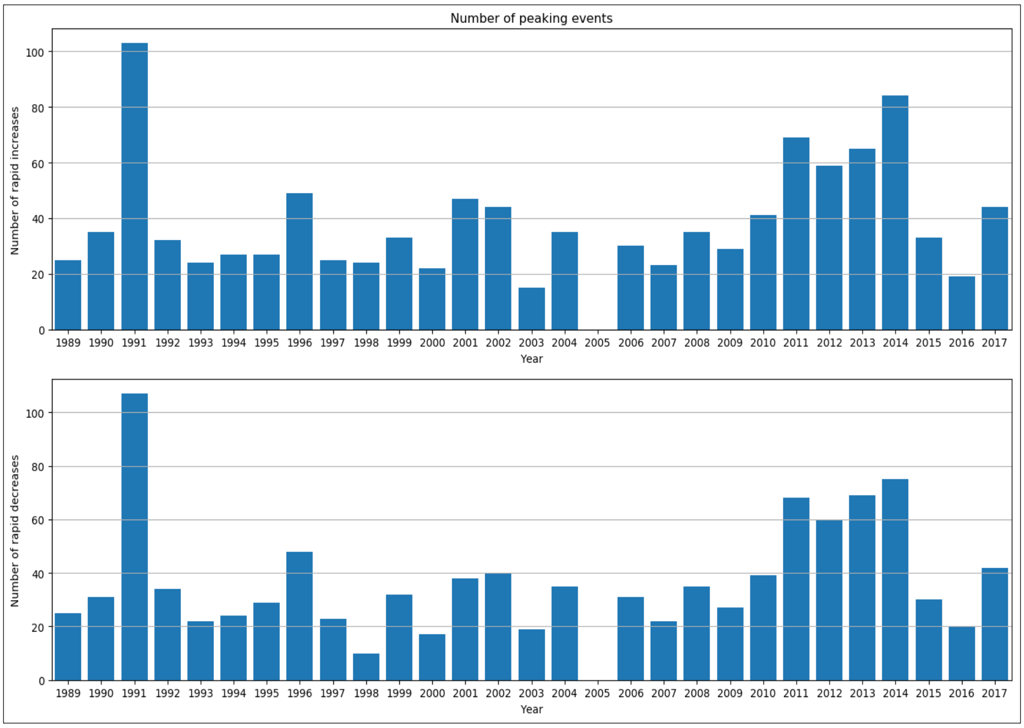

Figure 49. Kista. Number of peaks per year– Discharge

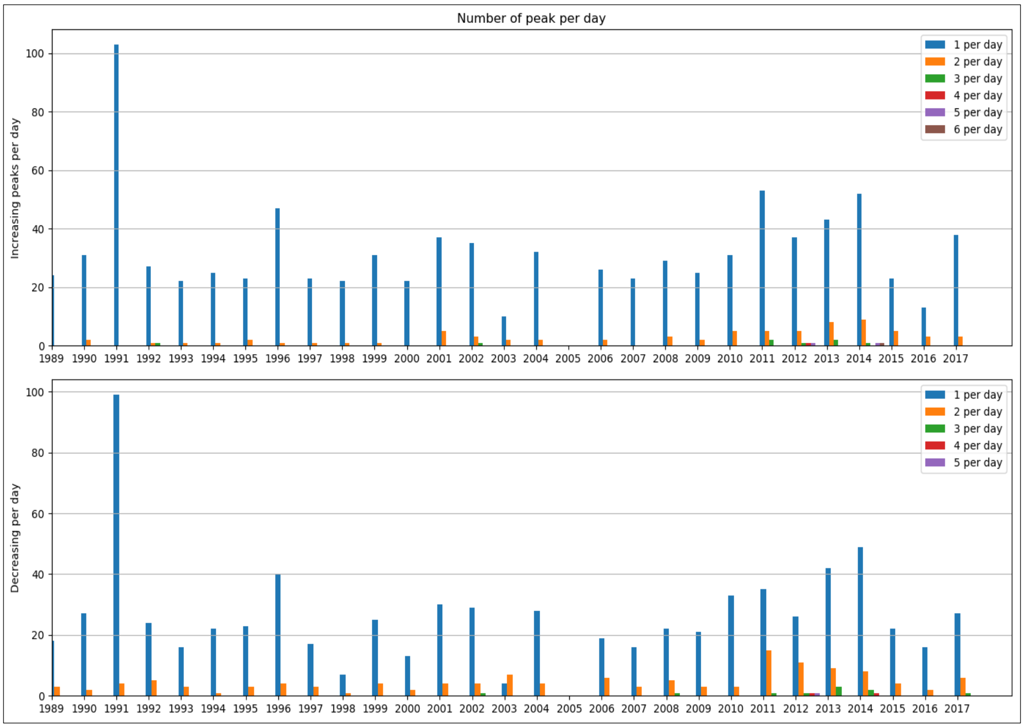

Figure 50. Kista. Number of peaks per day– Discharge

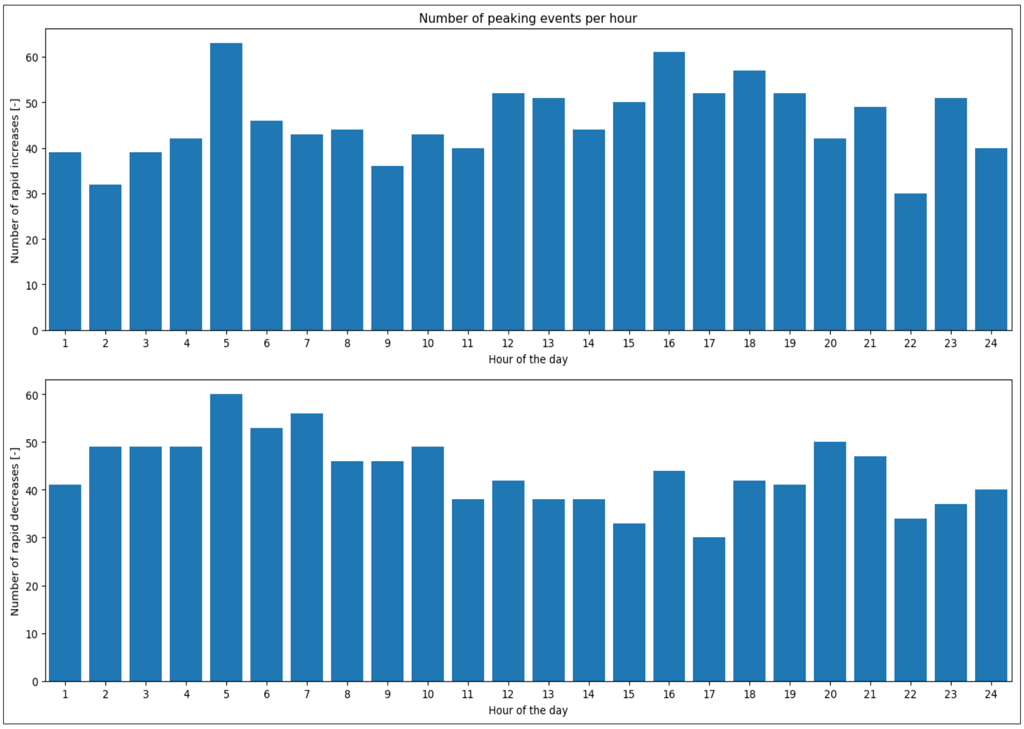

Figure 51. Kista. Number of peaks per hour– Discharge

1.9.2 Water level

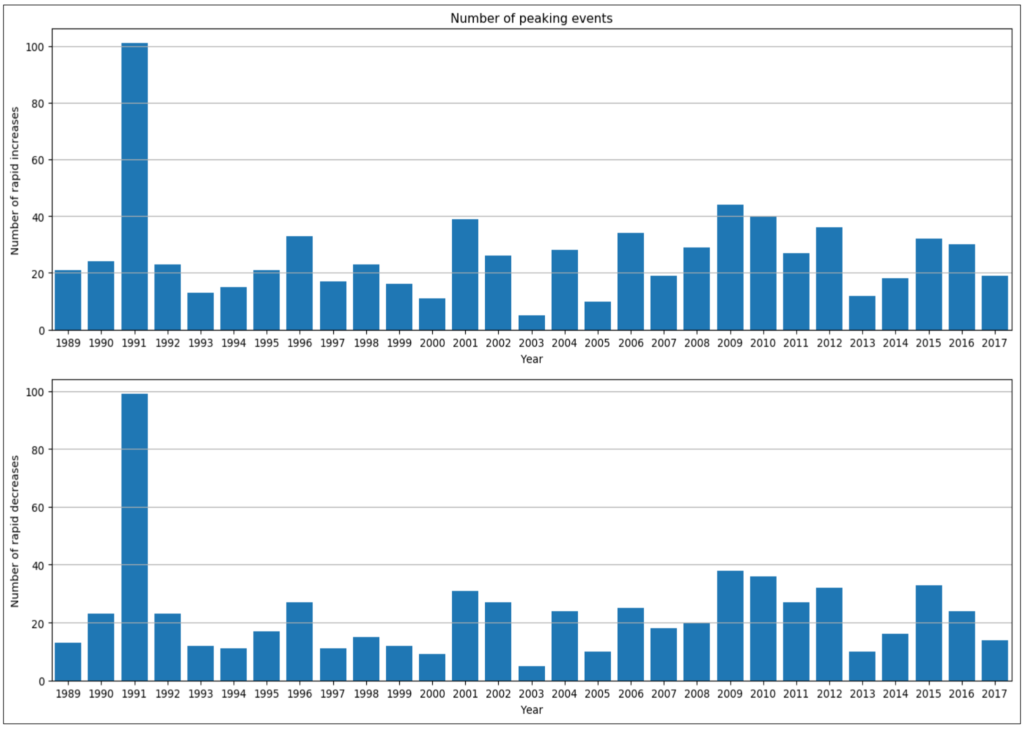

Figure 52. Kista. Number of peaks per year– Water level

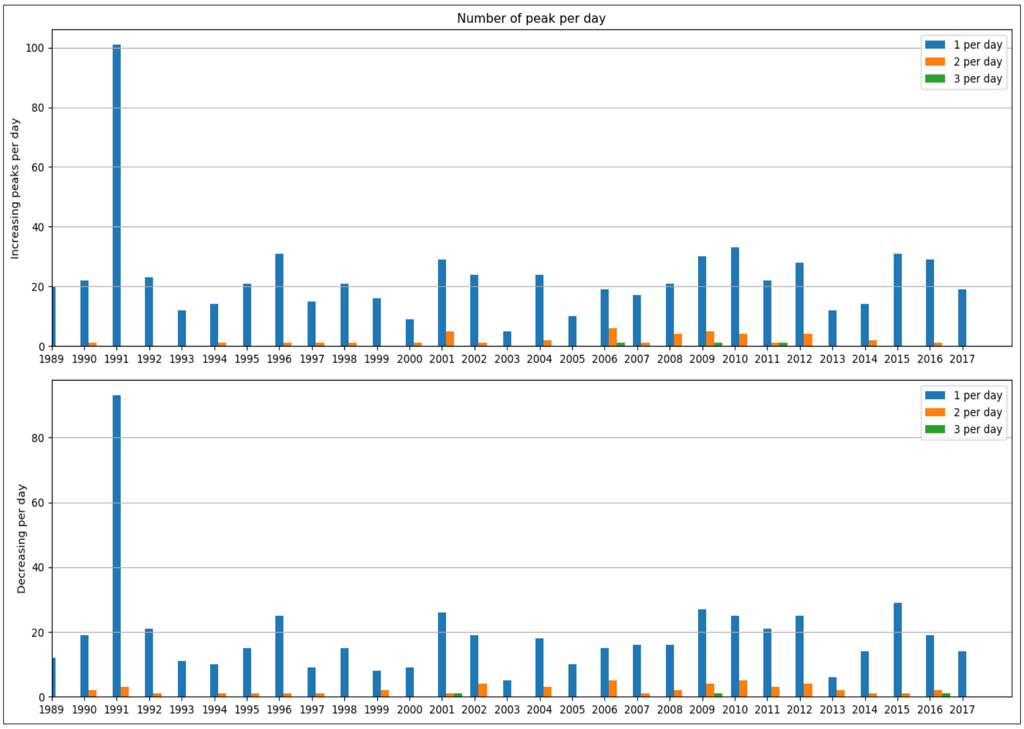

Figure 53. Kista. Number of peaks per day– Water level

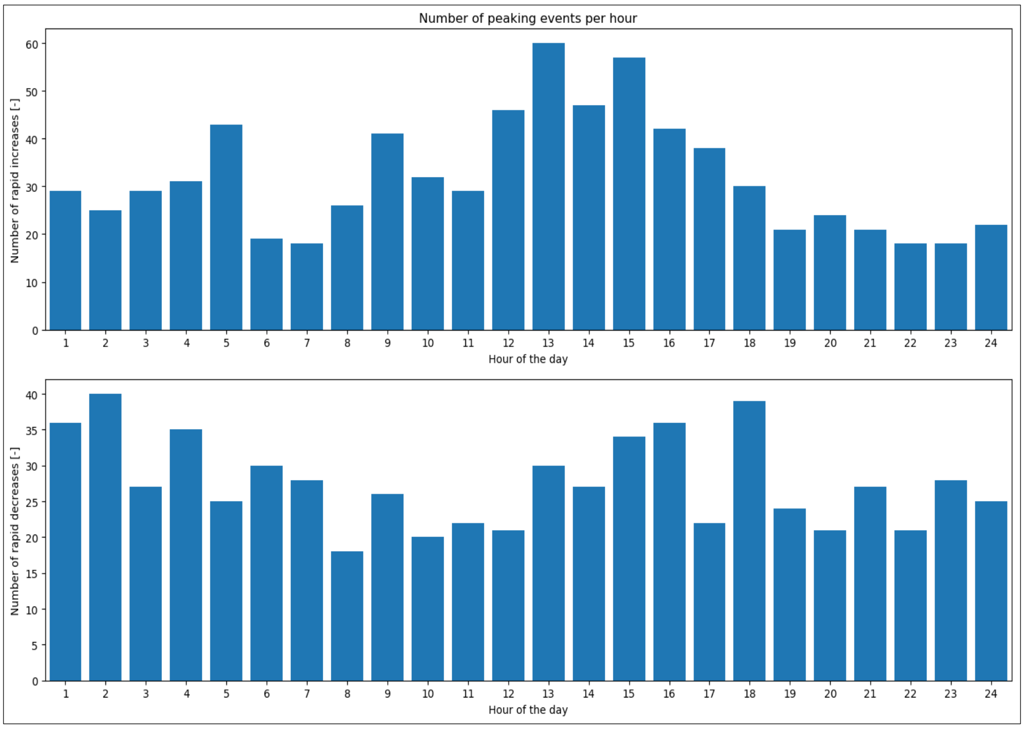

Figure 54. Kista. Number of peaks per hour– Water level

1.10 KJØLEMO

1.10.1 Discharge

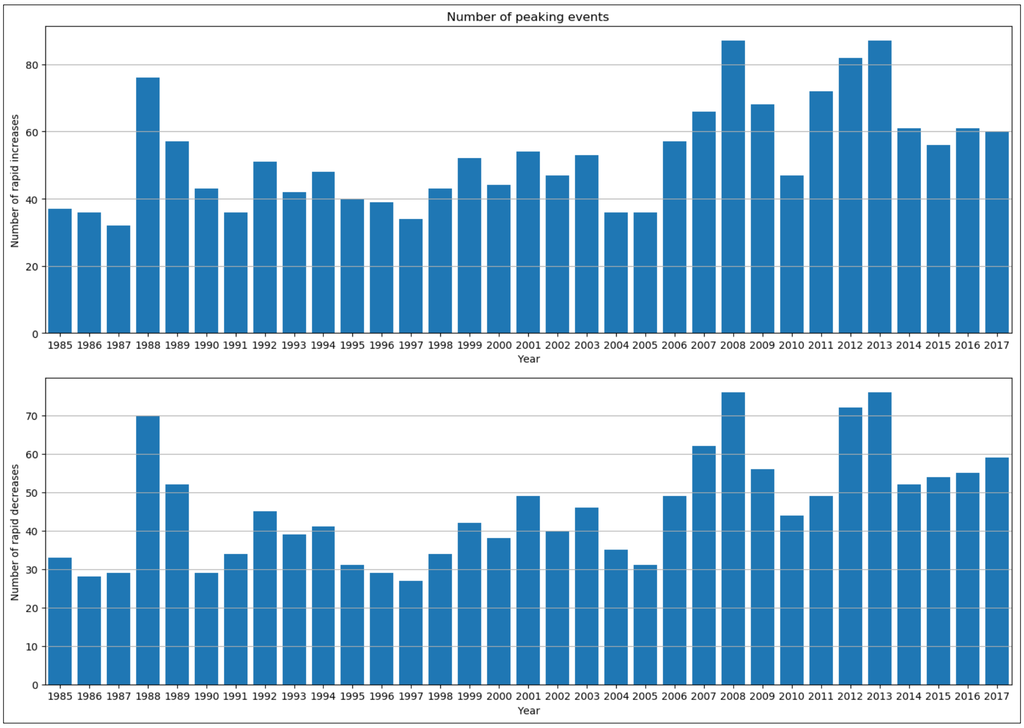

Figure 55. Kjølemo. Number of peaks per year– Discharge

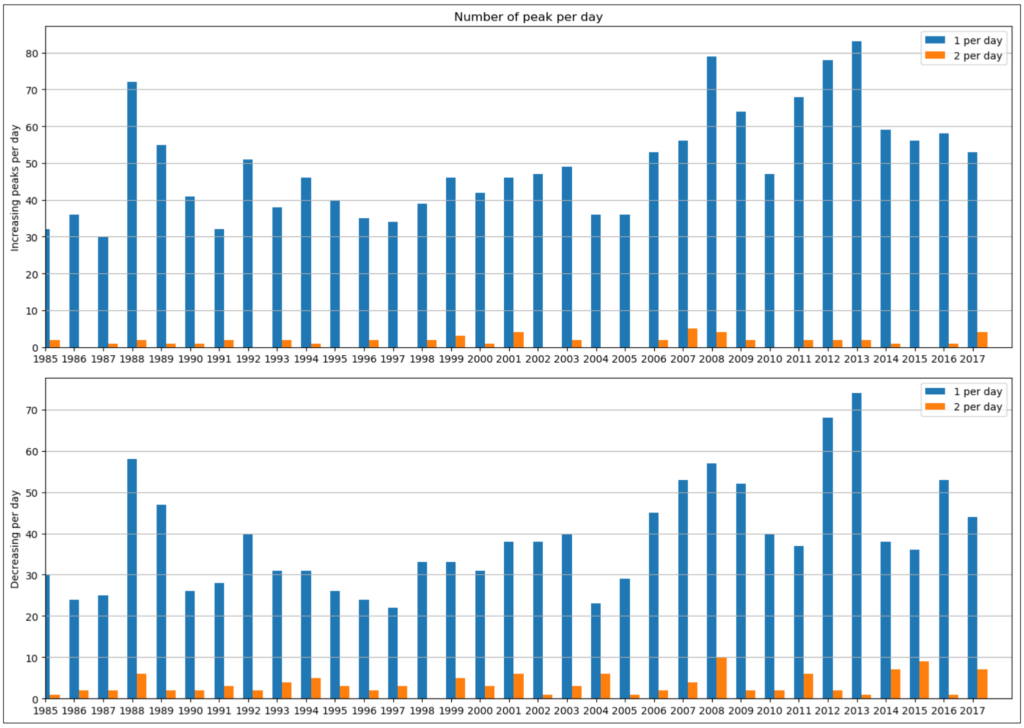

Figure 56. Kjølemo. Number of peaks per day– Discharge

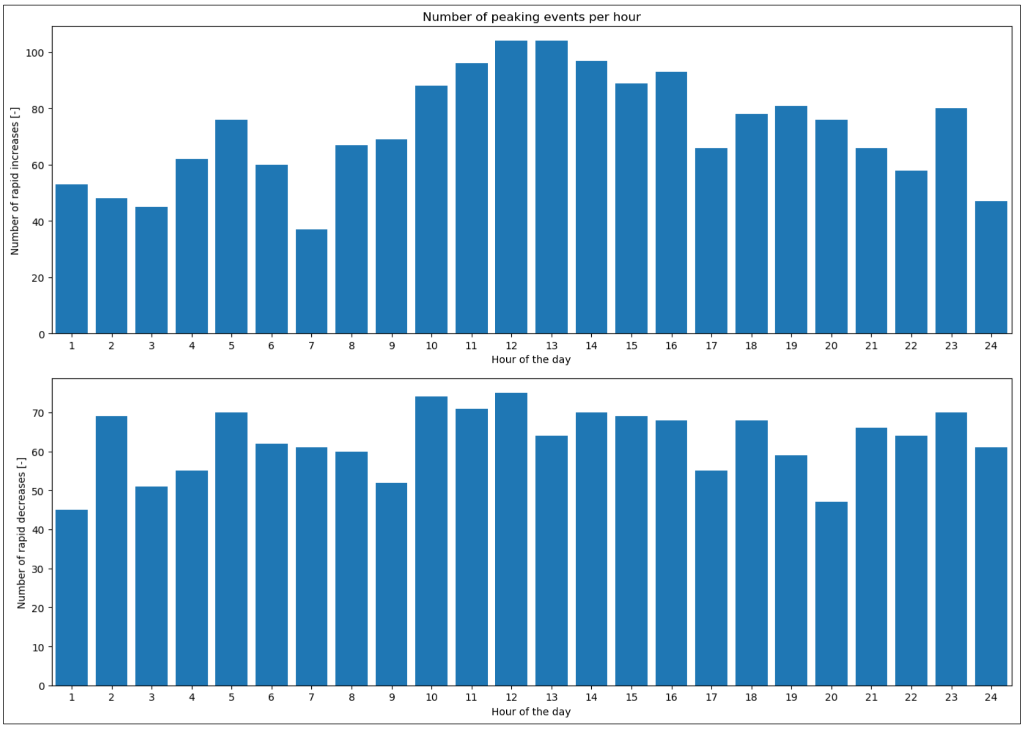

Figure 57. Kjølemo. Number of peaks per hour– Discharge

1.10.2 Water level

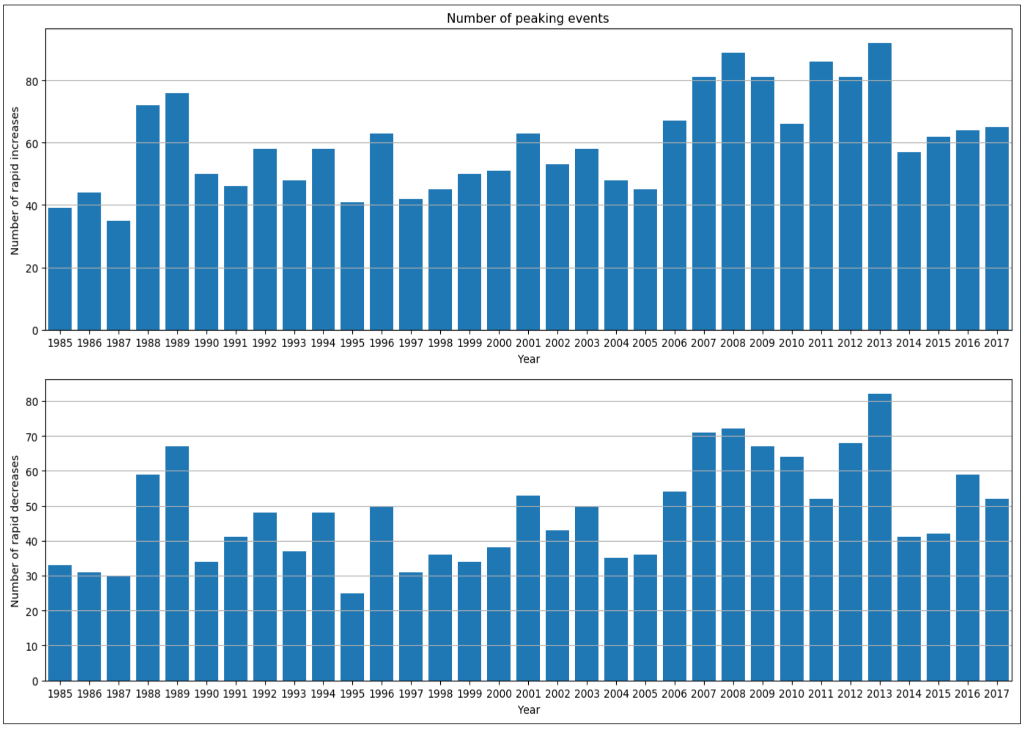

Figure 58. Kjølemo. Number of peaks per year– Water level

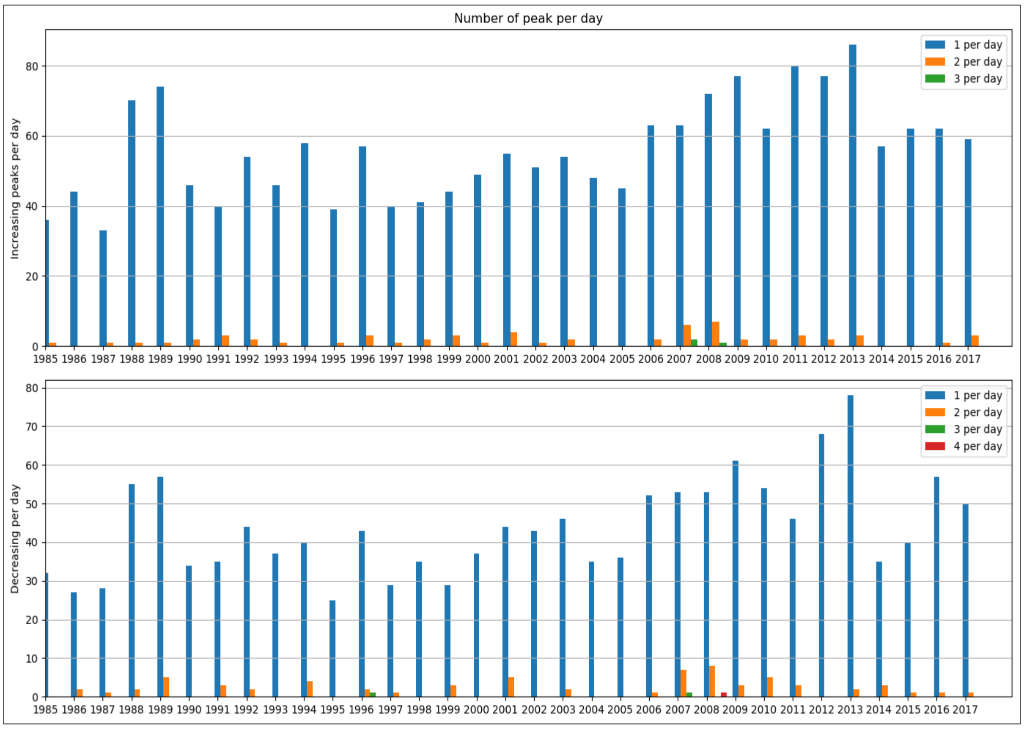

Figure 59. Kjølemo. Number of peaks per day - Water level

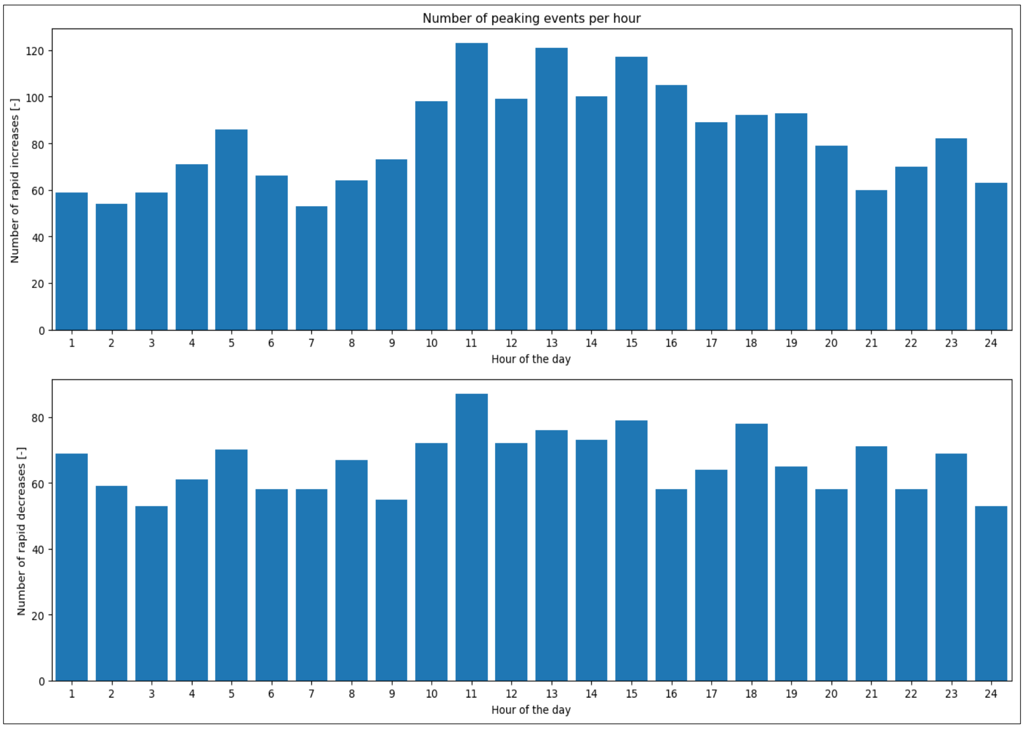

Figure 60. Kjølemo. Number of peaks per hour– Water level

1.11 KOBBVATN

1.11.1 Discharge

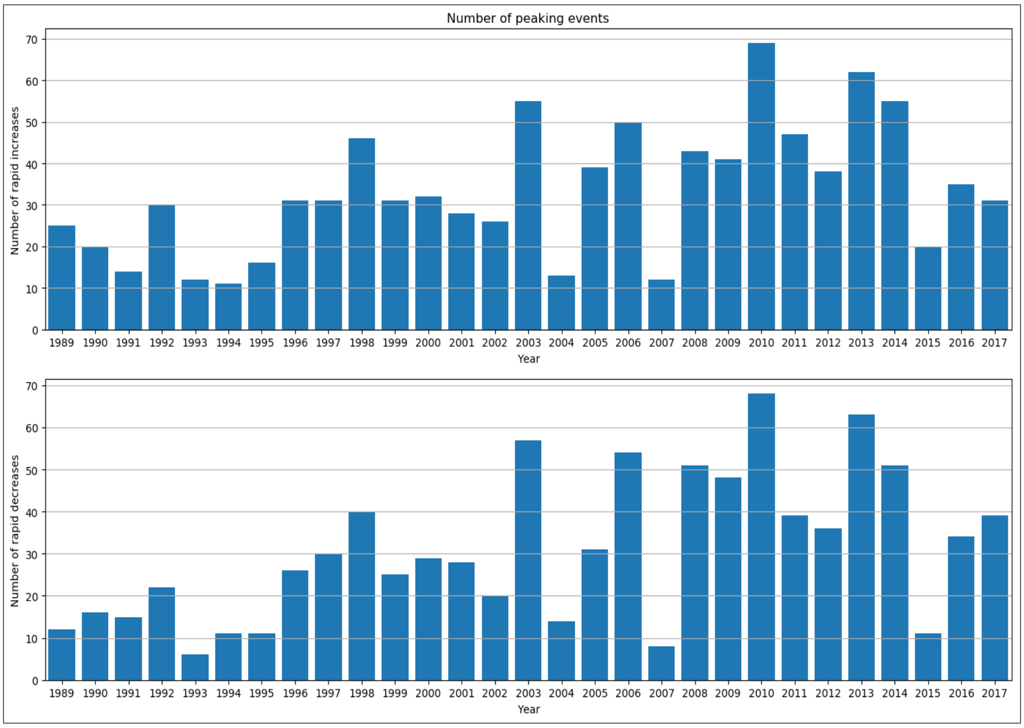

Figure 61. Kobbvatn. Number of peaks per year– Discharge

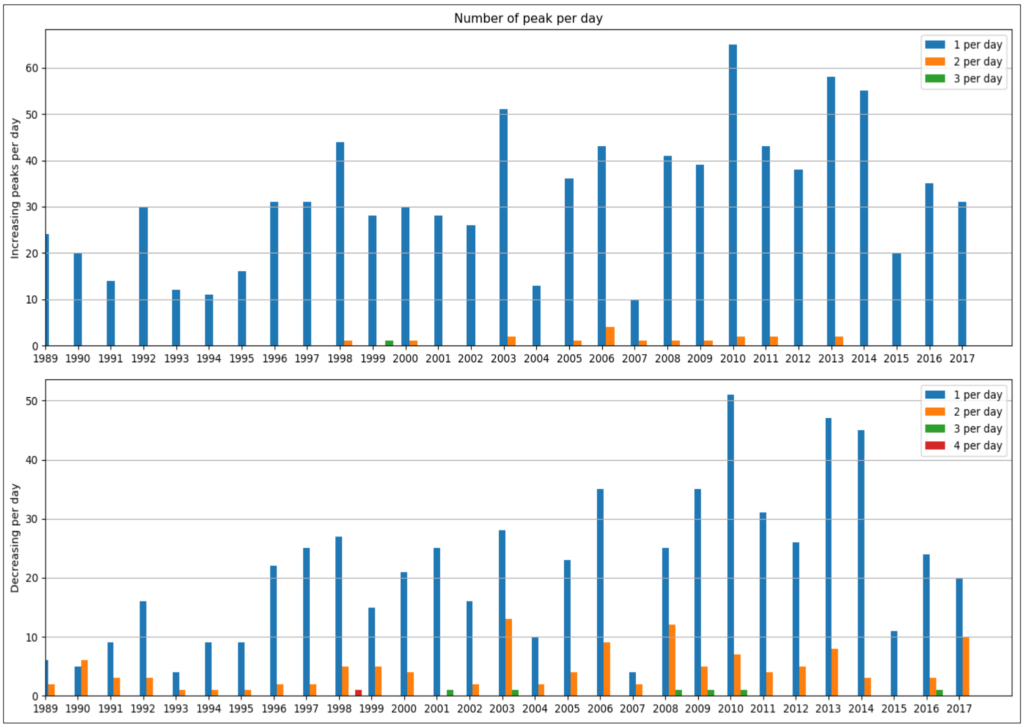

Figure 62. Kobbvatn. Number of peaks per day– Discharge

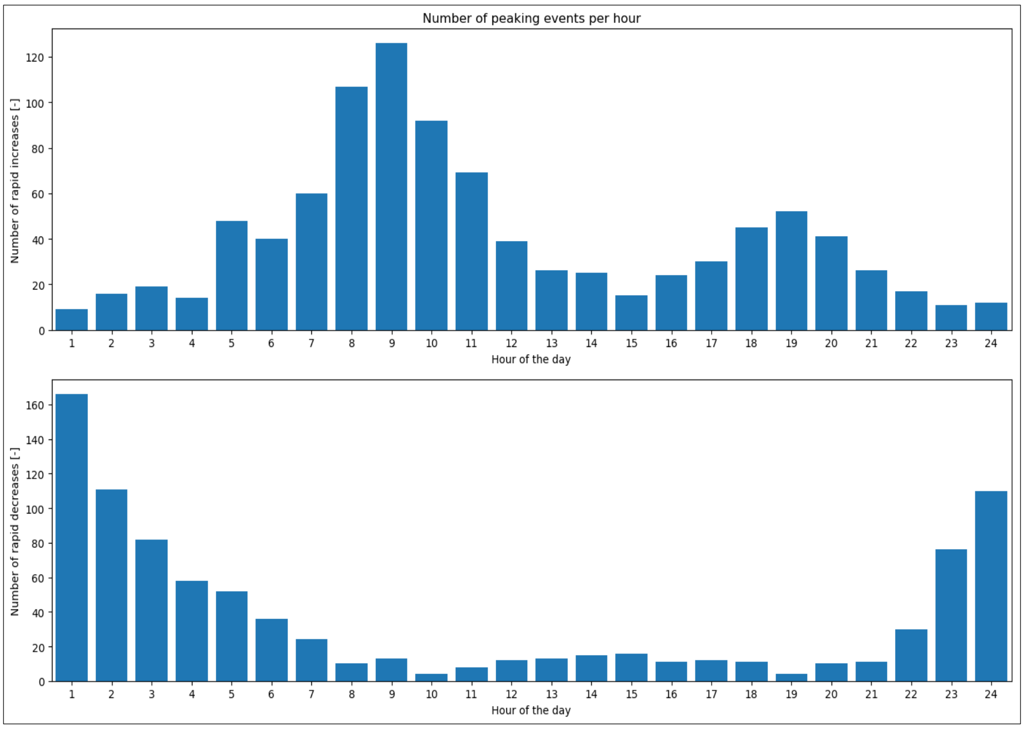

Figure 63. Kobbvatn. Number of peaks per hour– Discharge

1.11.2 Water level

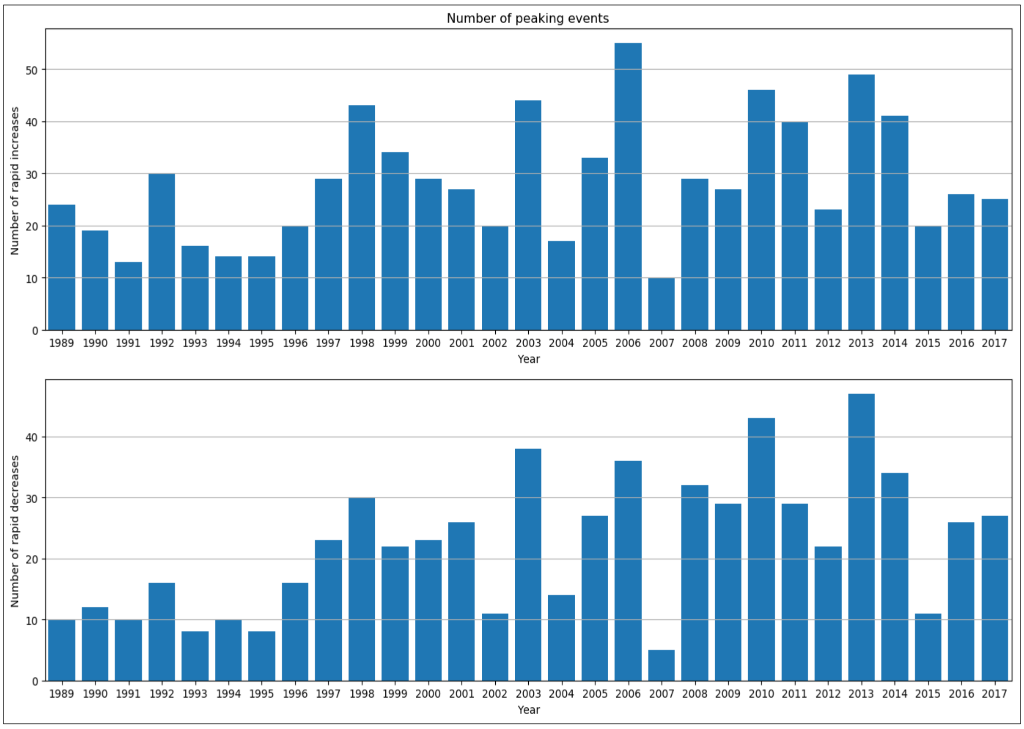

Figure 64. Kobbvatn. Number of peaks per year– Water level

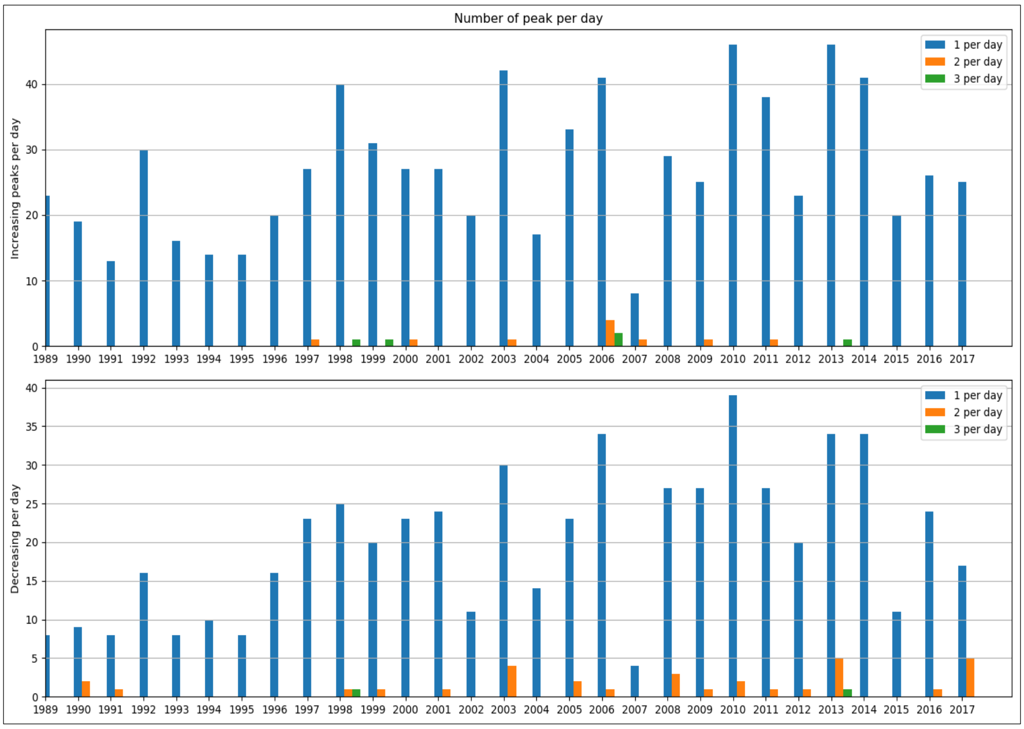

Figure 65. . Kobbvatn. Number of peaks per day– Water level

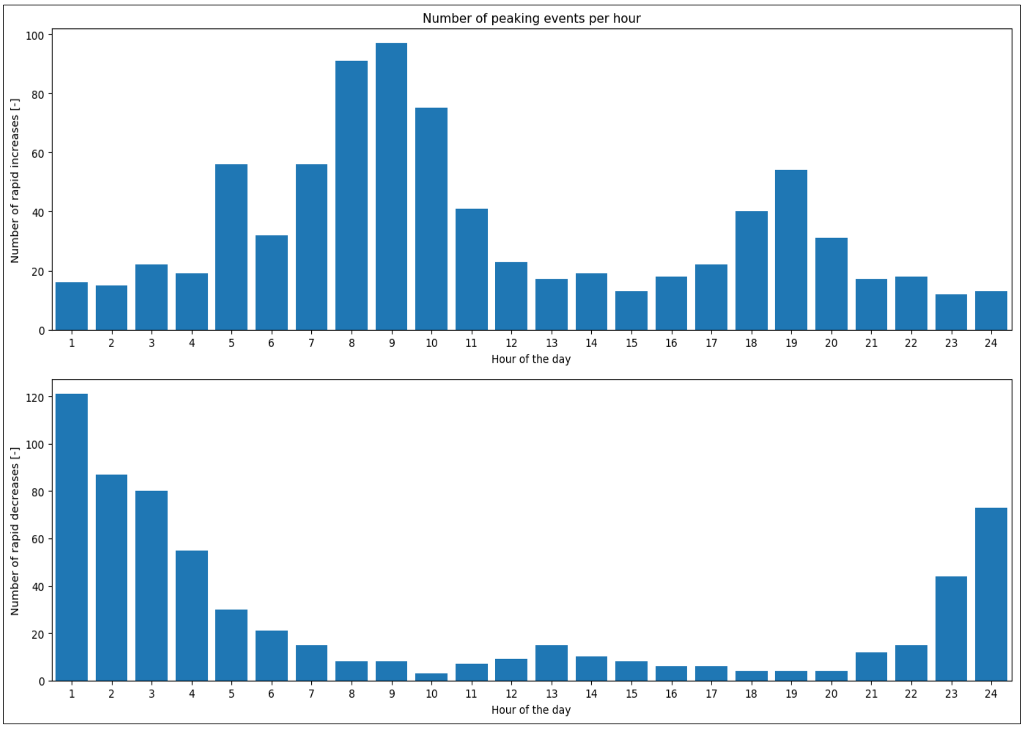

Figure 66. . Kobbvatn. Number of peaks per hour– Water level

1.12 KONGSFJORDELV

1.12.1 Discharge

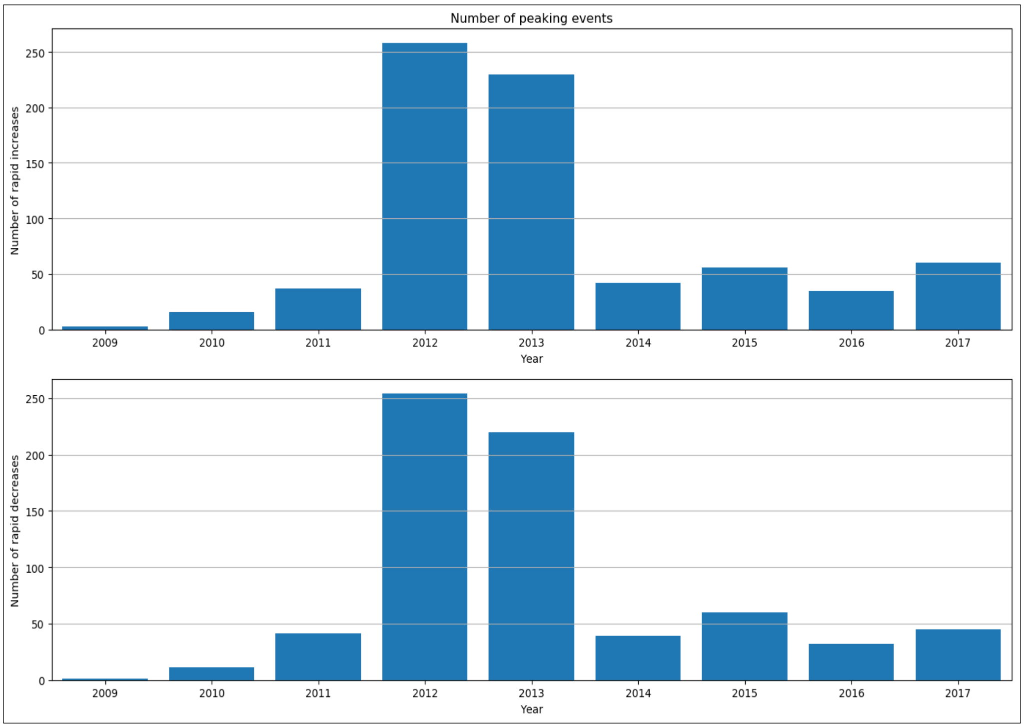

Figure 67. Kongsfjordelv. Number of peaks per year– Discharge

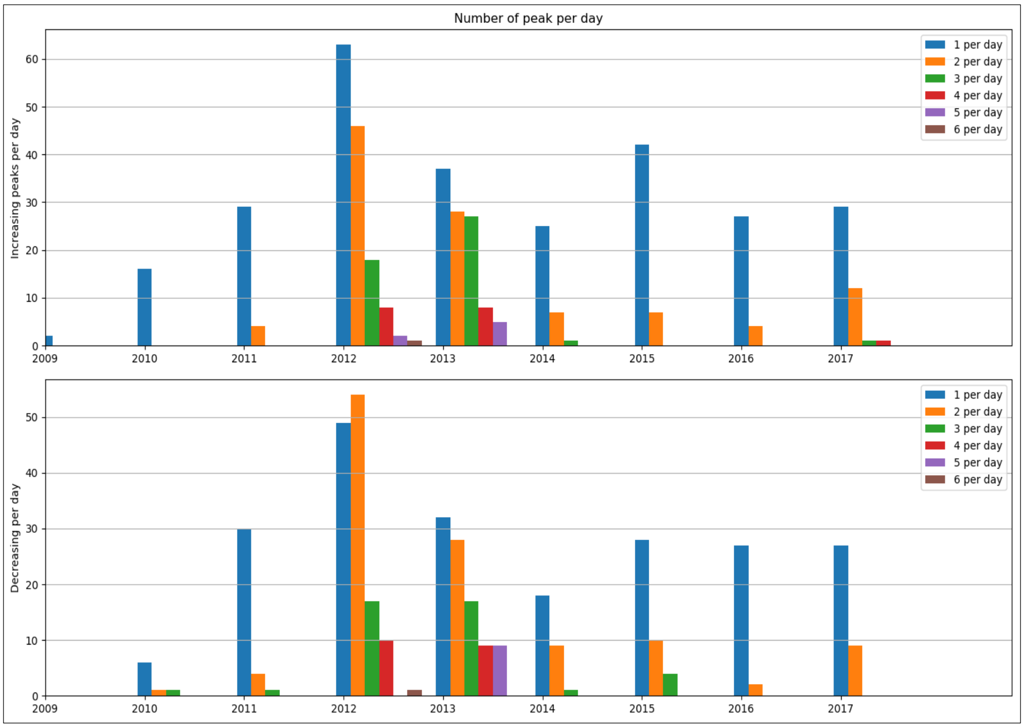

Figure 68. Kongsfjordelv. Number of peaks per day– Discharge

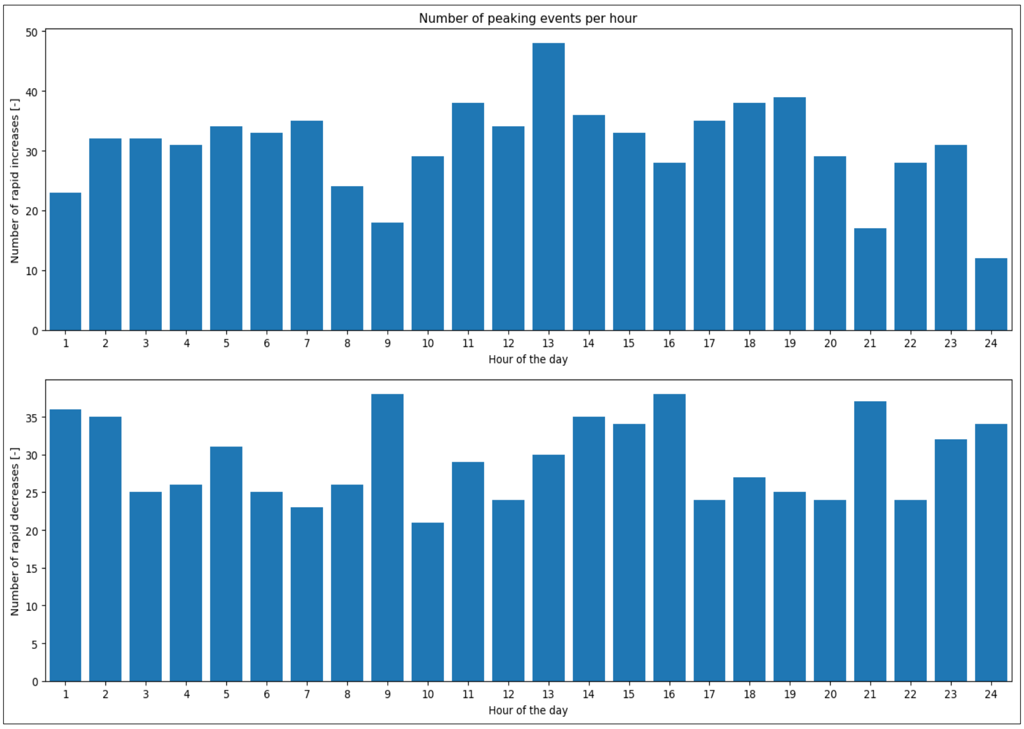

Figure 69. Kongsfjordelv. Number of peaks per hour– Discharge

1.12.2 Water level

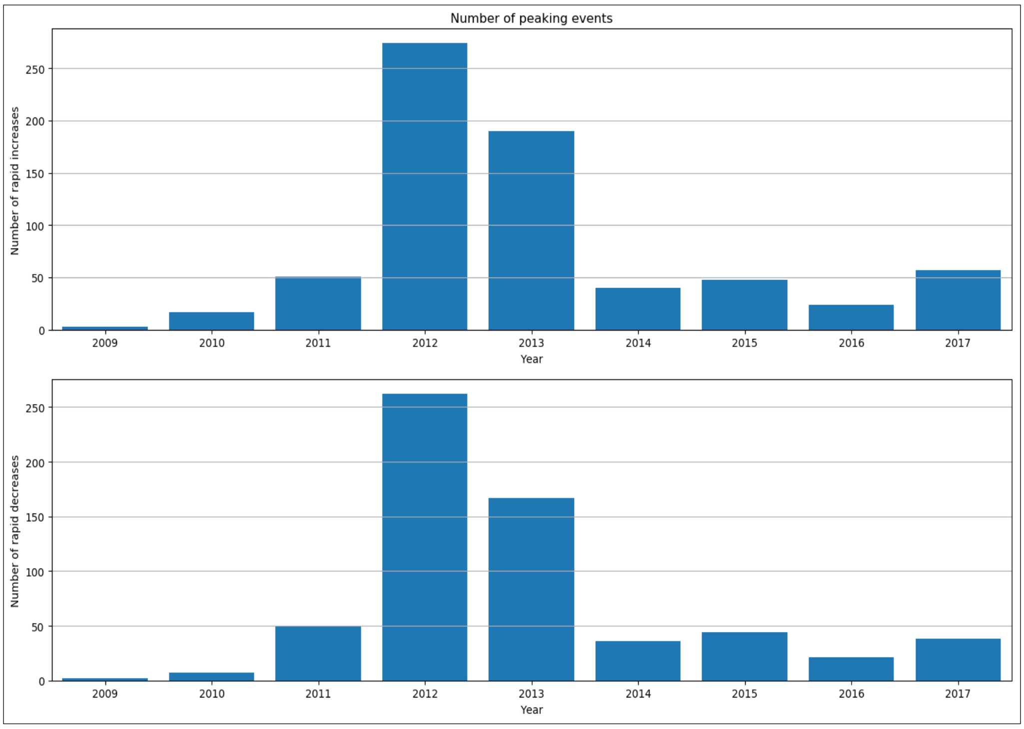

Figure 70. Kongsfjordelv. Number of peaks per year– Water level

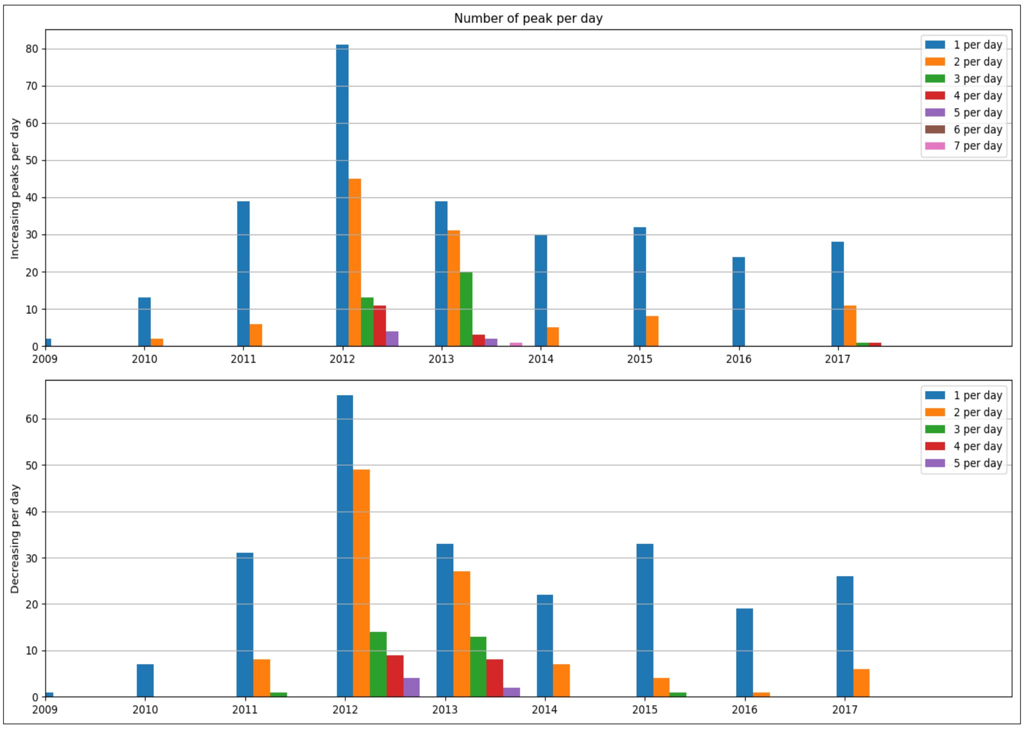

Figure 71. Kongsfjordelv. Number of peaks per day– Water level

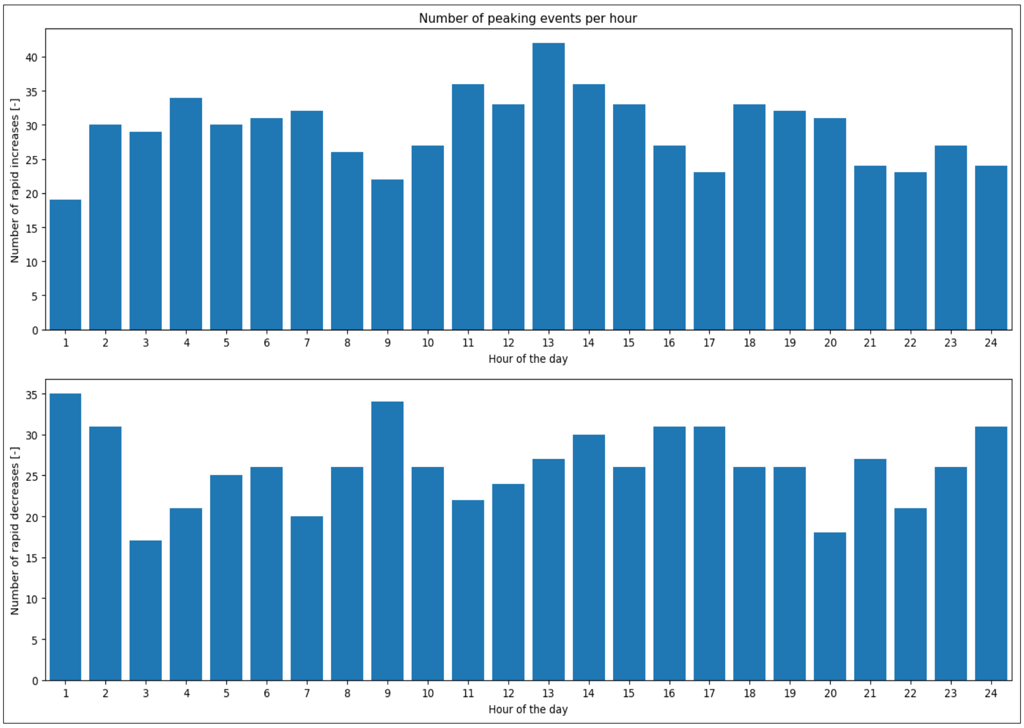

Figure 72. Kongsfjordelv. Number of peaks per hour– Water level

1.13 *KONGSFJORDFOSS*

1.13.1 Discharge

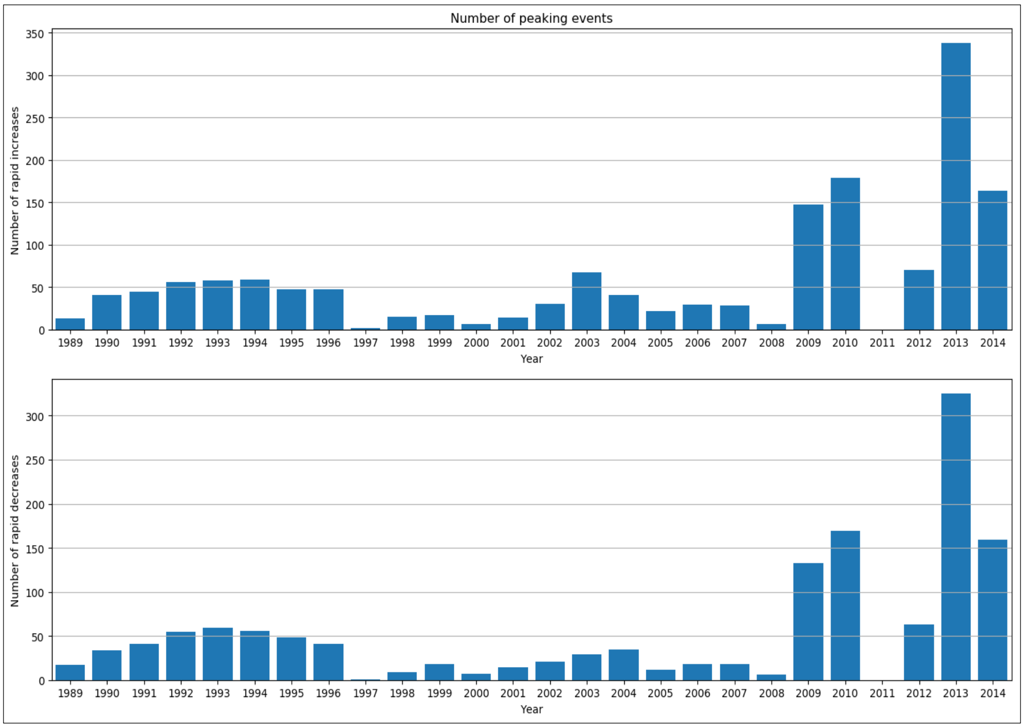

Figure 73. Kongsfjordfoss. Number of peaks per year– Discharge

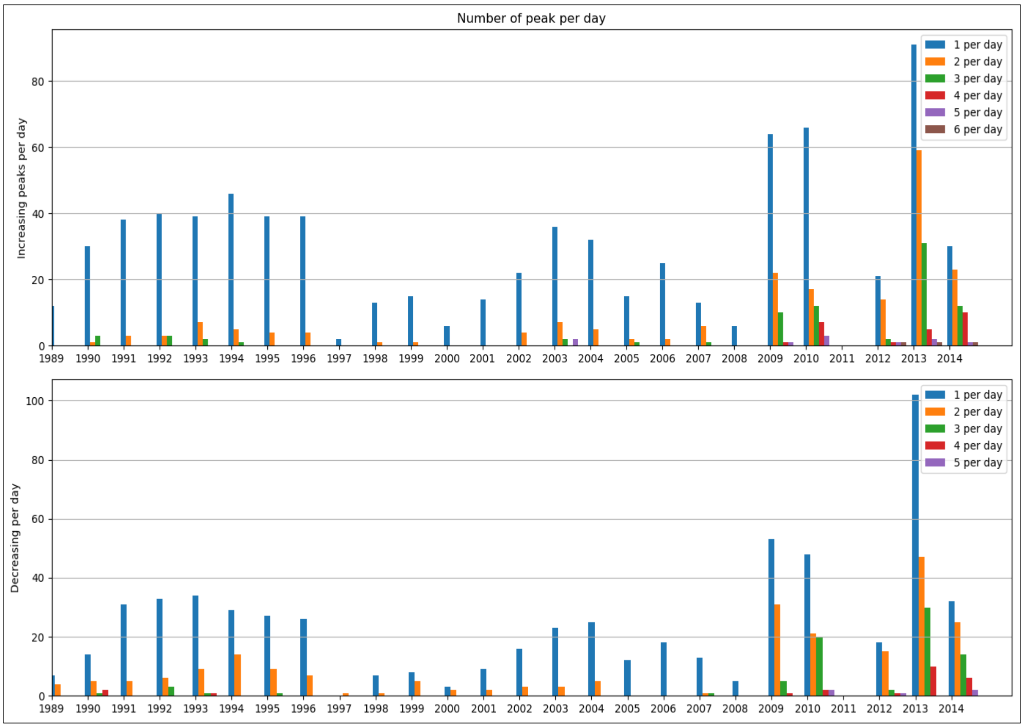

Figure 74. Kongsfjordfoss. Number of peaks per day– Discharge

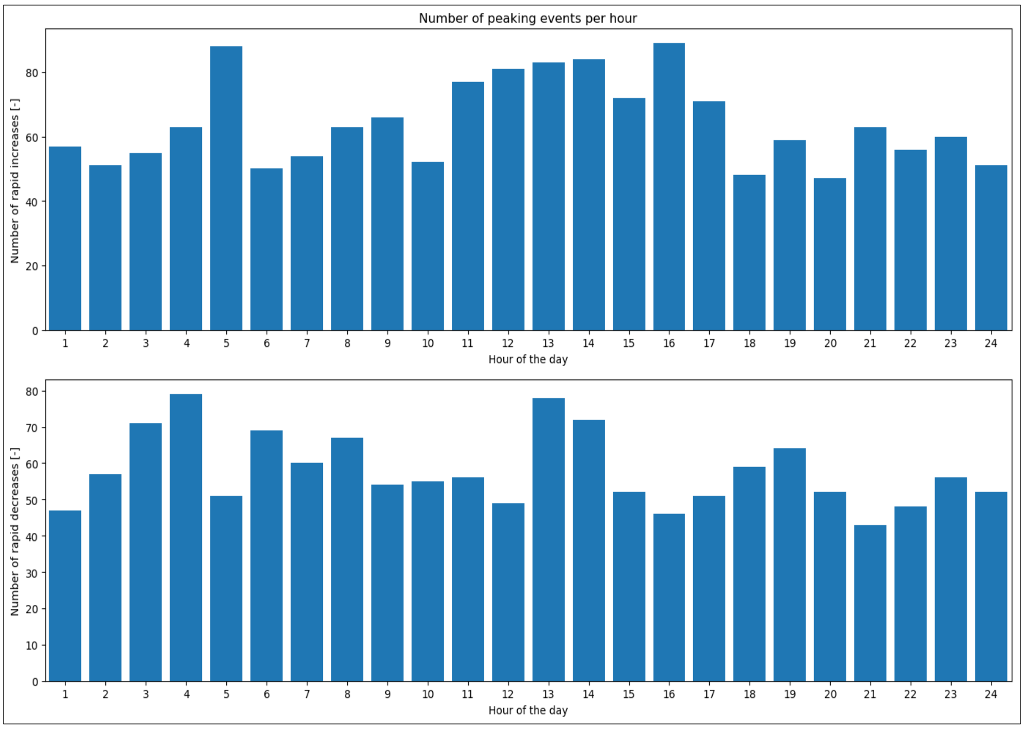

Figure 75. Kongsfjordfoss. Number of peaks per hour– Discharge

1.13.2 Water level

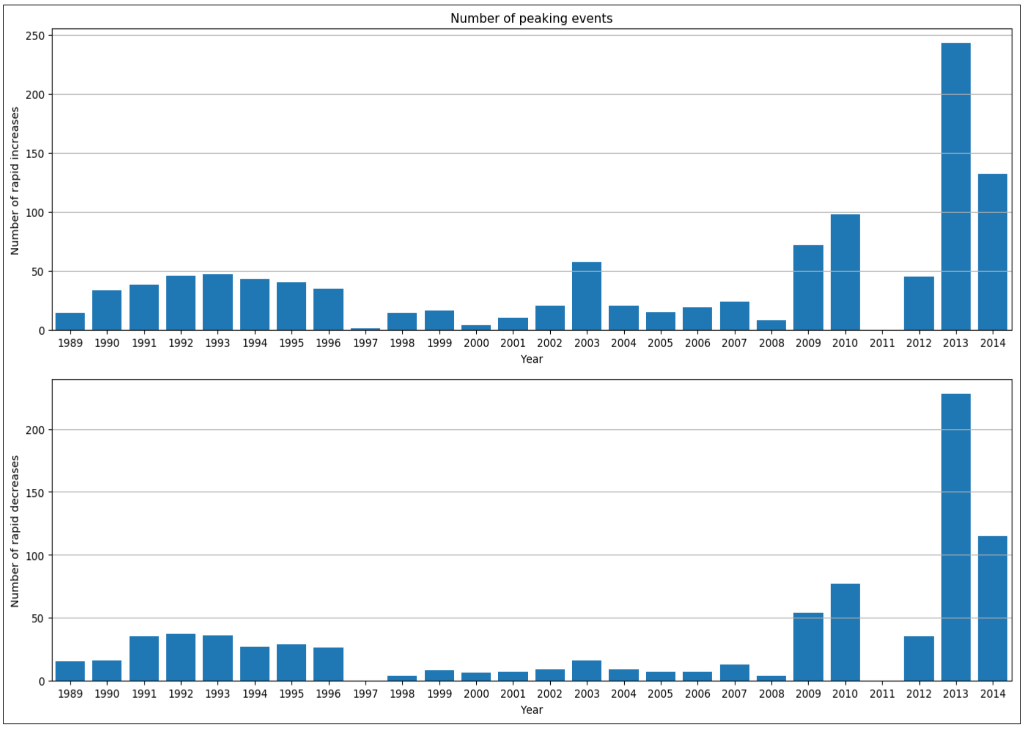

Figure 76. Kongsfjordfoss. Number of peaks per year– Water level

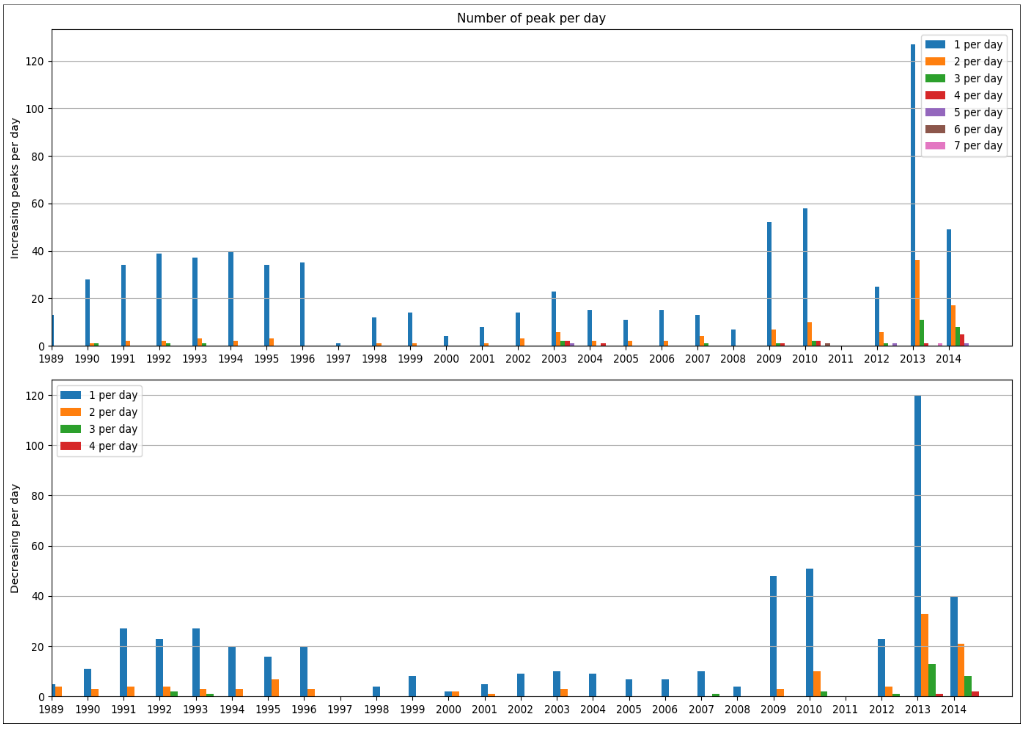

Figure 77. Kongsfjordfoss. Number of peaks per day– Water level

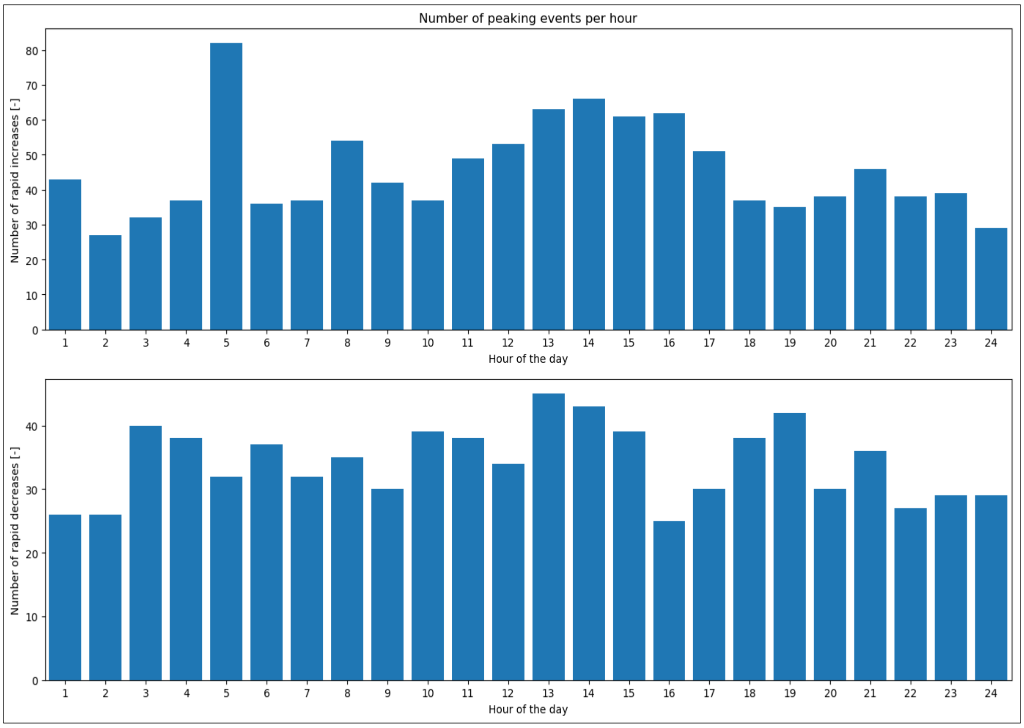

Figure 78. Kongsfjordfoss. Number of peaks per hour– Water level

1.14 KULSET BRU

1.14.1 Discharge

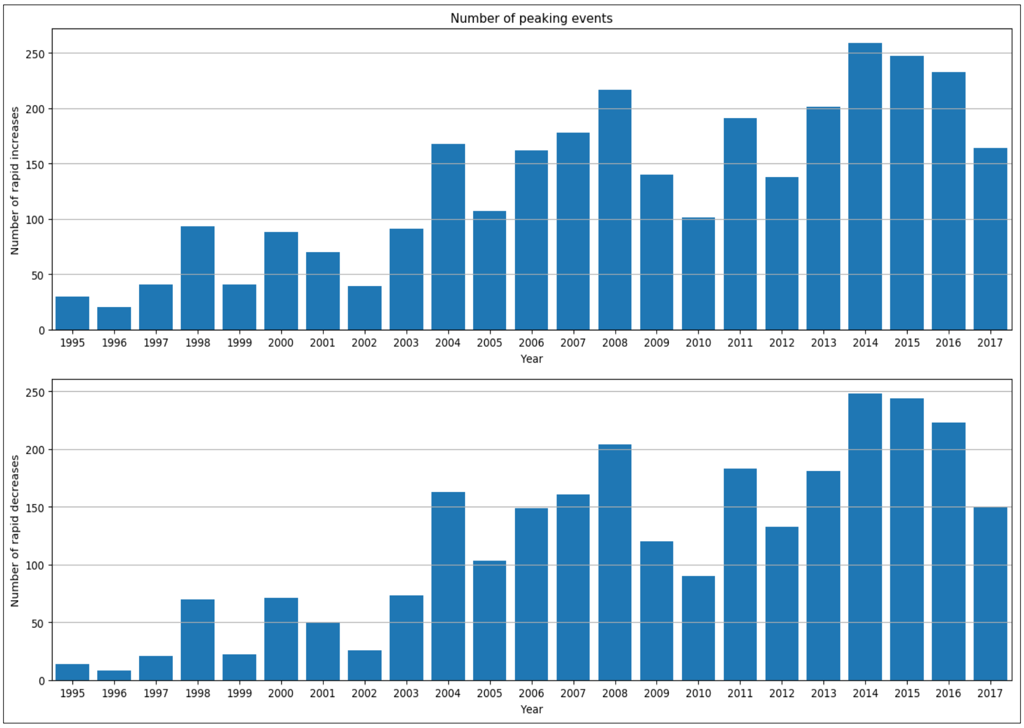

Figure 79. Kulset Bru. Number of peaks per year– Discharge

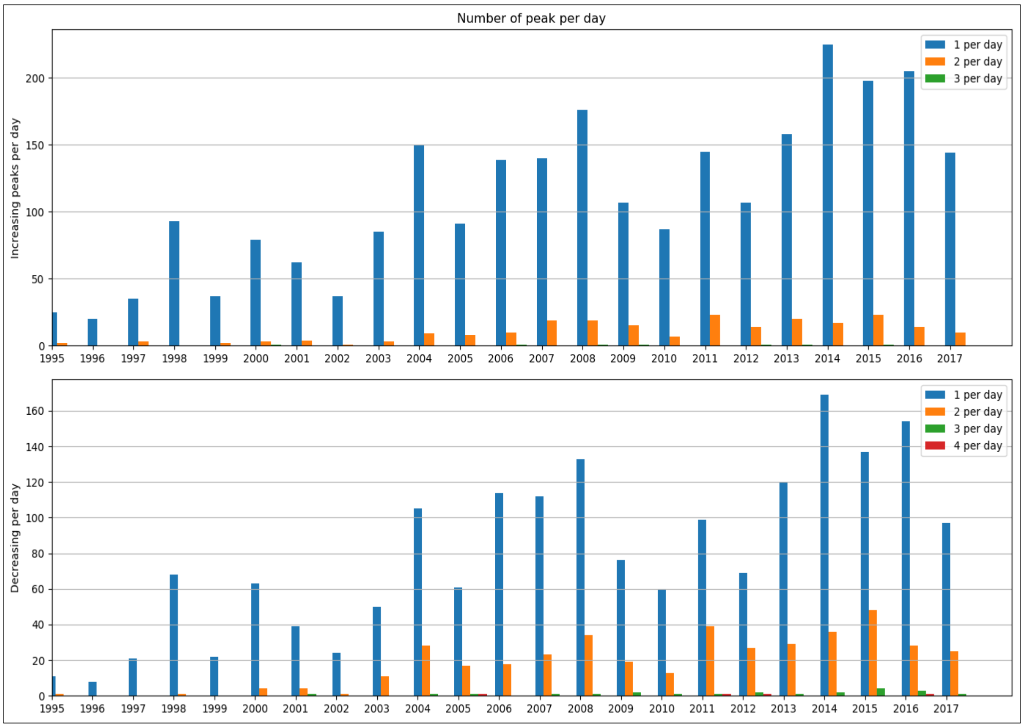

Figure 80. Kulset Bru. Number of peaks per day– Discharge

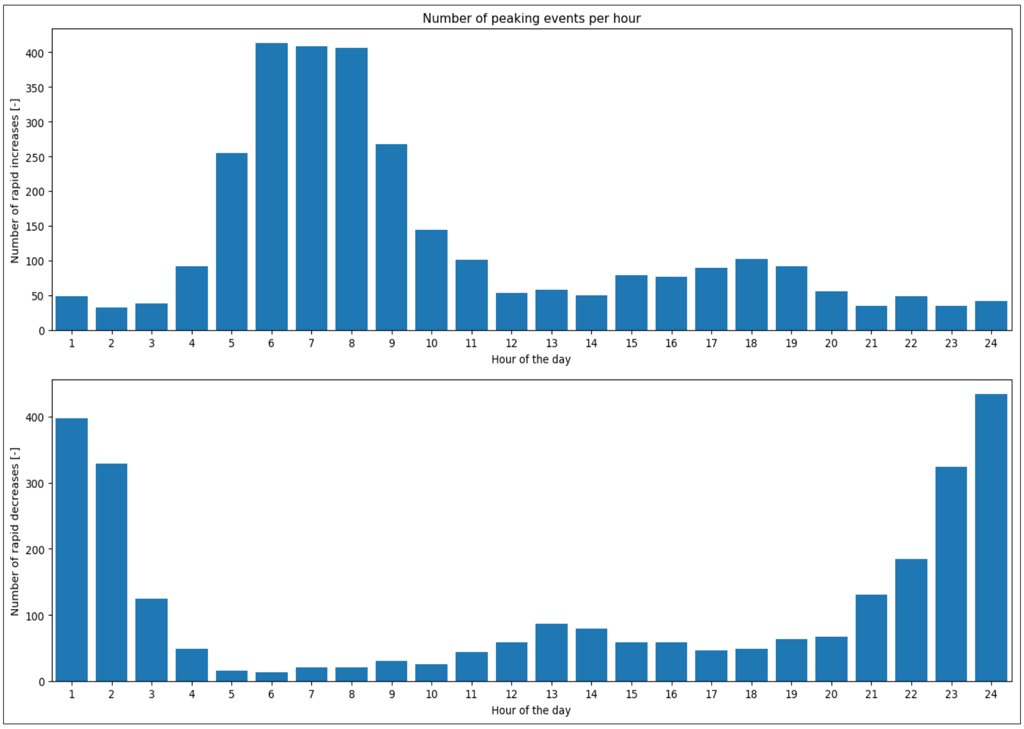

Figure 81. Kulset Bru. Number of peaks per hour– Discharge

1.14.2 Water level

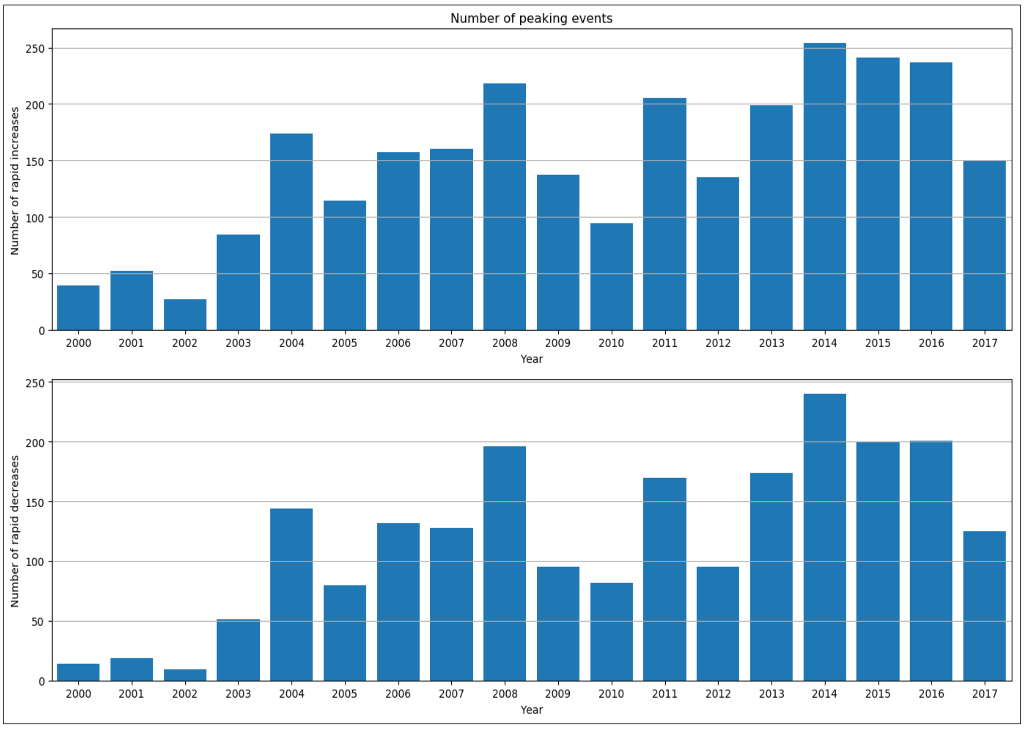

Figure 82. Kulset Bru. Number of peaks per year– Water level

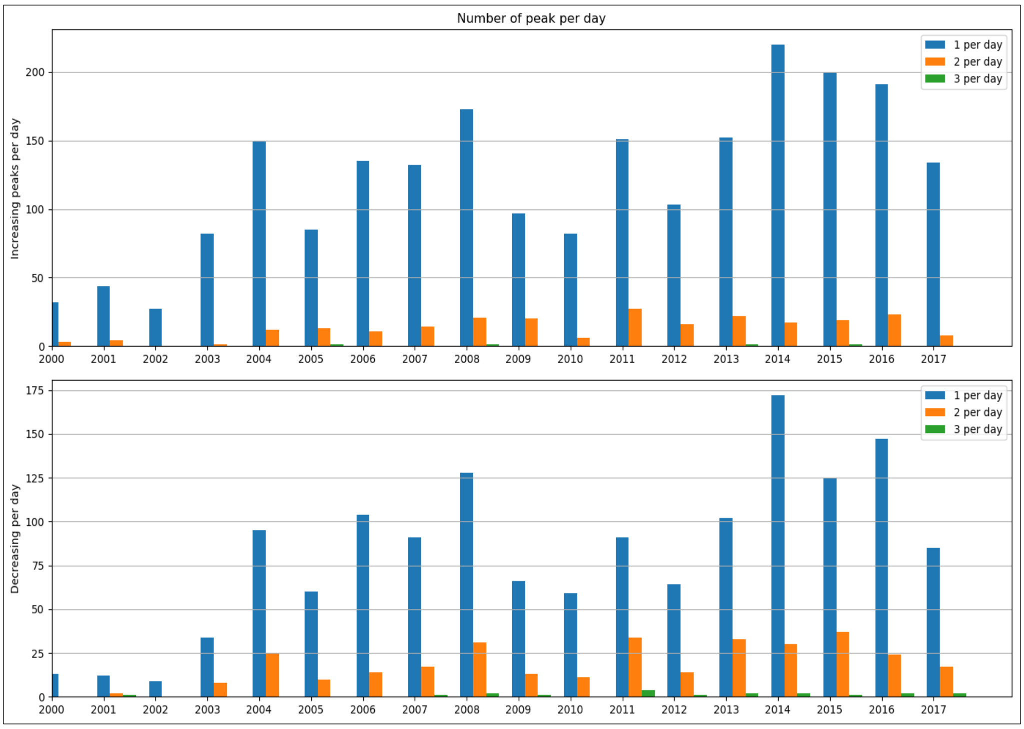

Figure 83. Kulset Bru. Number of peaks per day– Water level

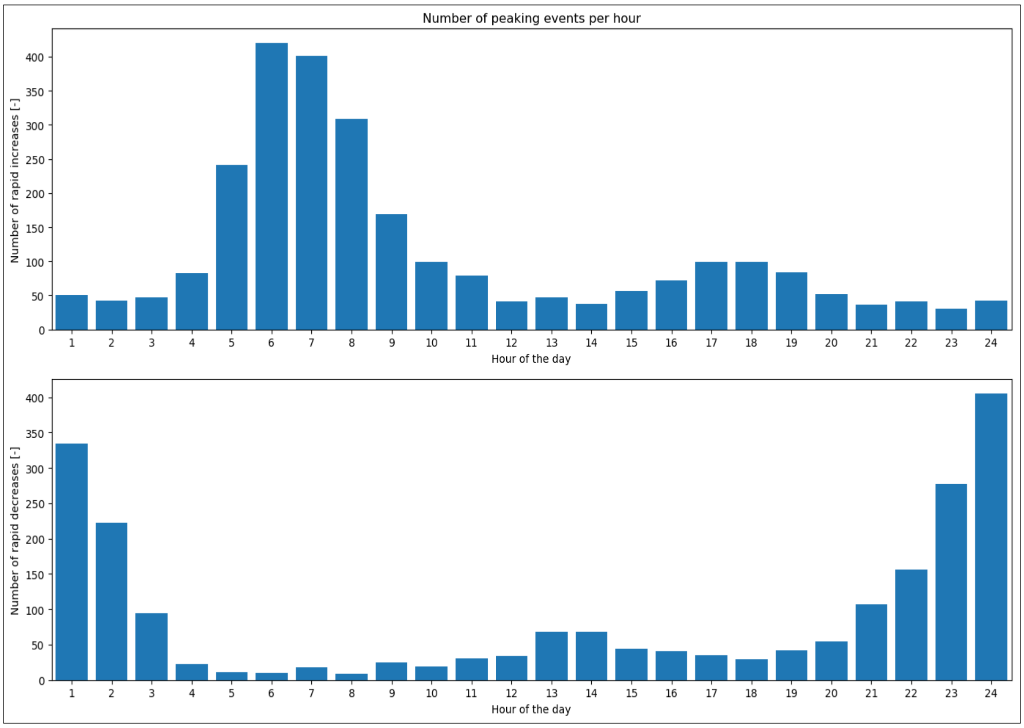

Figure 84. Kulset Bru. Number of peaks per hour– Water level

1.15 LAUDAL

1.15.1 Discharge

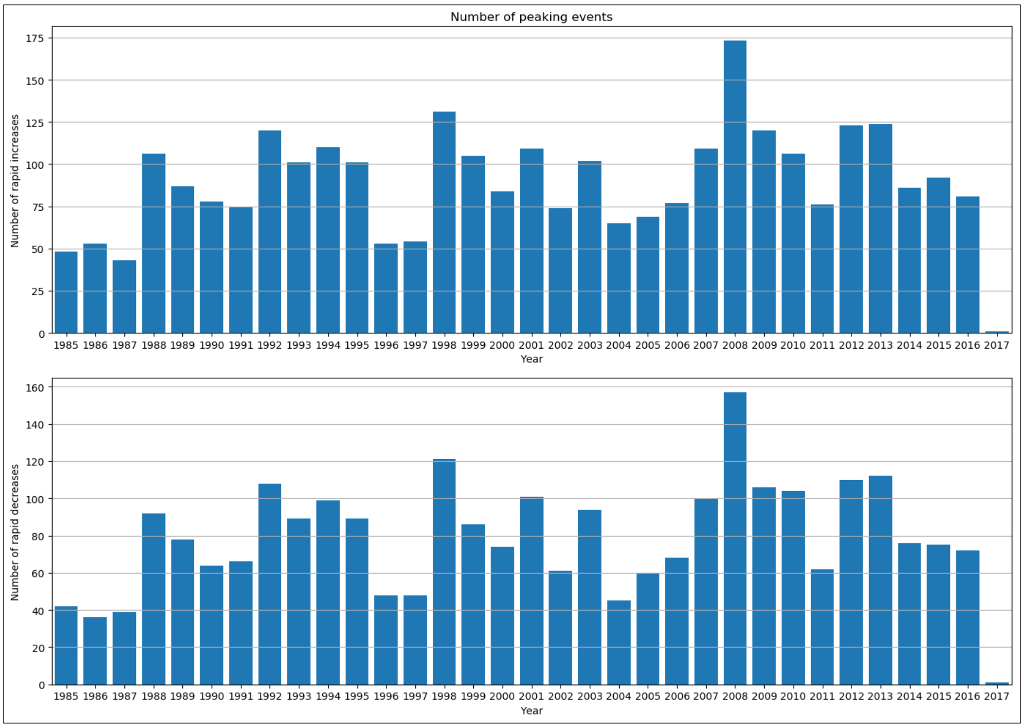

Figure 85. Laudal. Number of peaks per year– Discharge

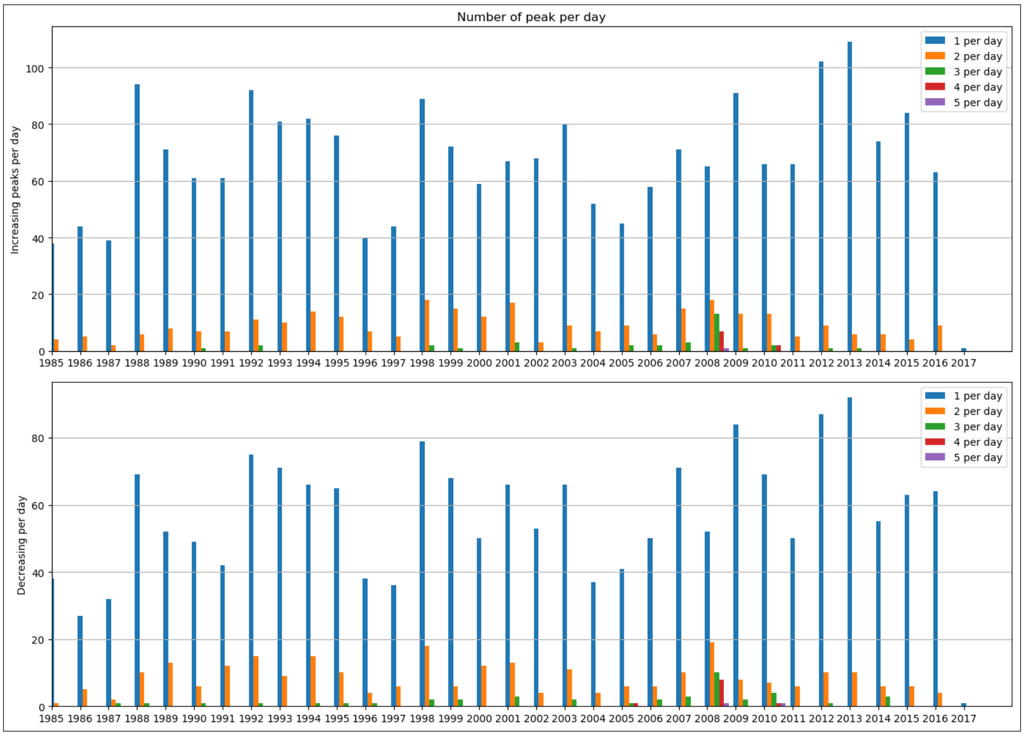

Figure 86. Laudal. Number of peaks per day– Discharge

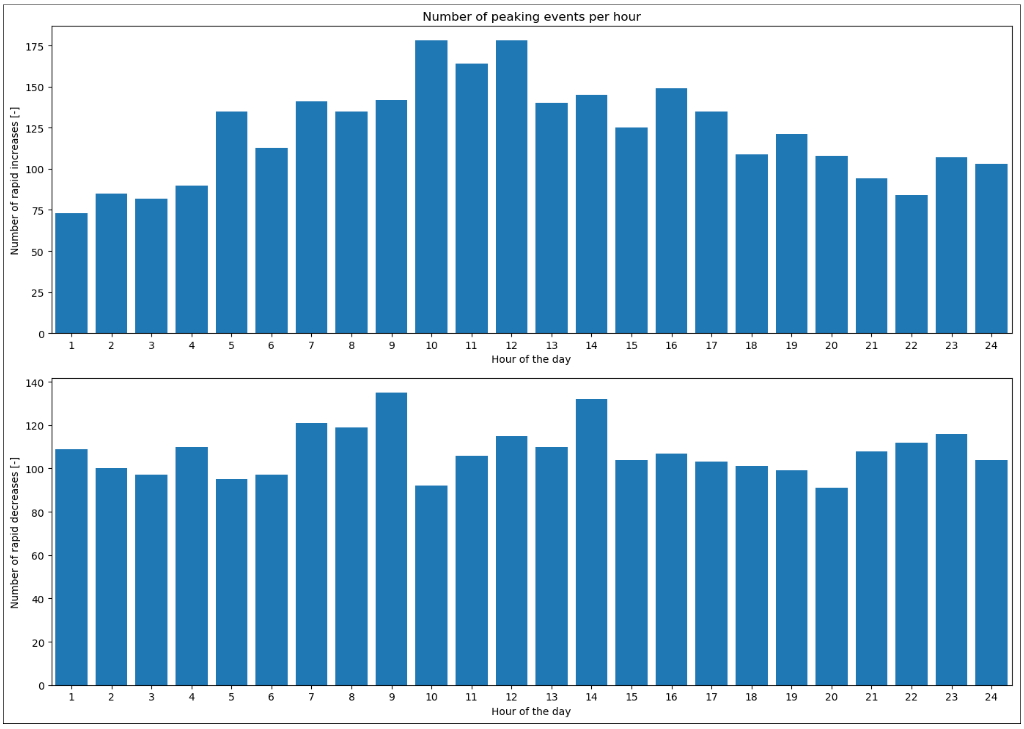

Figure 87. Laudal. Number of peaks per hour– Discharge

1.15.2 Water level

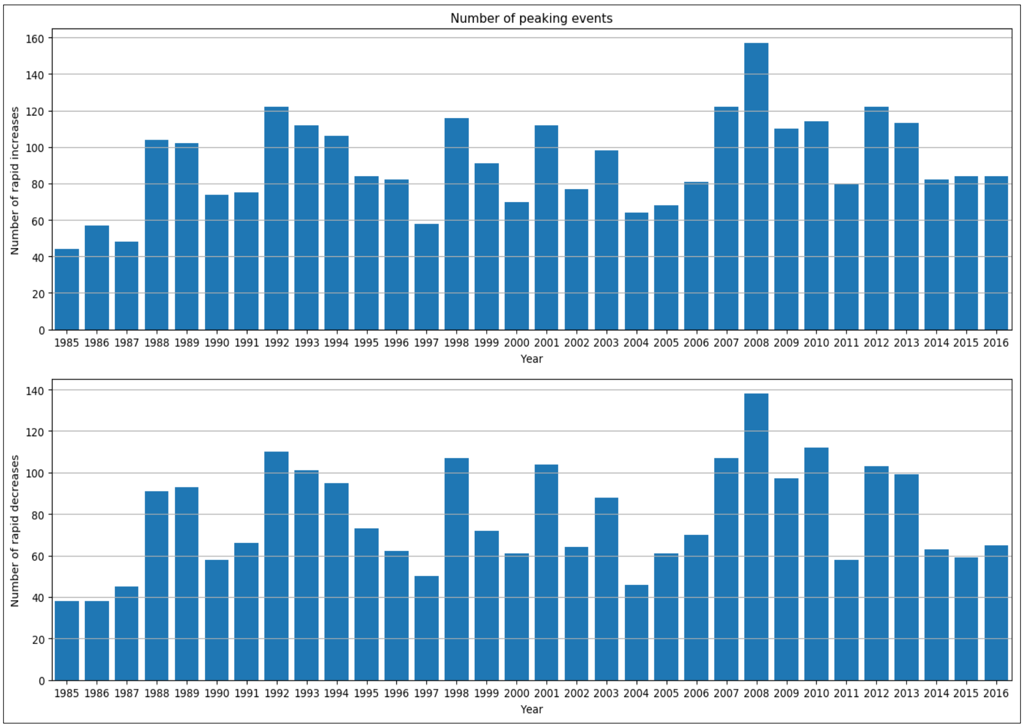

Figure 88. Laudal. Number of peaks per year– Water level

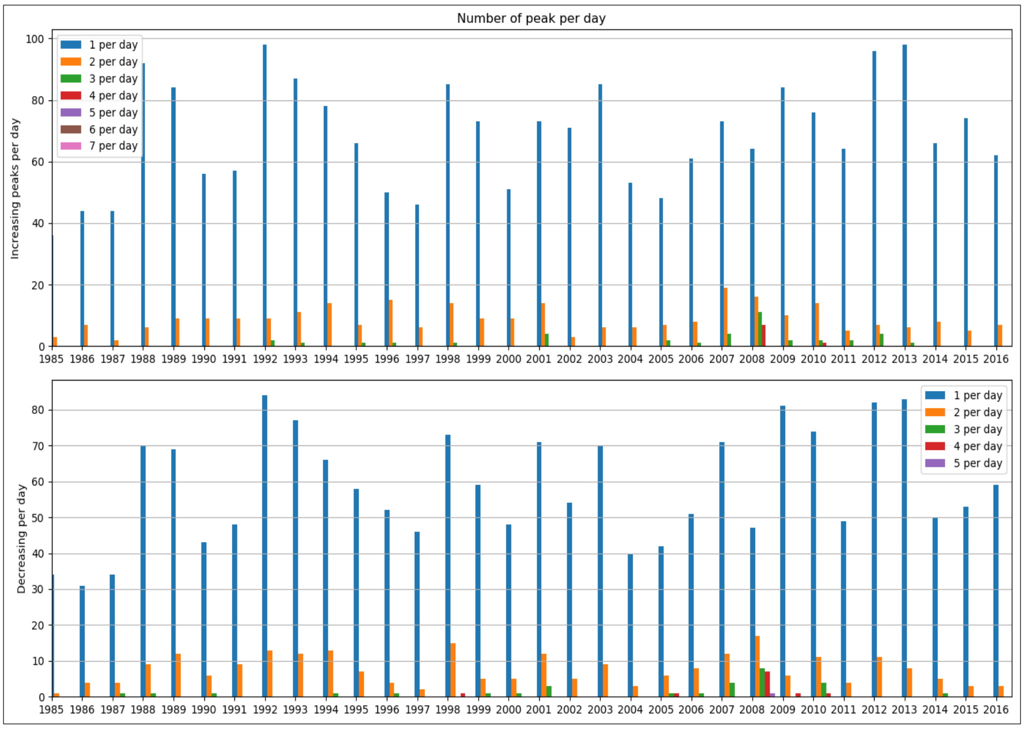

Figure 89. . Laudal. Number of peaks per day– Water level

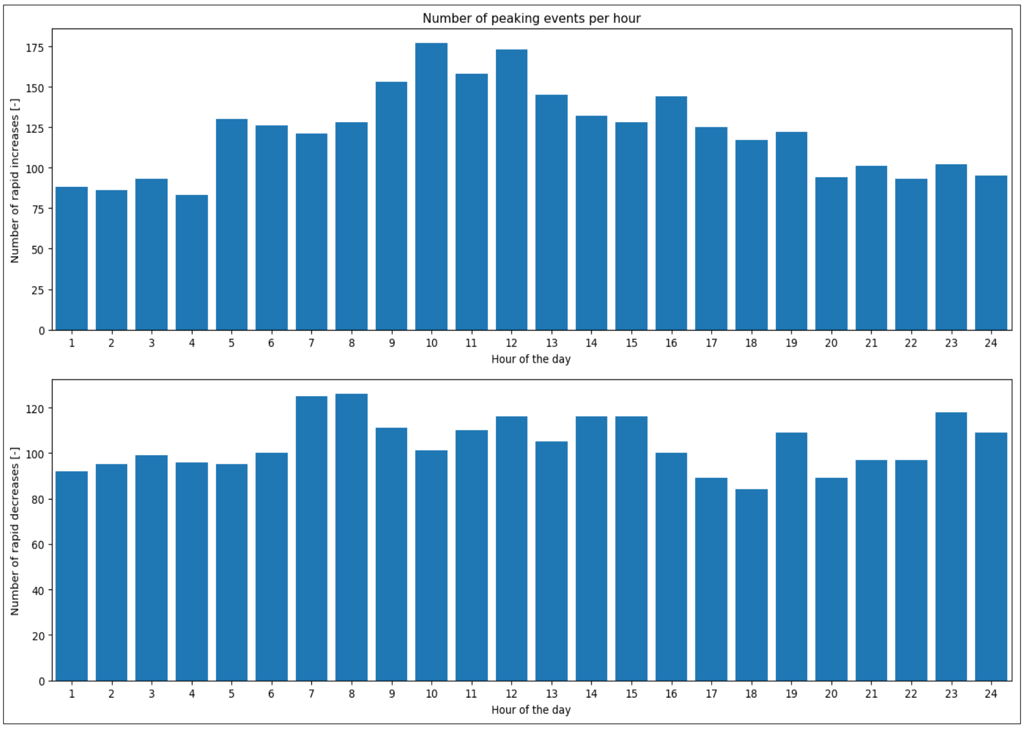

Figure 90. . Laudal. Number of peaks per hour– Water level

1.16 LÅVISBRUA

1.16.1 Discharge

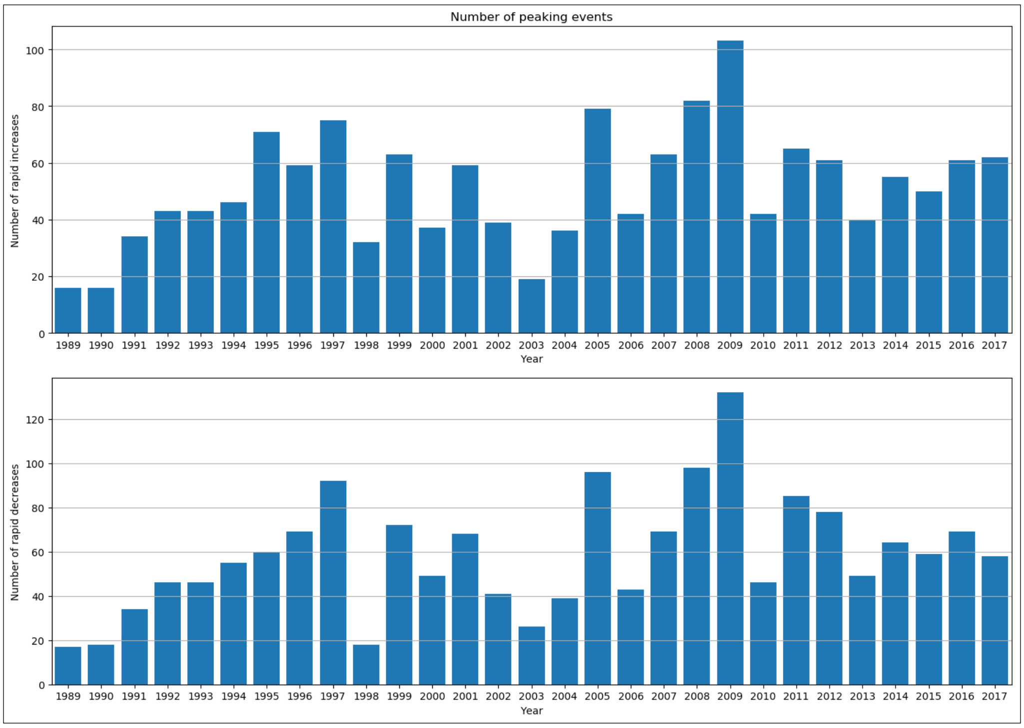

Figure 91. Låvisbrua. Number of peaks per year– Discharge

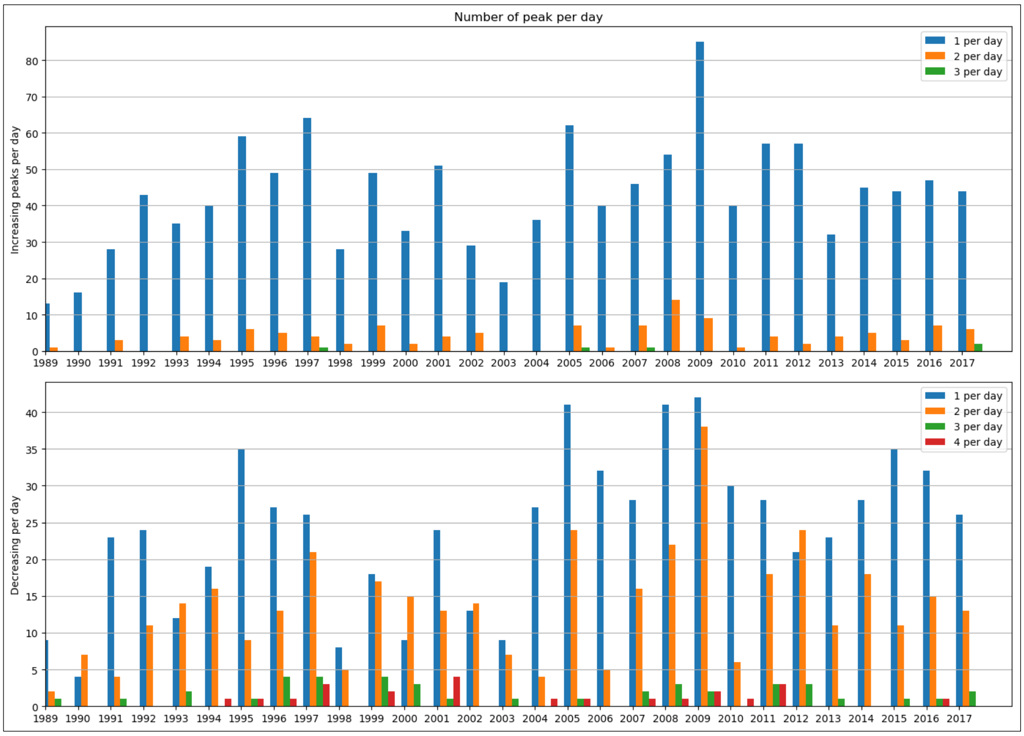

Figure 92. . Låvisbrua. Number of peaks per day– Discharge

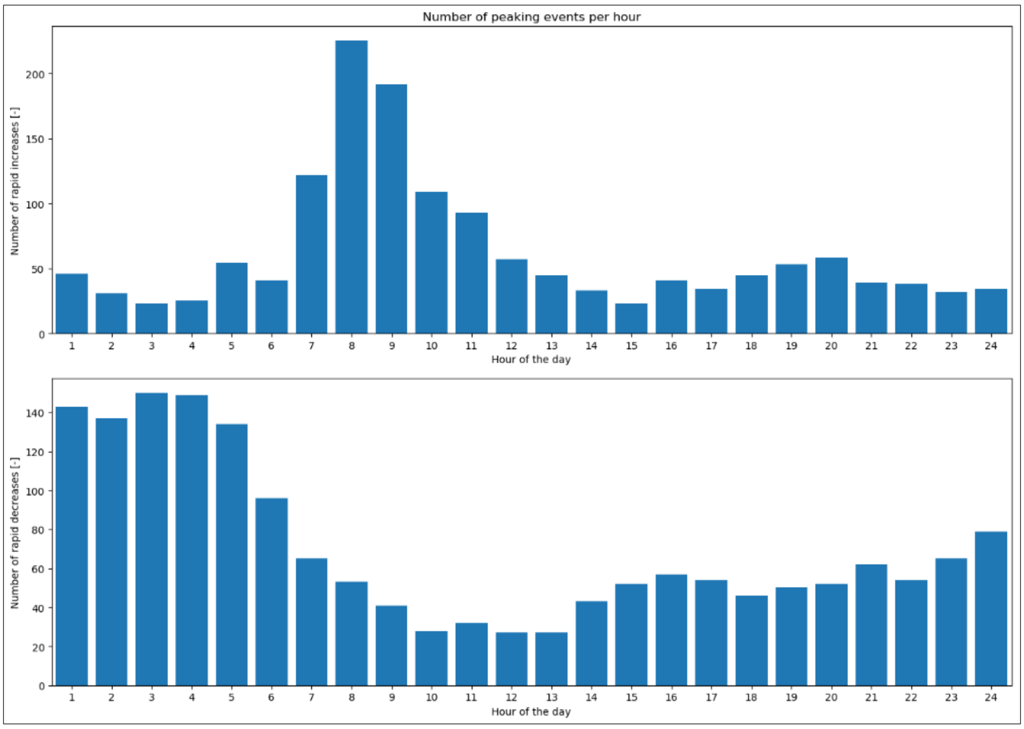

Figure 93. Låvisbrua. Number of peaks per hour– Discharge

1.16.2 Water level

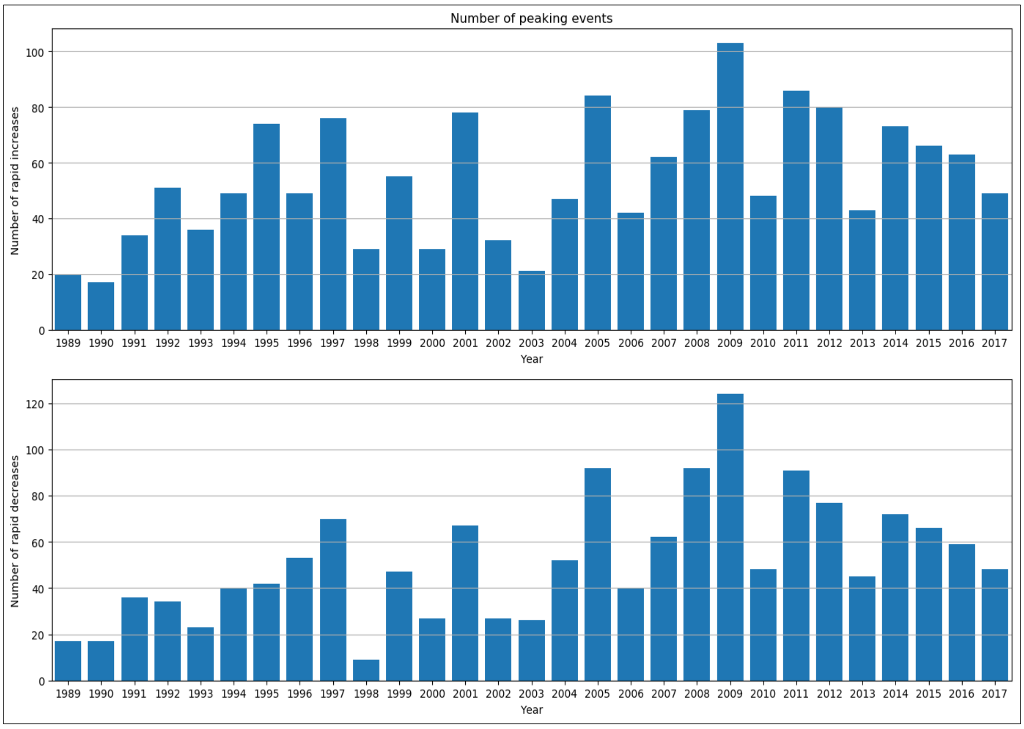

Figure 94. Låvisbrua. Number of peaks per year– Water level

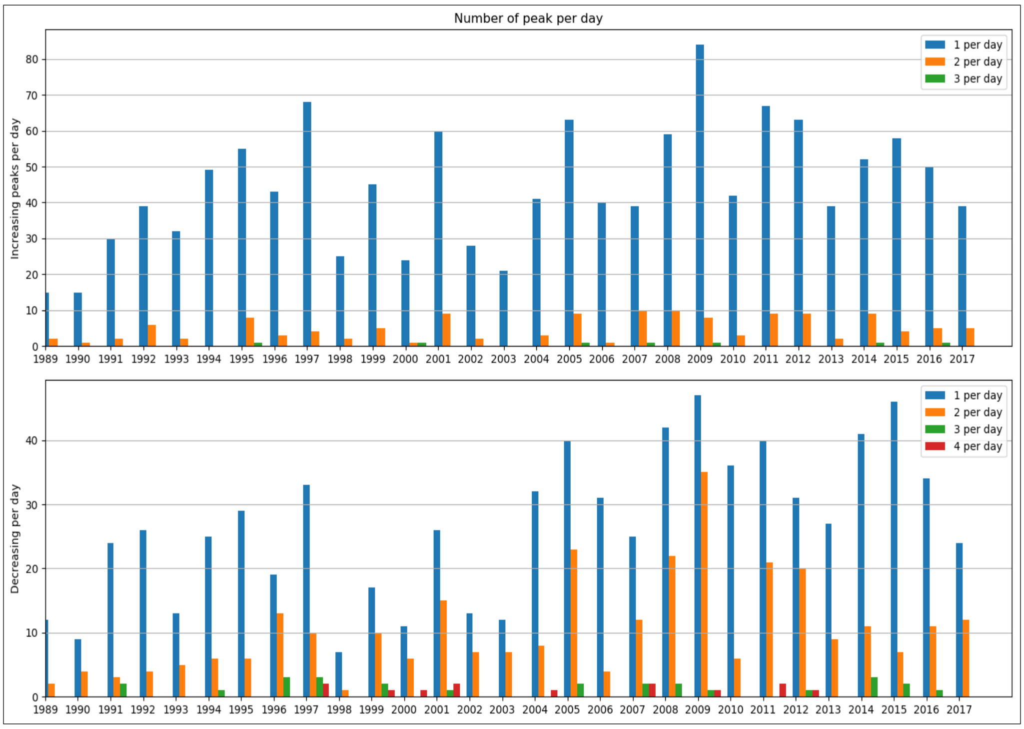

Figure 95. Låvisbrua. Number of peaks per day– Water level

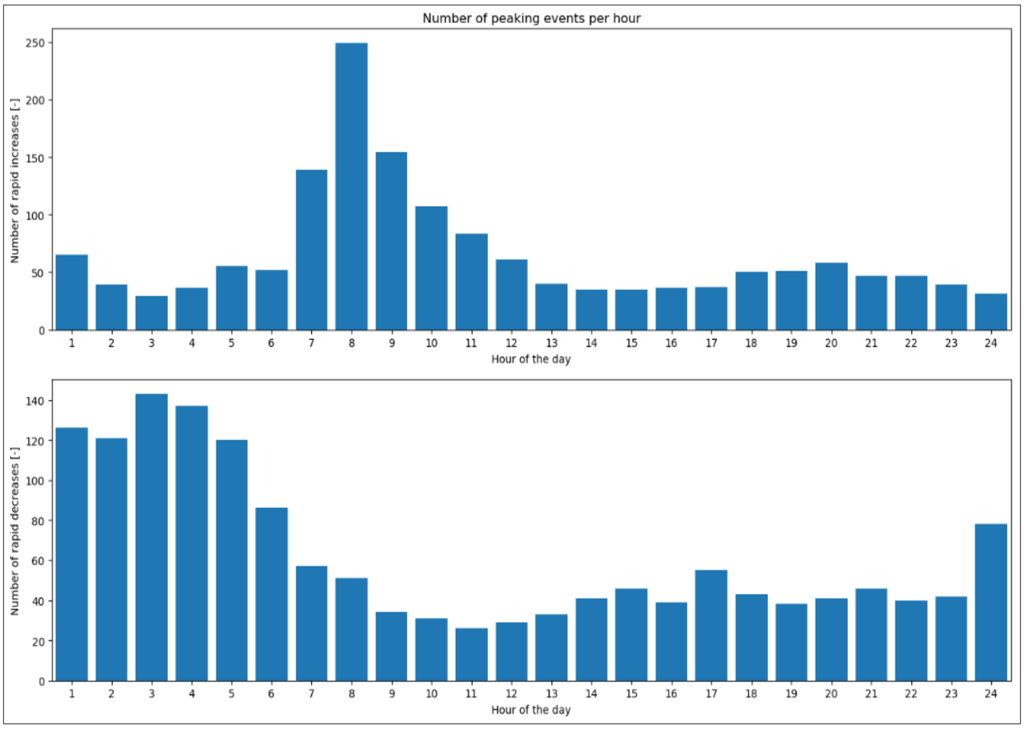

Figure 96. Låvisbrua. Number of peaks per hour– Water level

1.17 MERÅKER

1.17.1 Discharge

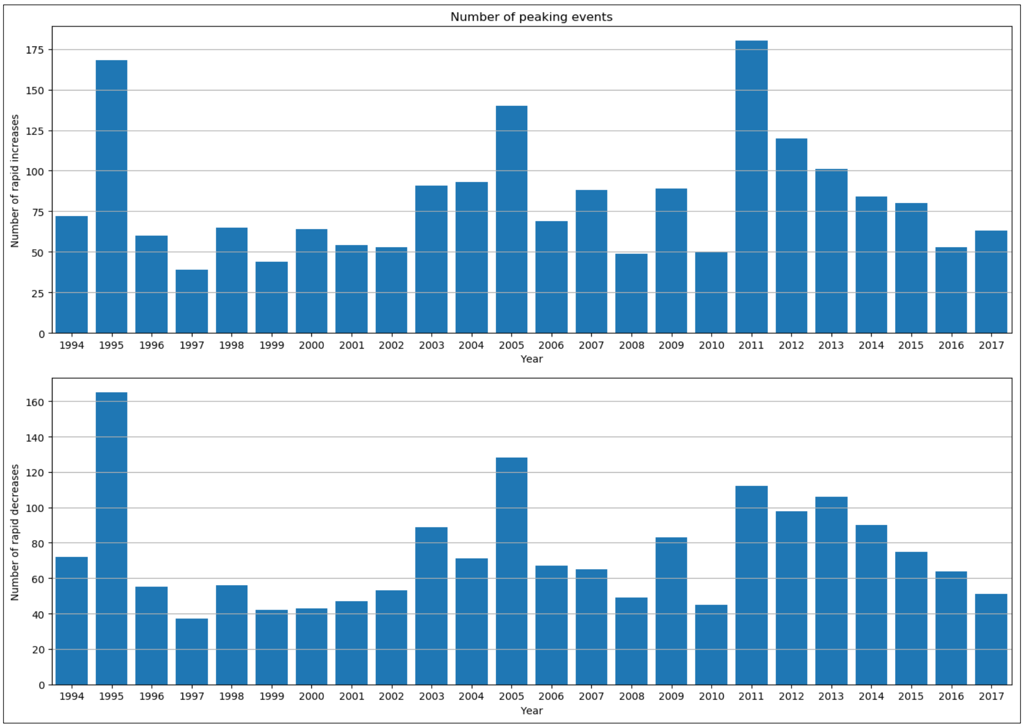

Figure 97. Meråker. Number of peaks per year– Discharge

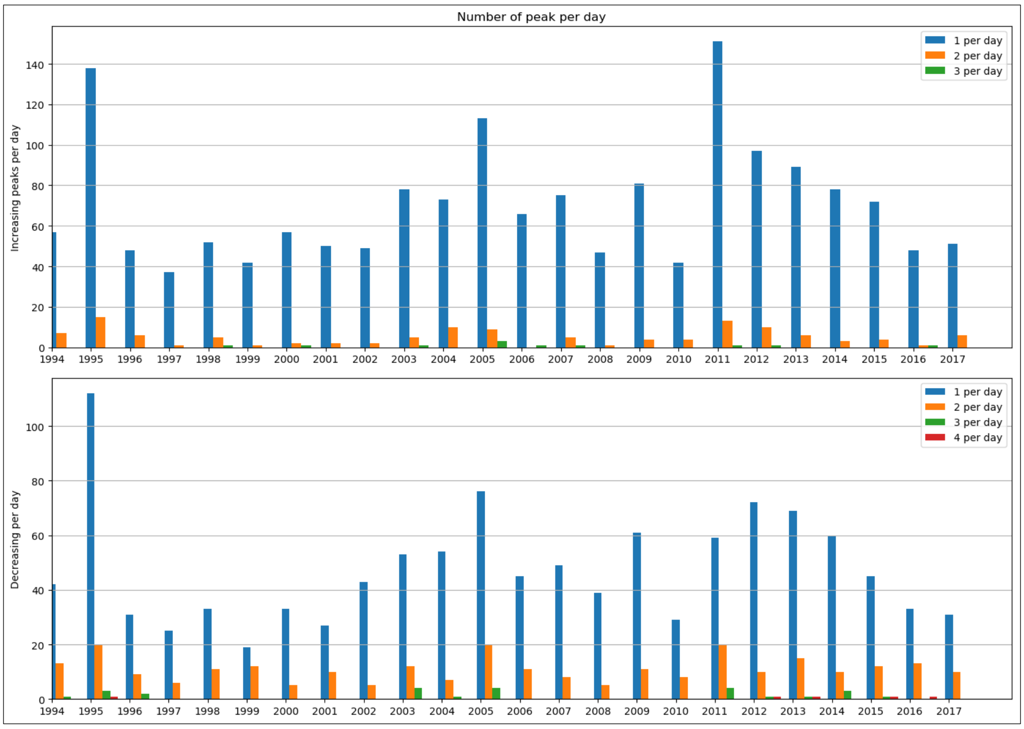

Figure 98. Meråker. Number of peaks per day– Discharge

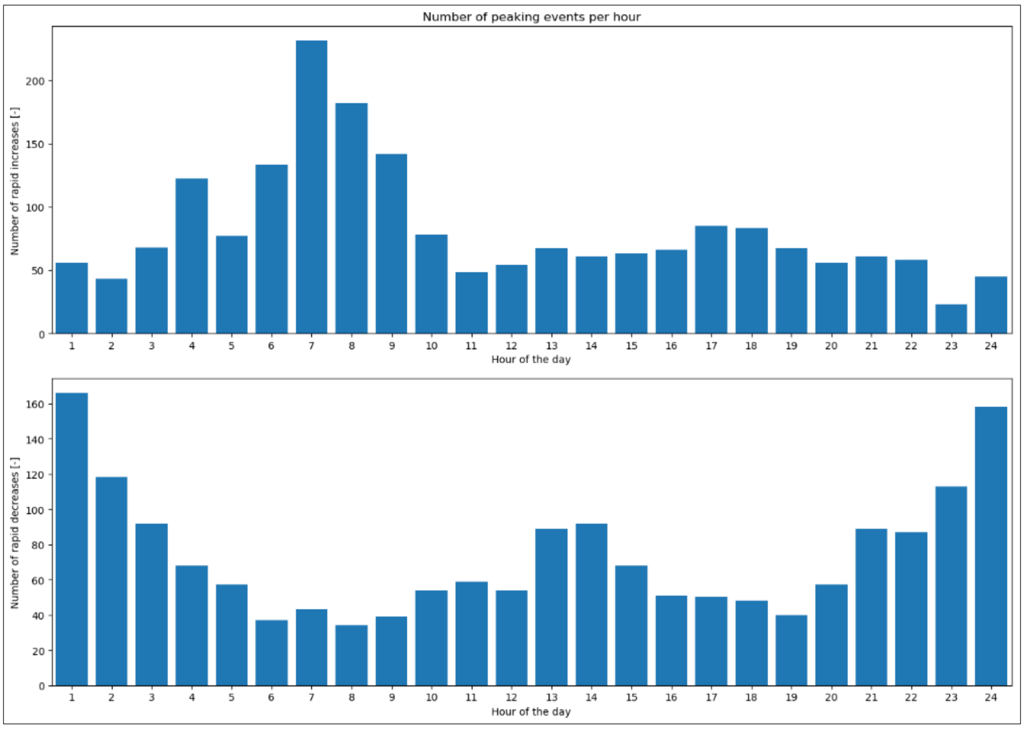

Figure 99. Meråker. Number of peaks per hour– Discharge

1.17.2 Water level

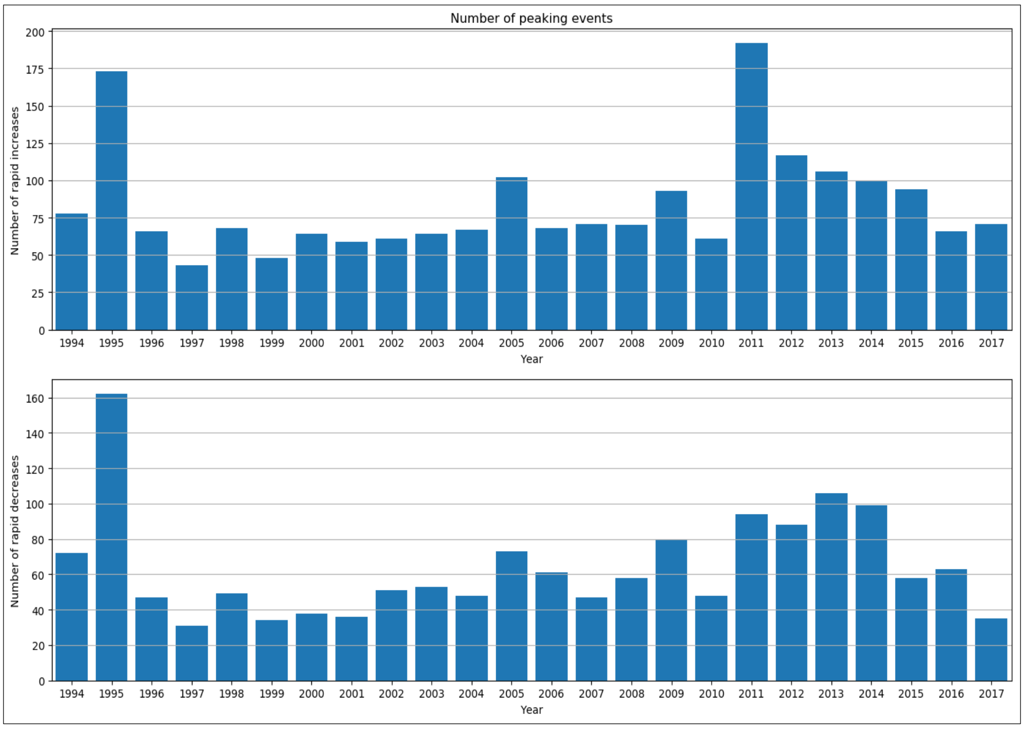

Figure 100. Meråker. Number of peaks per year – Water level

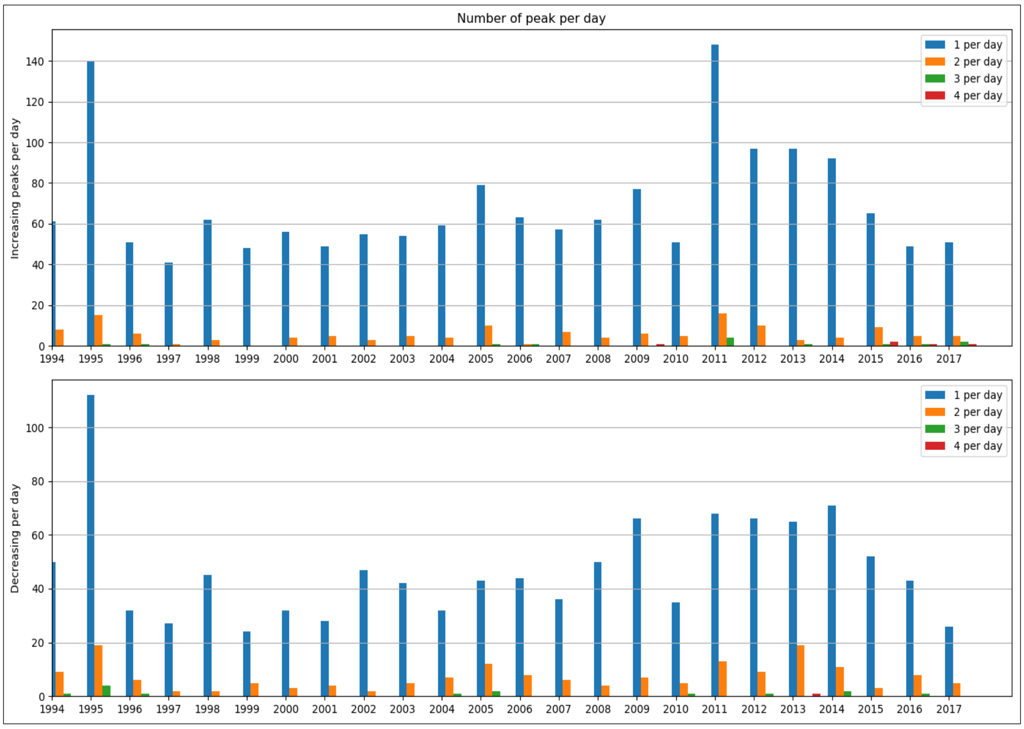

Figure 101. Meråker. Number of peaks per day – Water level

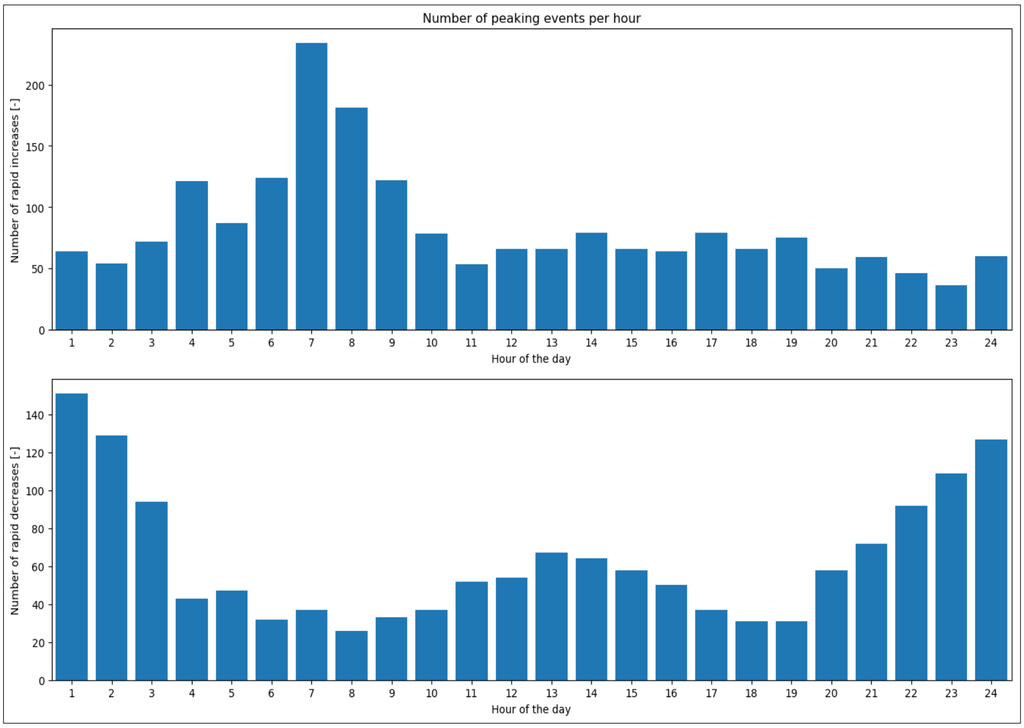

Figure 102. Meråker. Number of peaks per hour – Water level

1.18 RUUD

1.18.1 Discharge

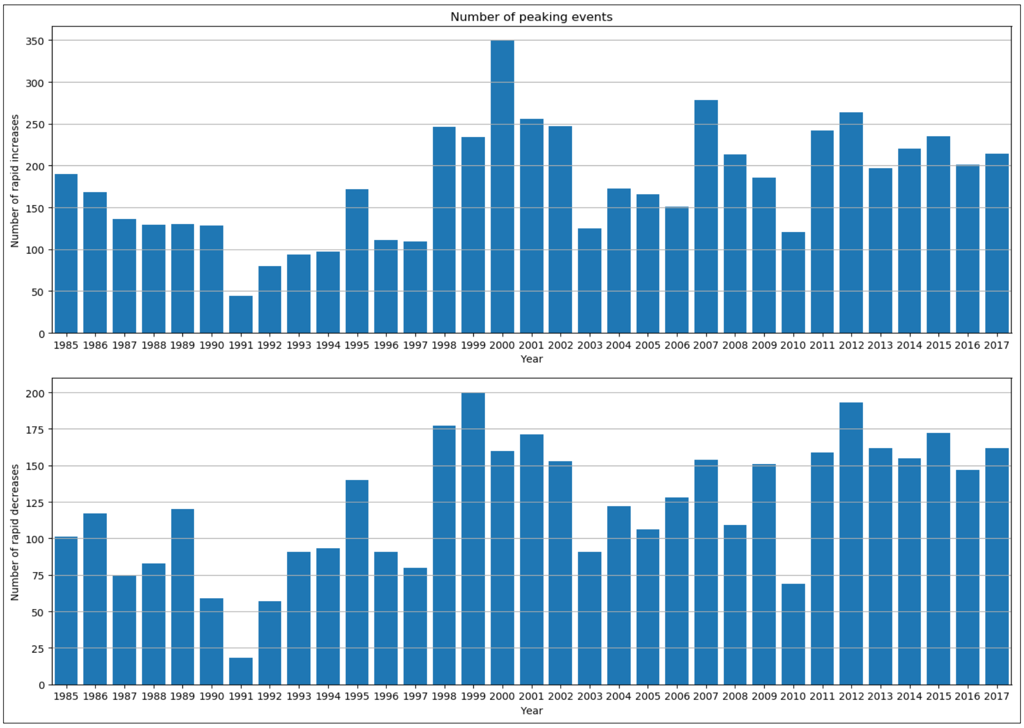

Figure 103. Ruud. Number of peaks per year – Discharge

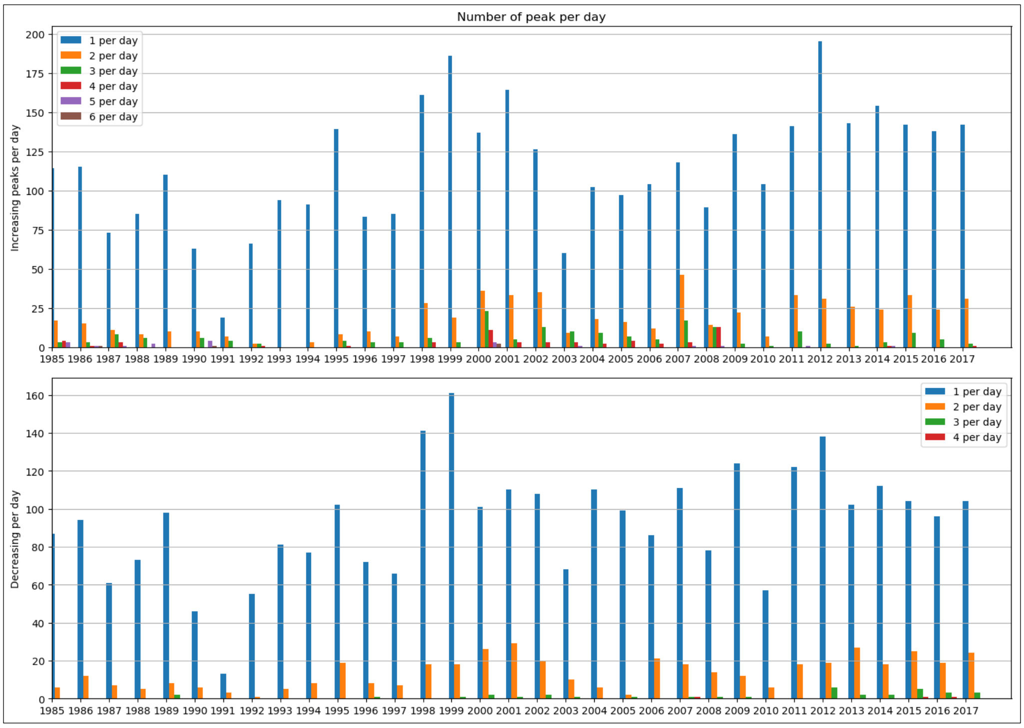

Figure 104. Ruud. Number of peaks per day – Discharge

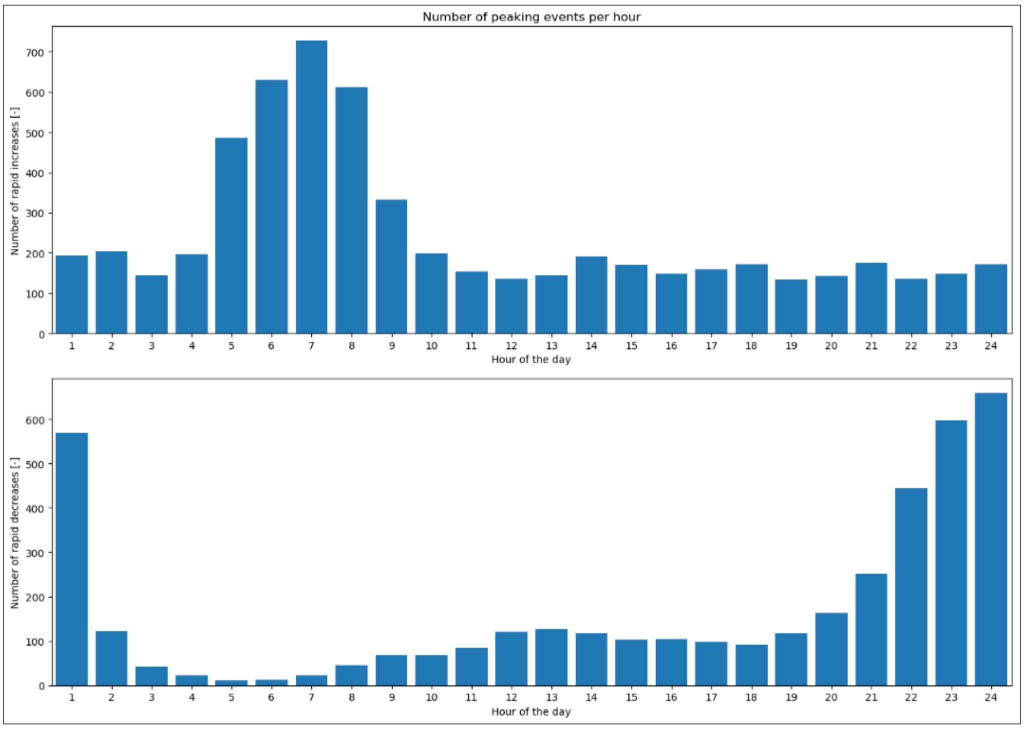

Figure 105. Ruud. Number of peaks per hour – Discharge

1.18.2 Water level

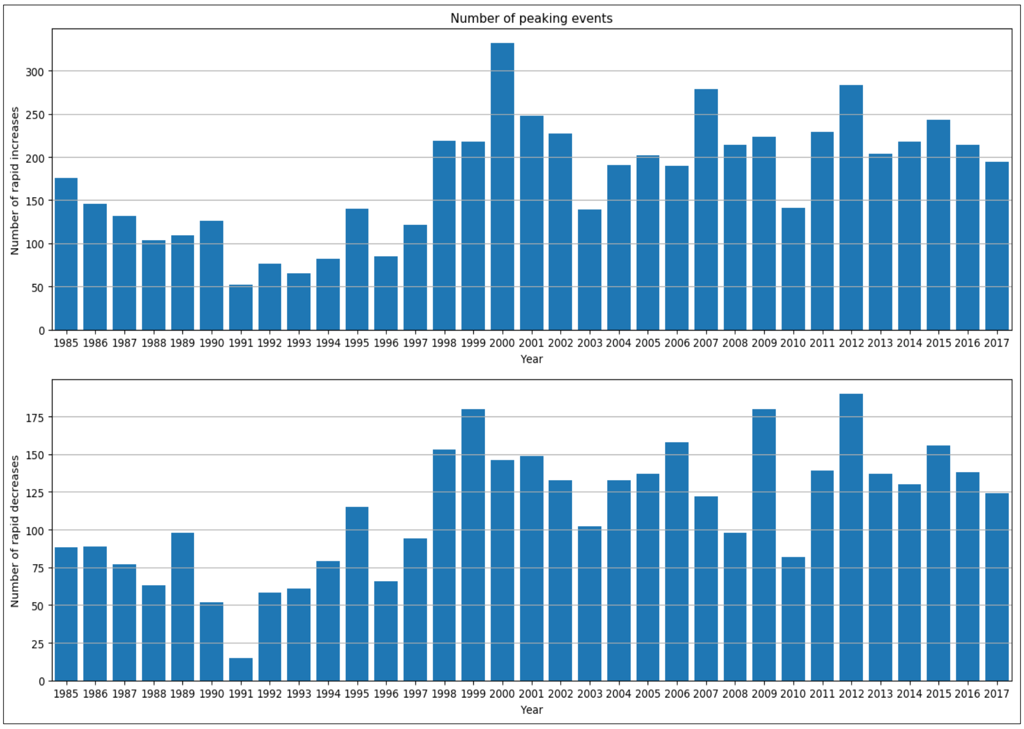

Figure 106. Ruud. Number of peaks per year – Water level

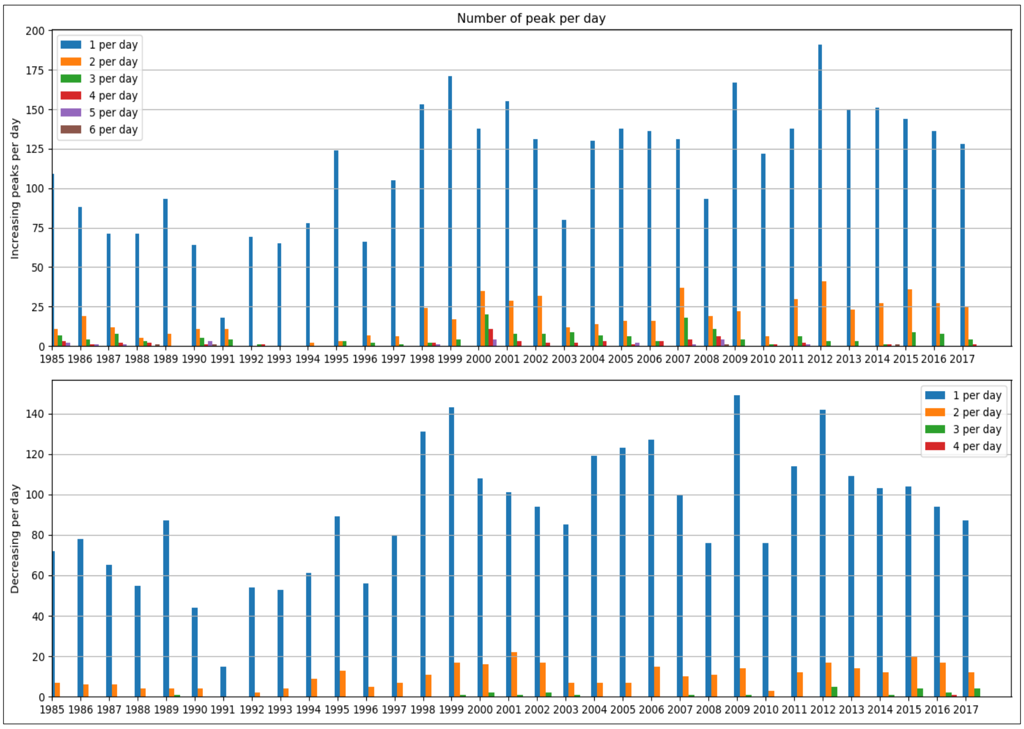

Figure 107. Ruud. Number of peaks per day – Water level

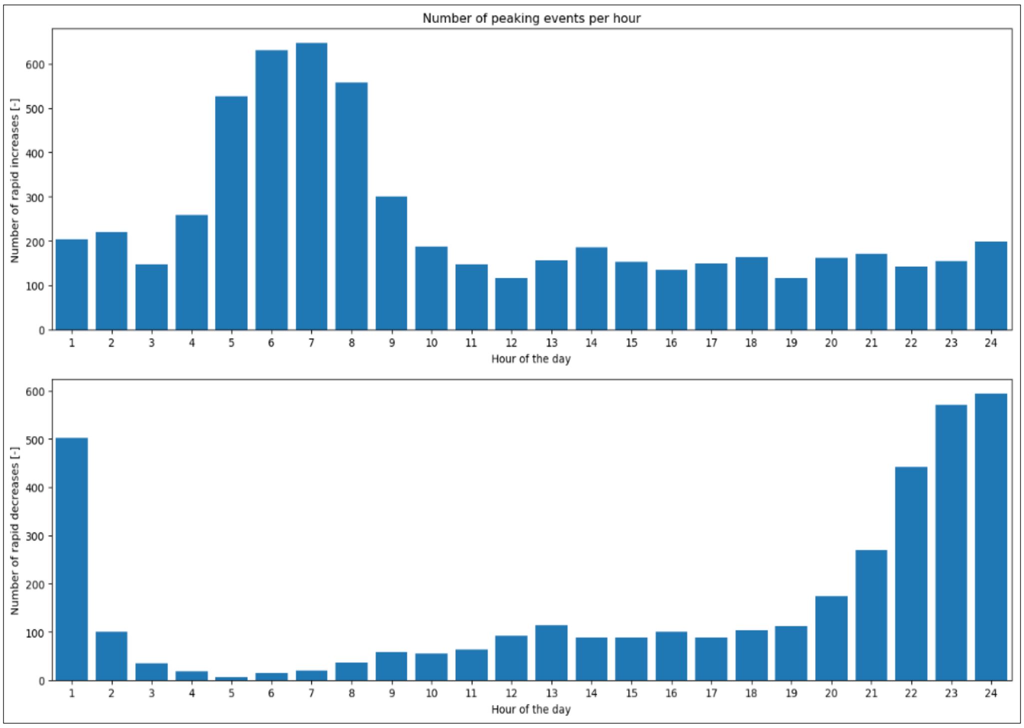

Figure 108. Ruud. Number of peaks per hour – Water level

1.19 SÆLTHUN

1.19.1 Discharge

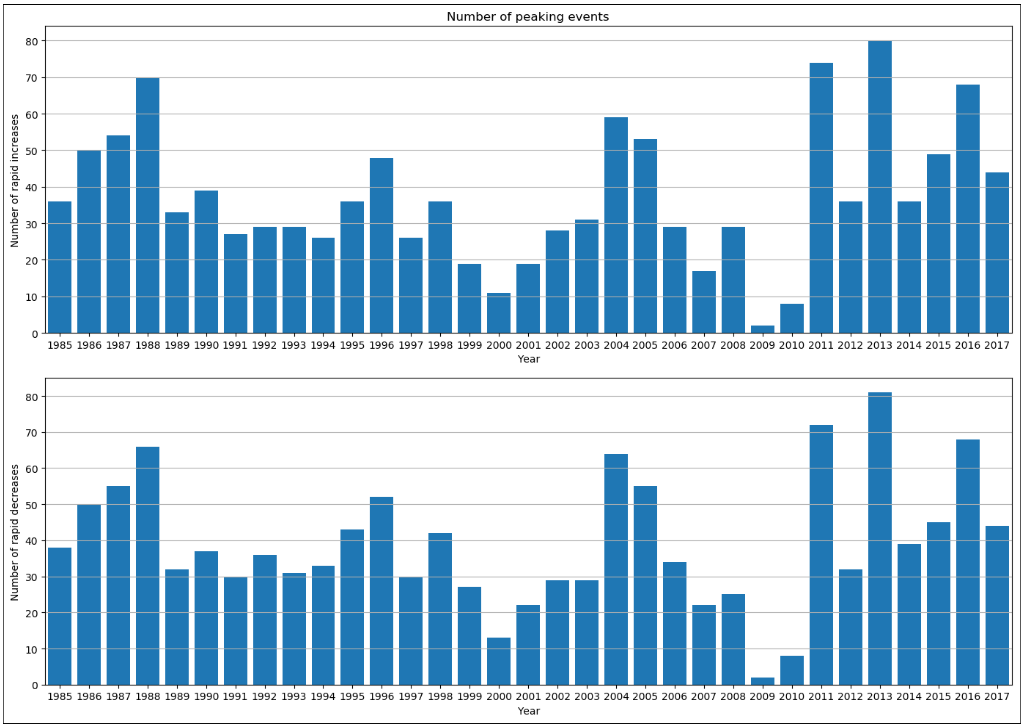

Figure 109. Sælthun. Number of peaks per year – Discharge

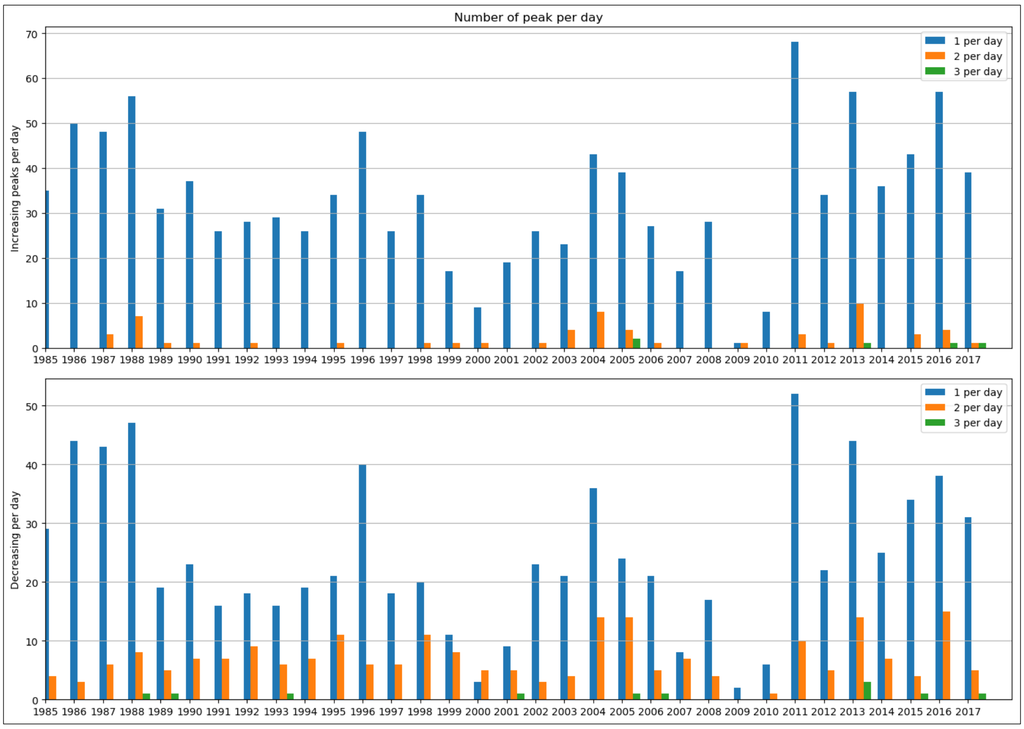

Figure 110. Sælthun. Number of peaks per day – Discharge

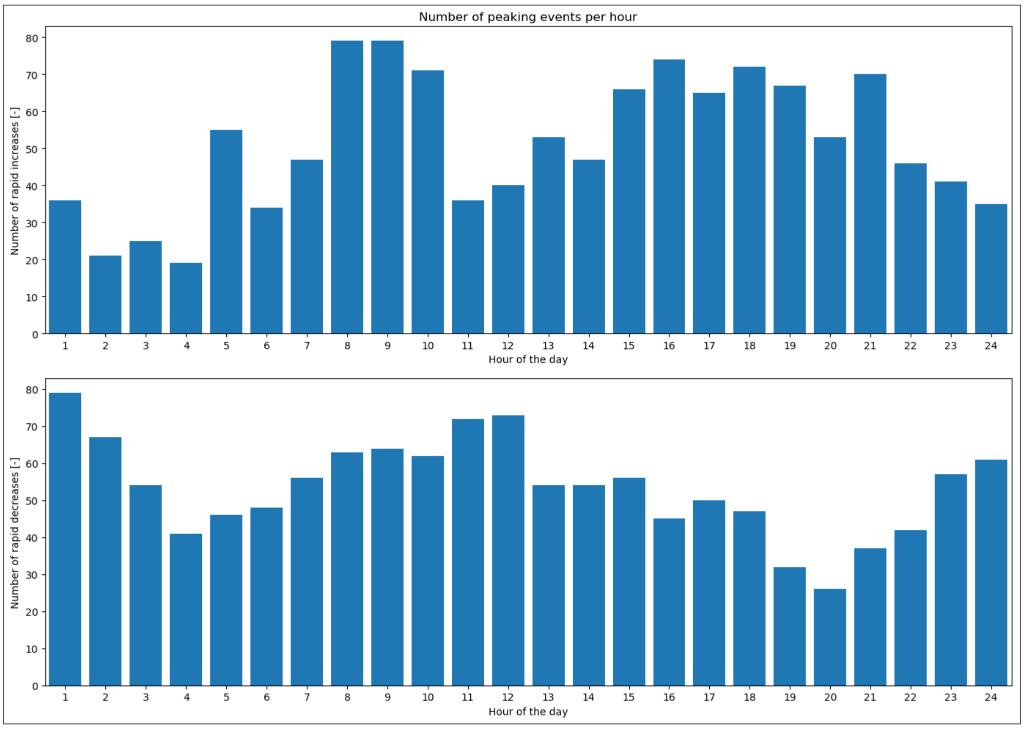

Figure 111. Sælthun. Number of peaks per hour – Discharge

1.19.2 Water level

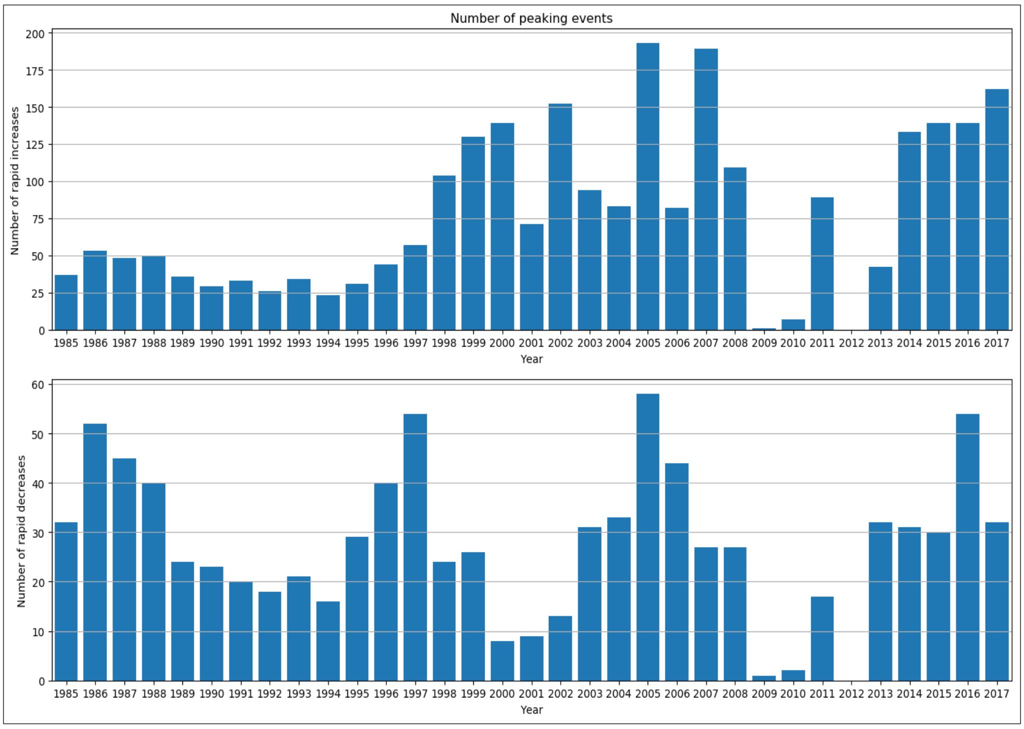

Figure 112. Sælthun. Number of peaks per year – Water level

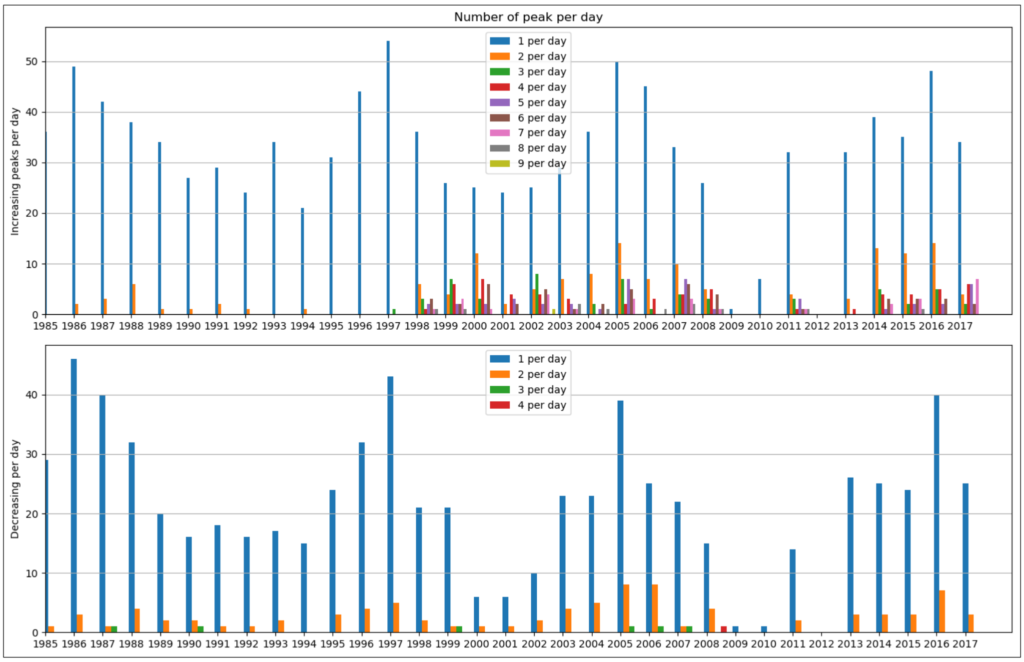

Figure 113. Sælthun. Number of peaks per day – Water level

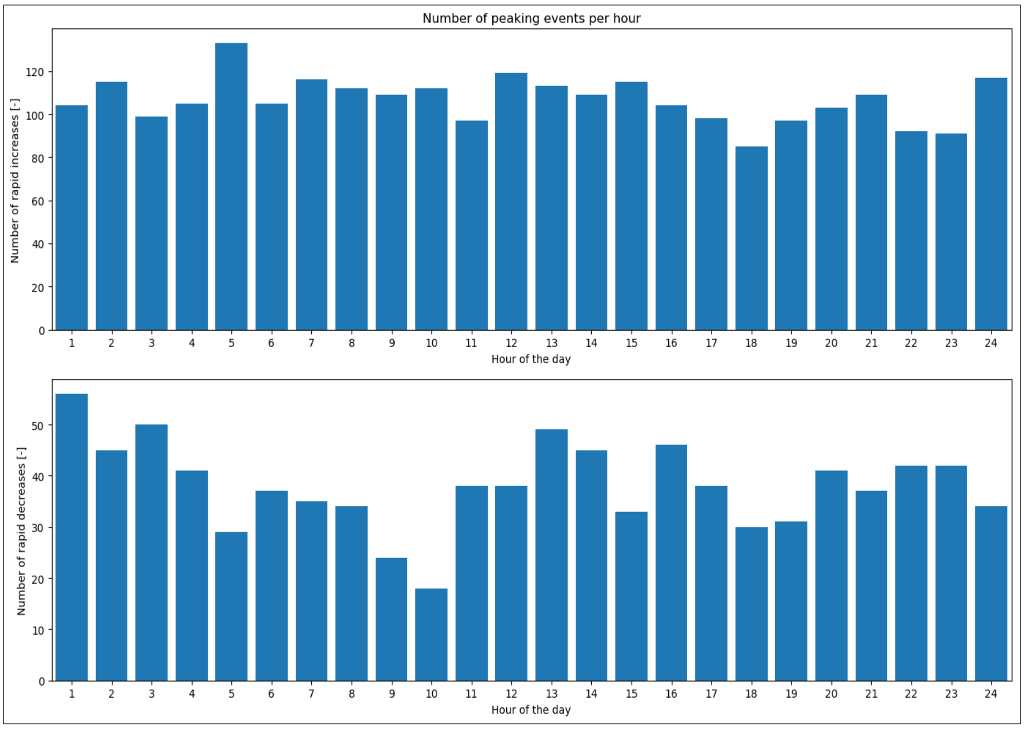

Figure 114. Sælthun. Number of peaks per hour – Water level

1.20 SKIBOTN BRU

1.20.1 Discharge

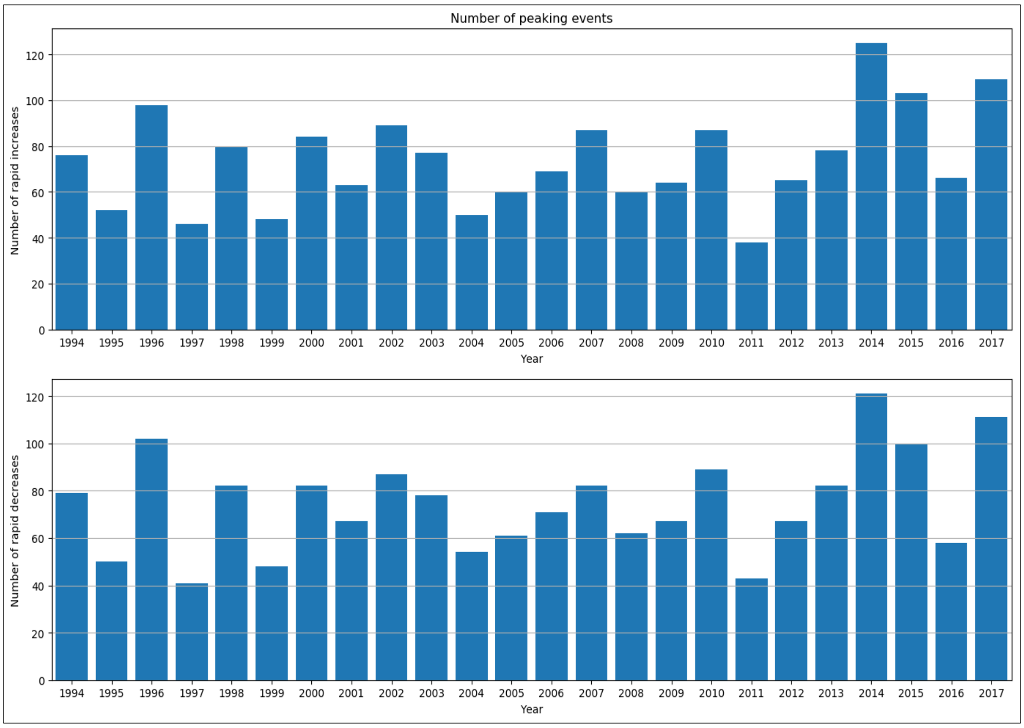

Figure 115. Skibotn bru. Number of peaks per year – Discharge

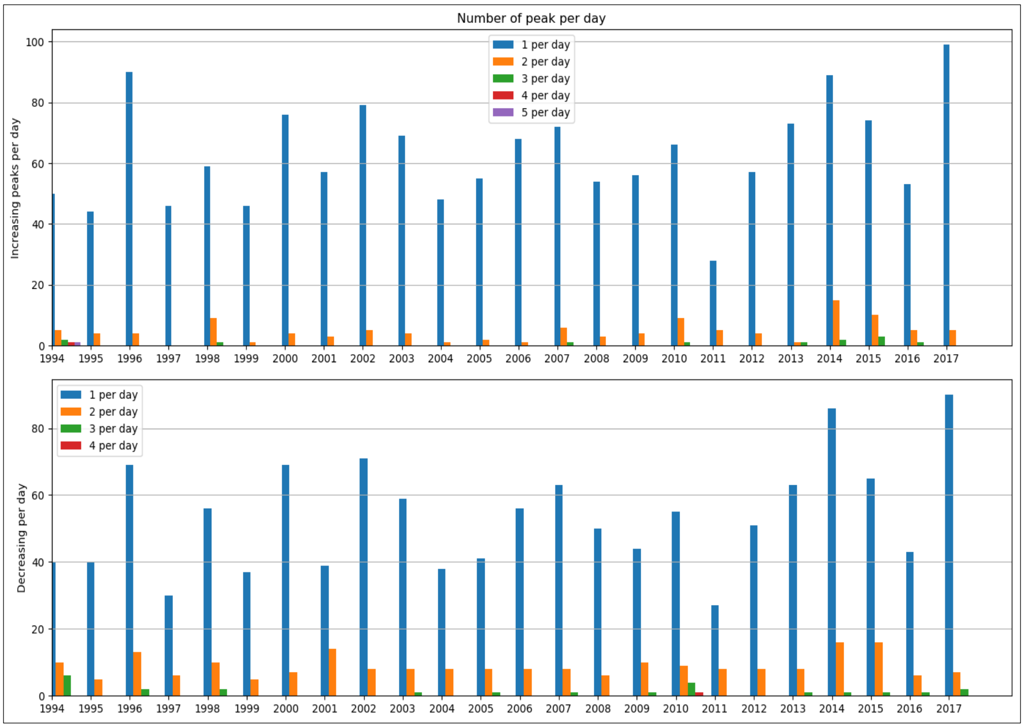

Figure 116. Skibotn bru. Number of peaks per day – Discharge

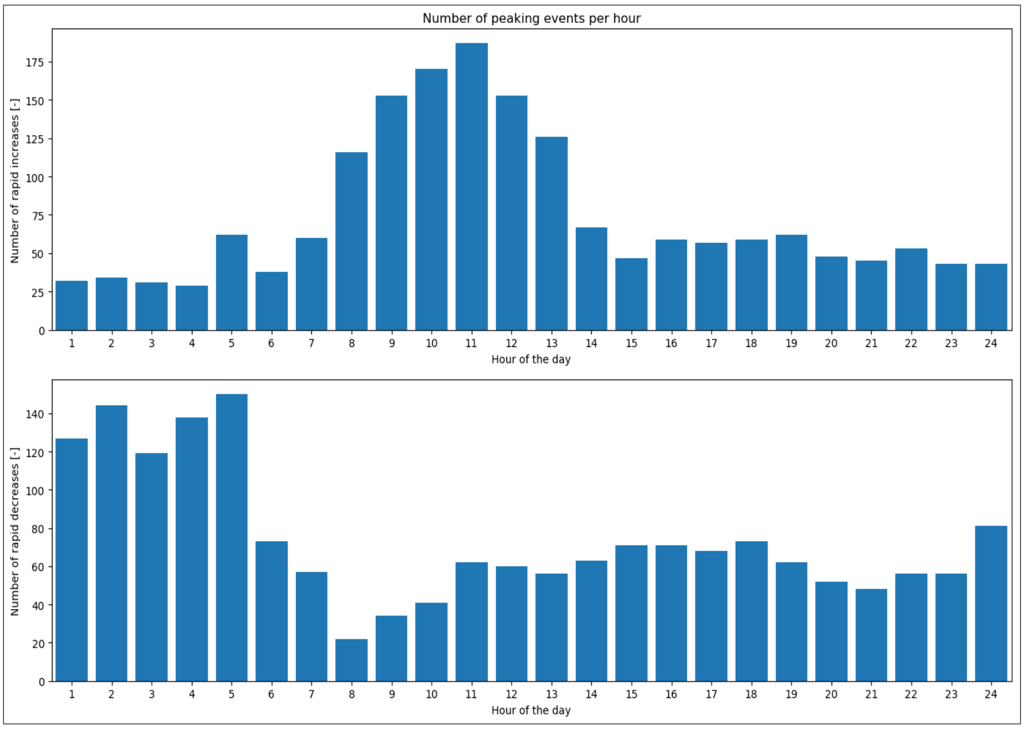

Figure 117. Skibotn bru. Number of peaks per hour – Discharge

1.20.2 Water level

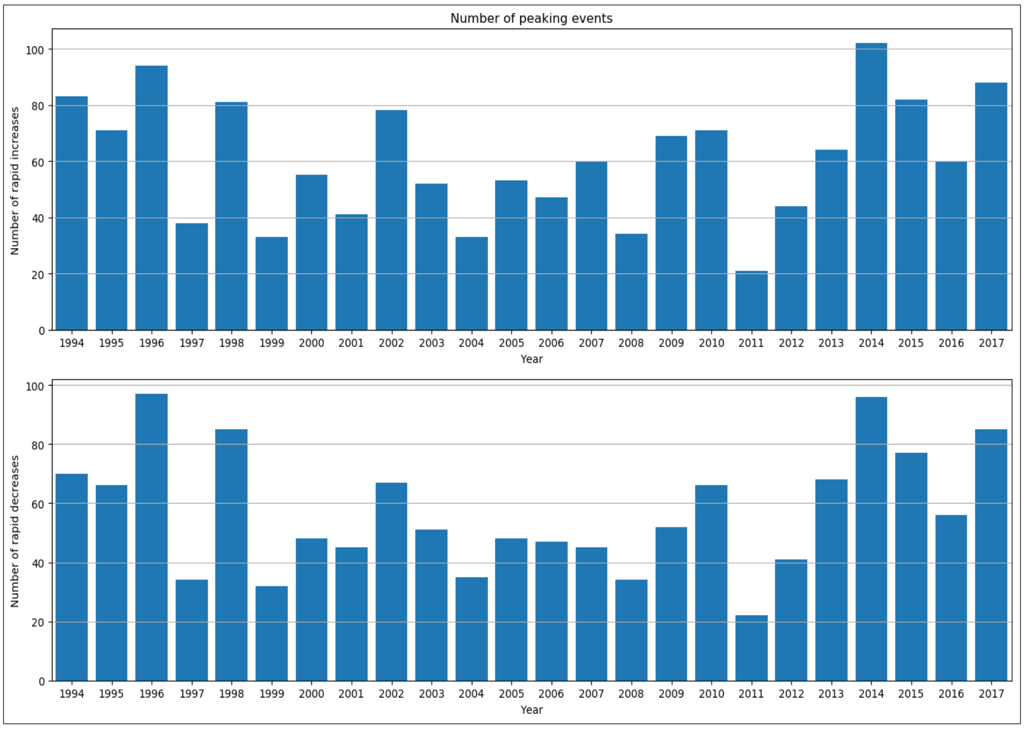

Figure 118. Skibotn bru. Number of peaks per year – Water level

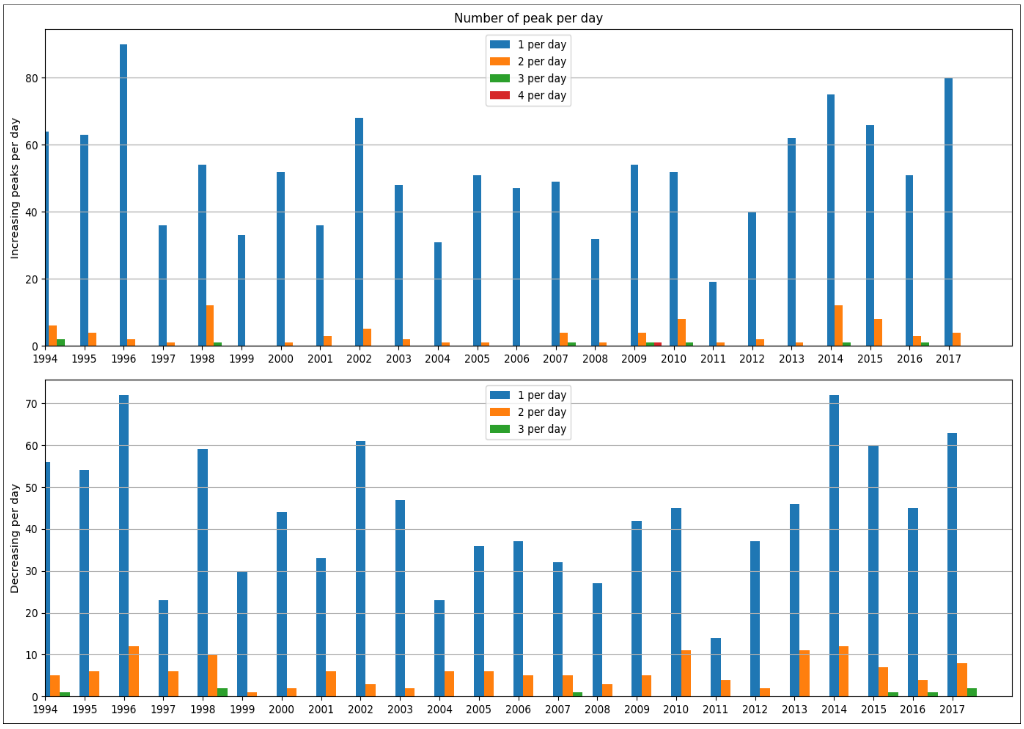

Figure 119. Skibotn bru. Number of peaks per day – Water level

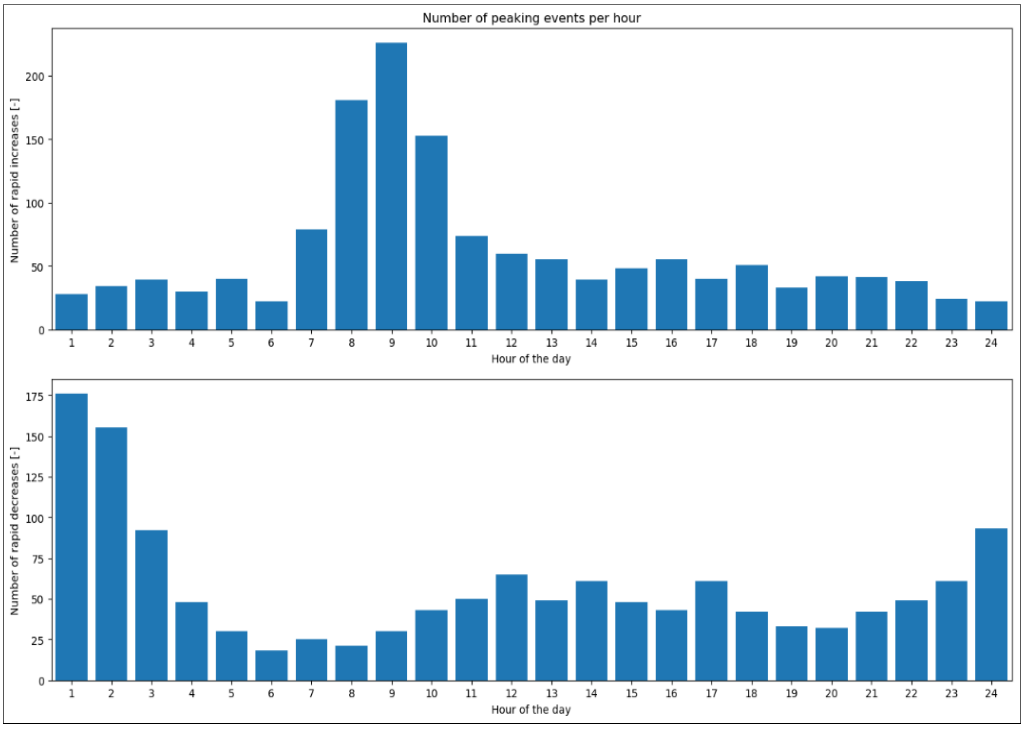

Figure 120. Skibotn bru. Number of peaks per hour – Water level

1.21 SKJERMO

1.21.1 Discharge

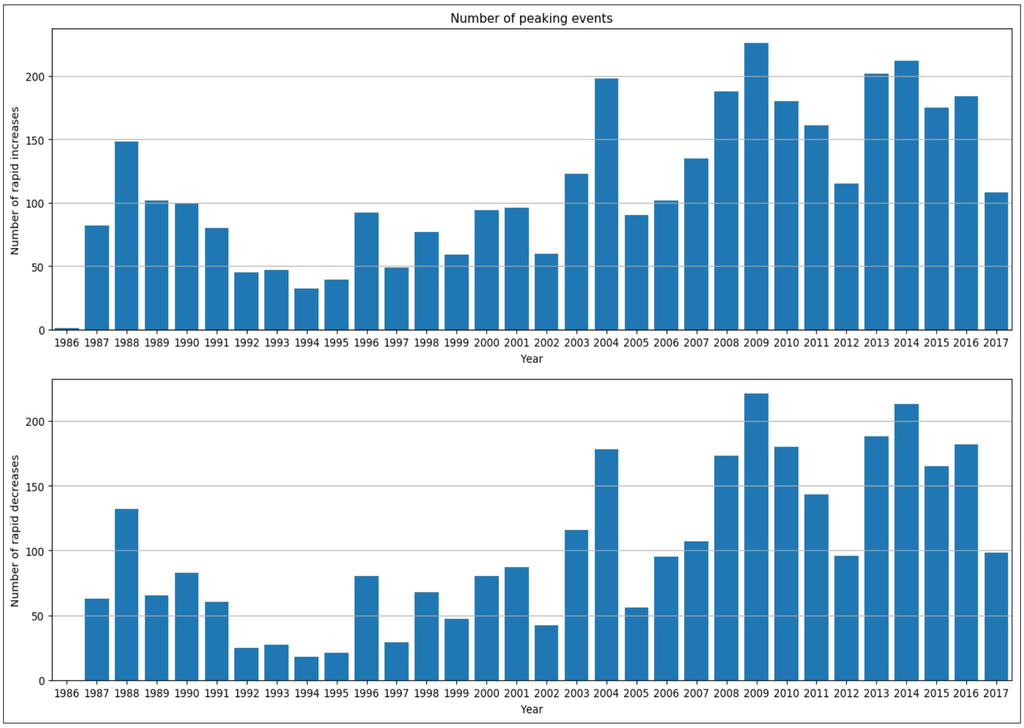

Figure 121. Skjermo. Number of peaks per year – Discharge

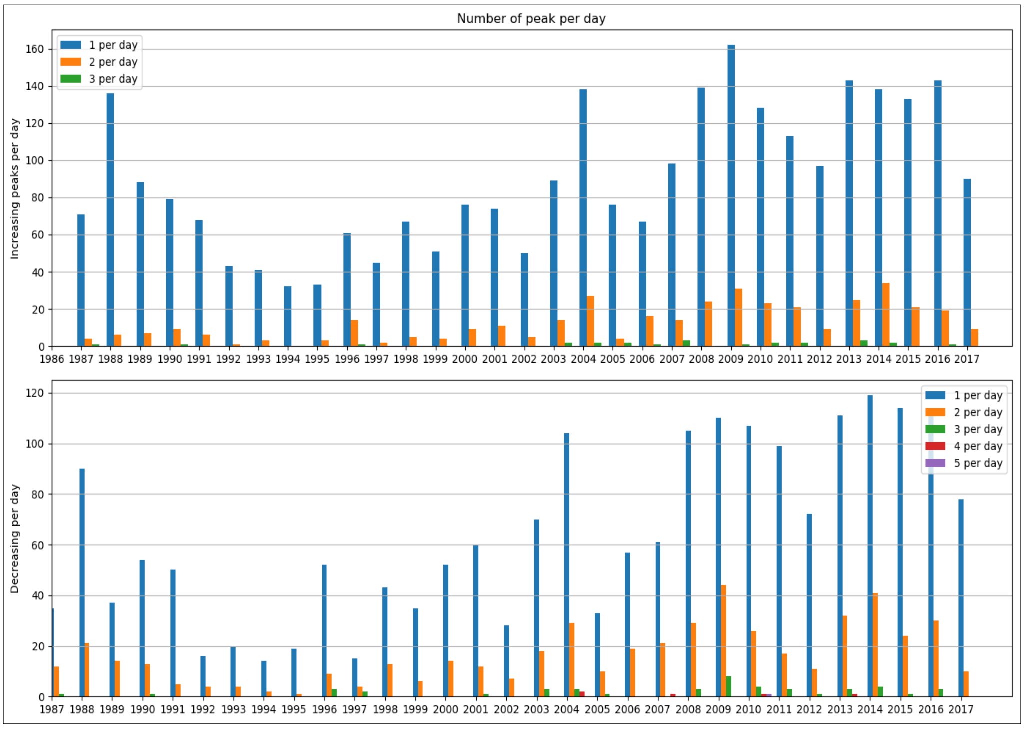

Figure 122. Skjermo. Number of peaks per day– Discharge

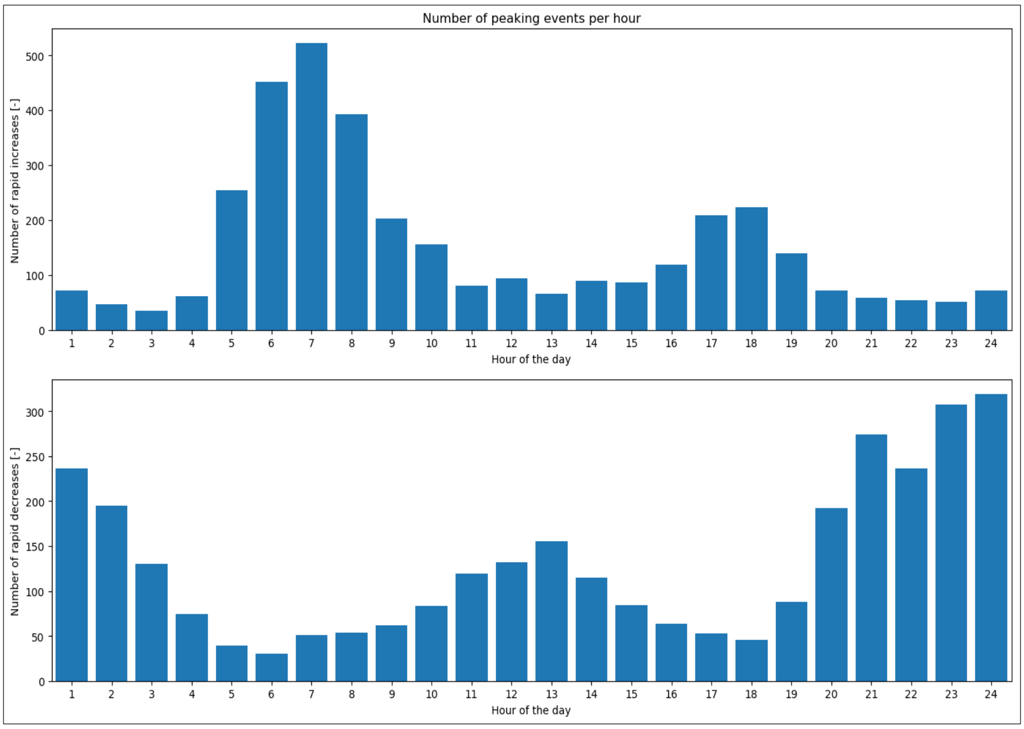

Figure 123. Skjermo. Number of peaks per hour – Discharge

1.21.2 Water level

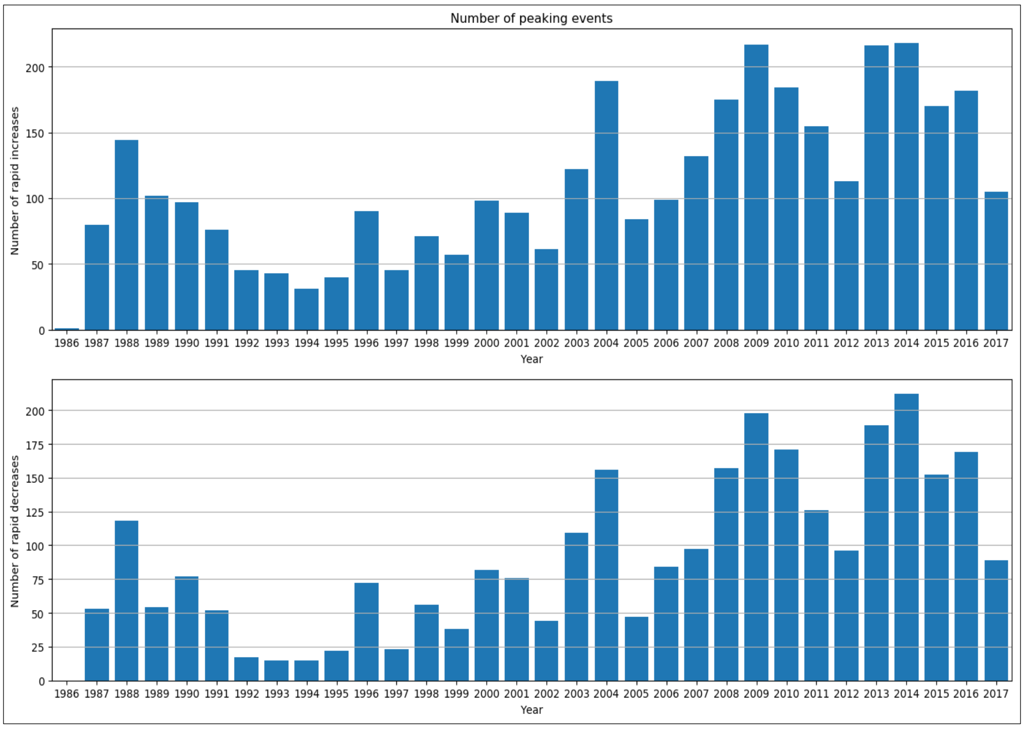

Figure 124. Skjermo. Number of peaks per year – Water level

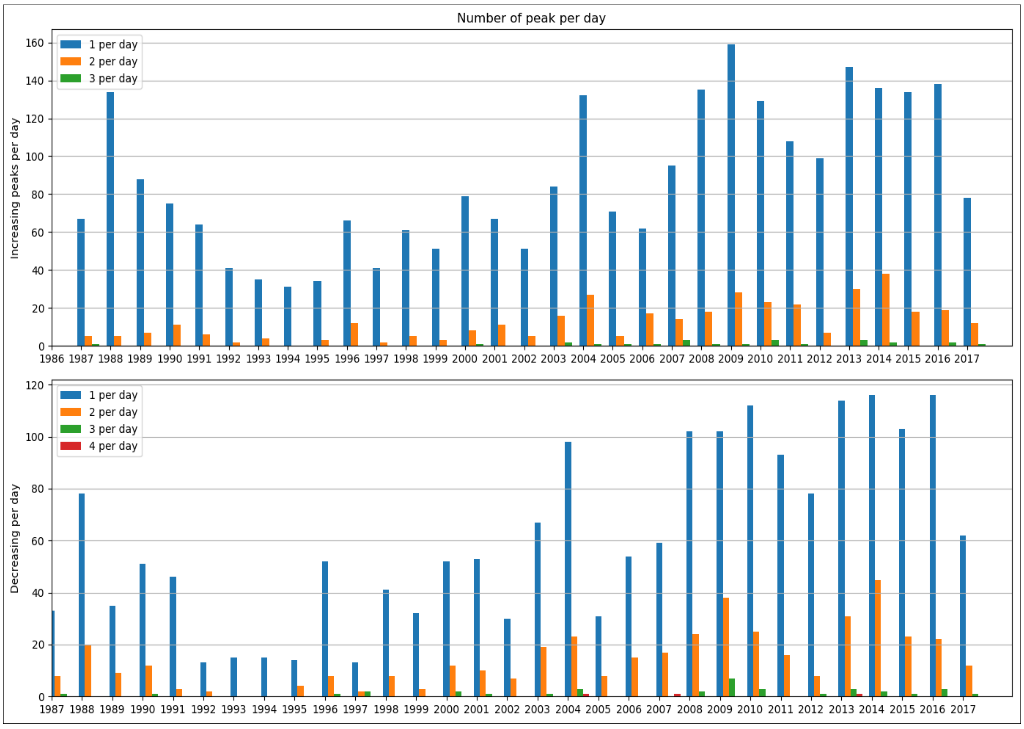

Figure 125. Skjermo. Number of peaks per day - Water level

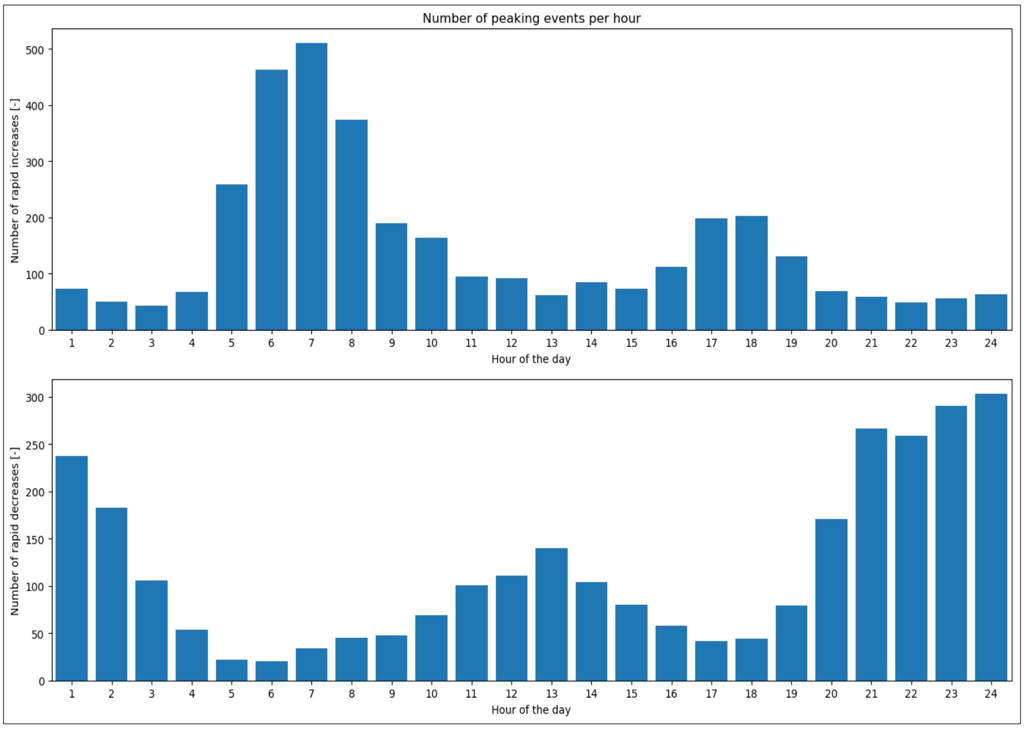

Figure 126. Skjermo. Number of peaks per hour - Water level

1.22 SYRSTAD

1.22.1 Discharge

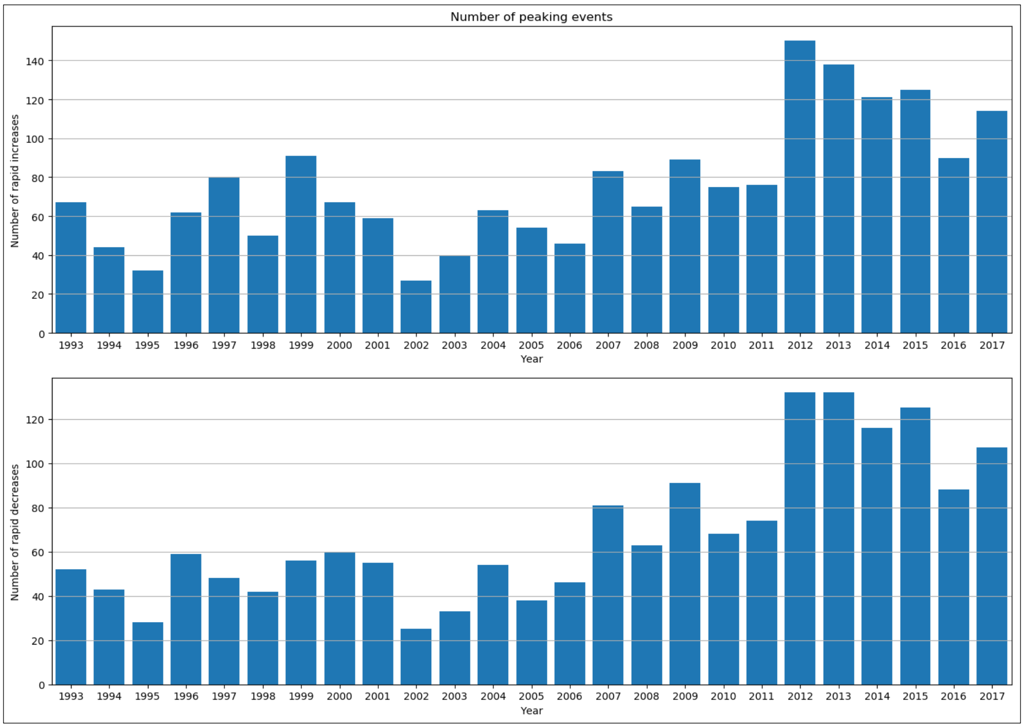

Figure 127. Syrstad. Number of peaks per year - Discharge

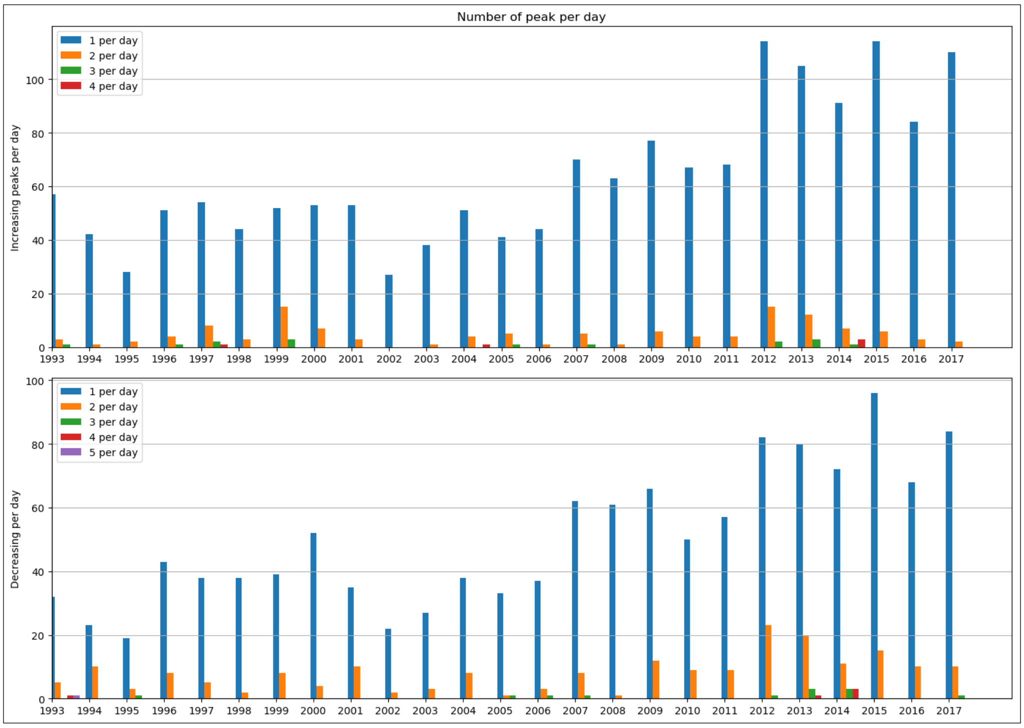

Figure 128. Syrstad. Number of peaks per day- Discharge

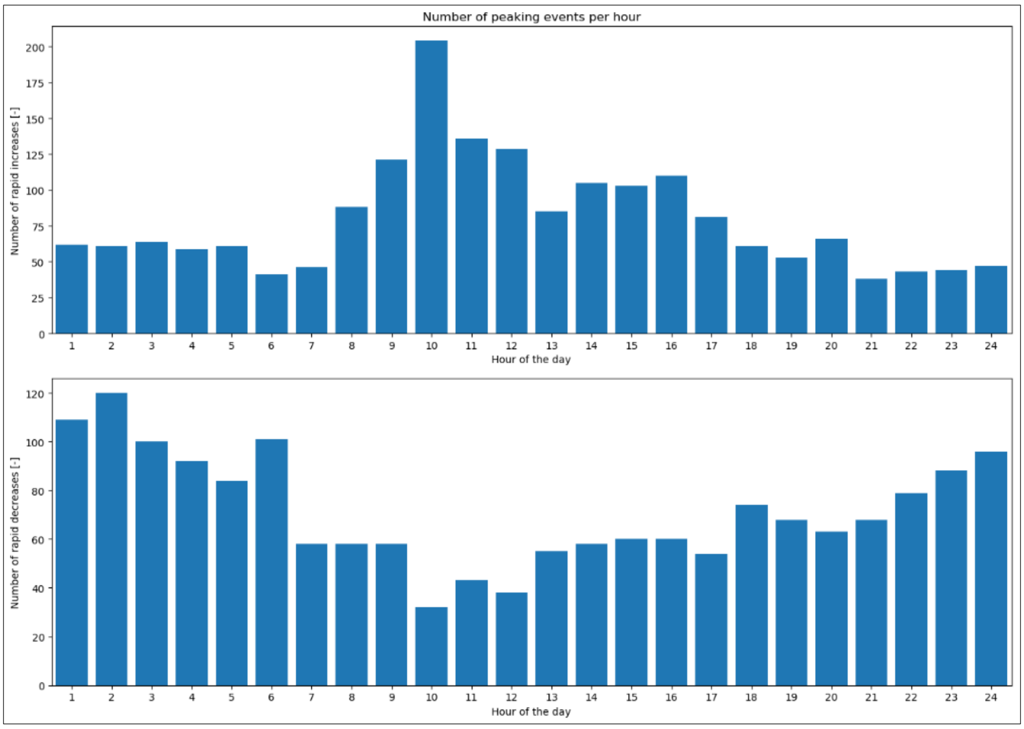

Figure 129. Syrstad. Number of peaks per hour - Discharge

1.22.2 Water level

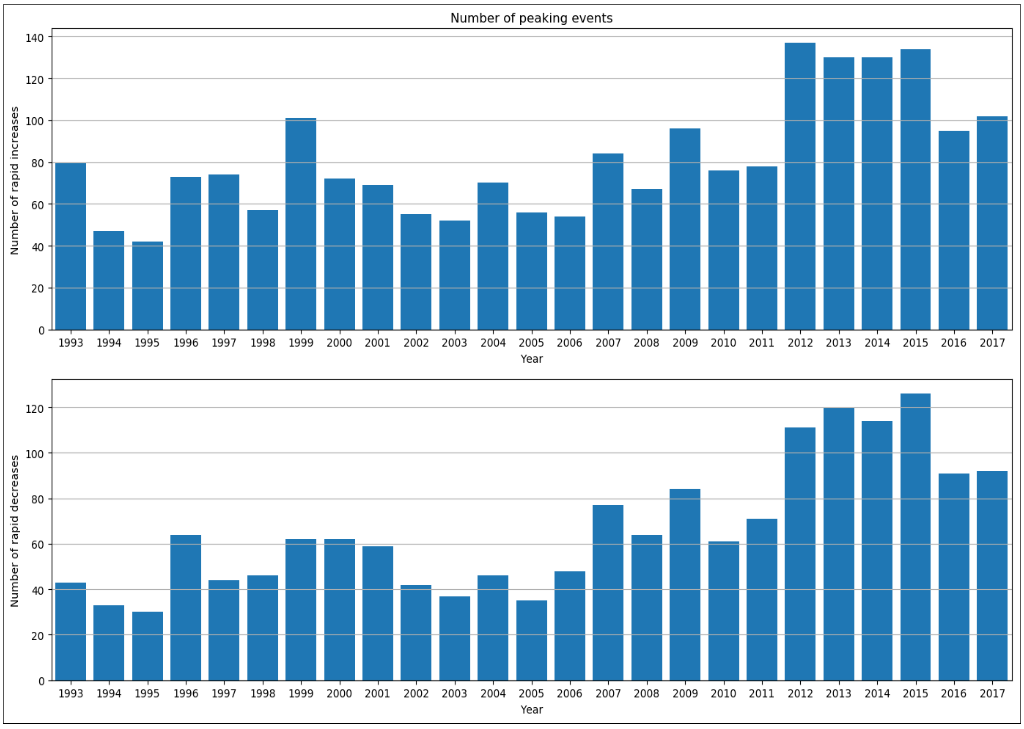

Figure 130. Syrstad. Number of peaks per year - Water level

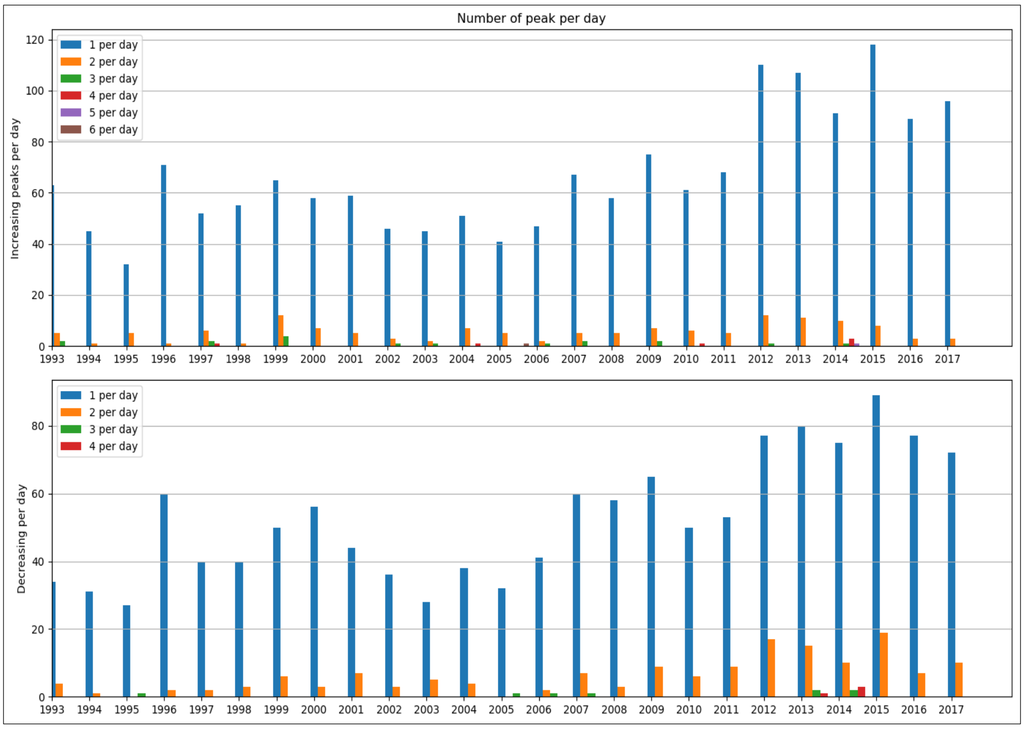

Figure 131. Syrstad. Number of peaks per day - Water level

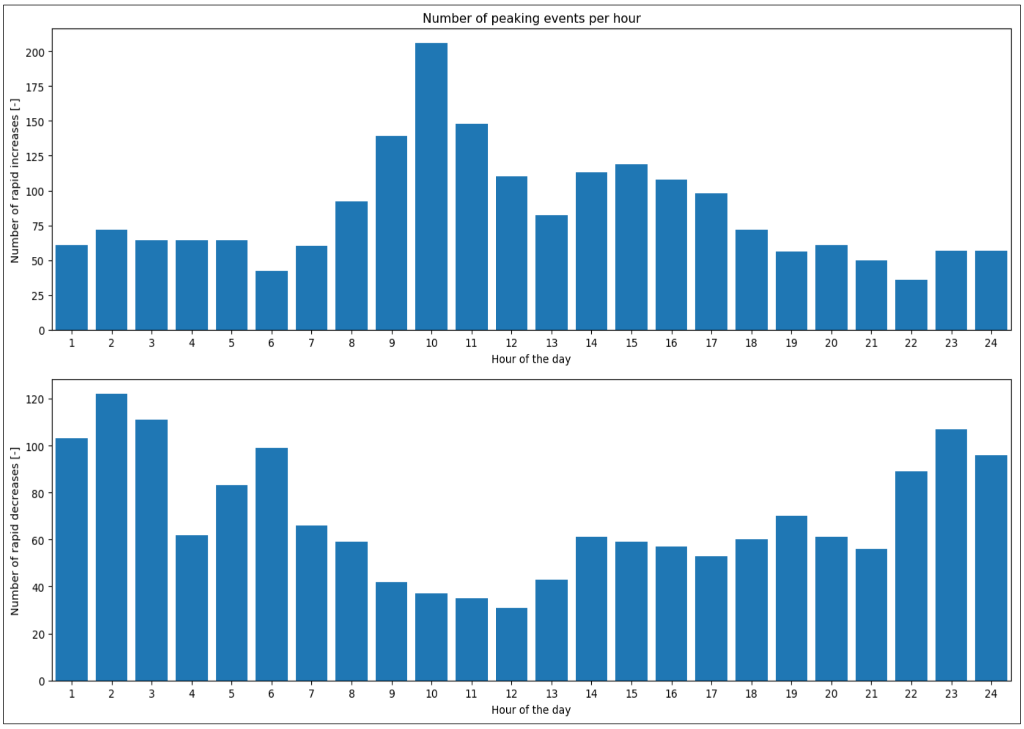

Figure 132. Syrstad. Number of peaks per hour - Water level

1.23 TØRRISDAL

1.23.1 Discharge

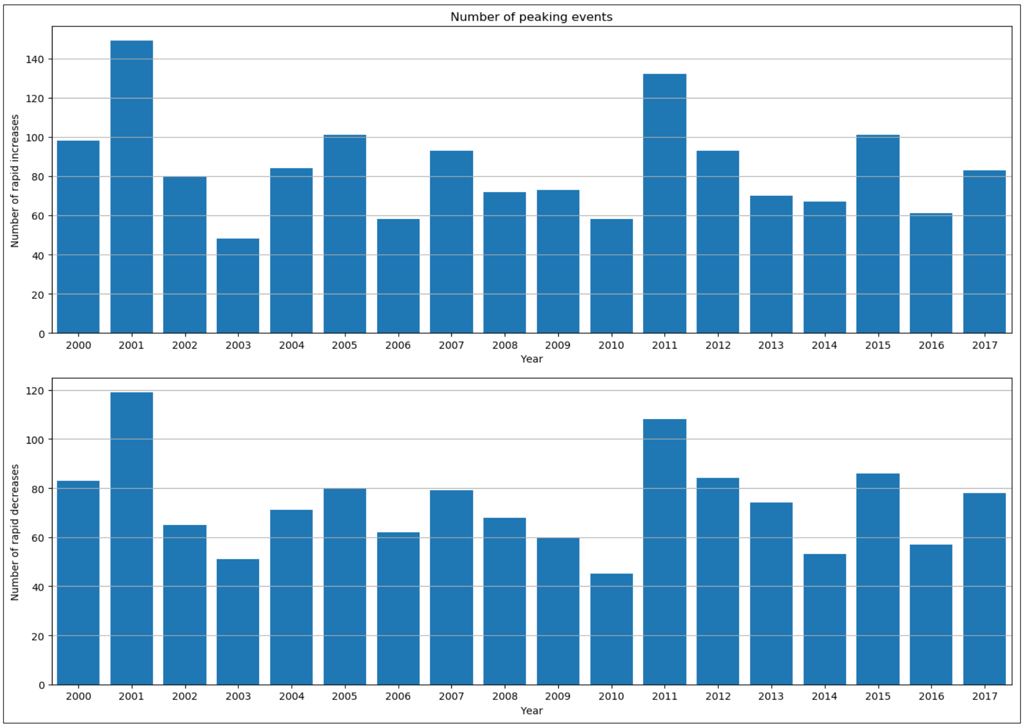

Figure 133. Tørrisdal. Number of peaks per year - Discharge

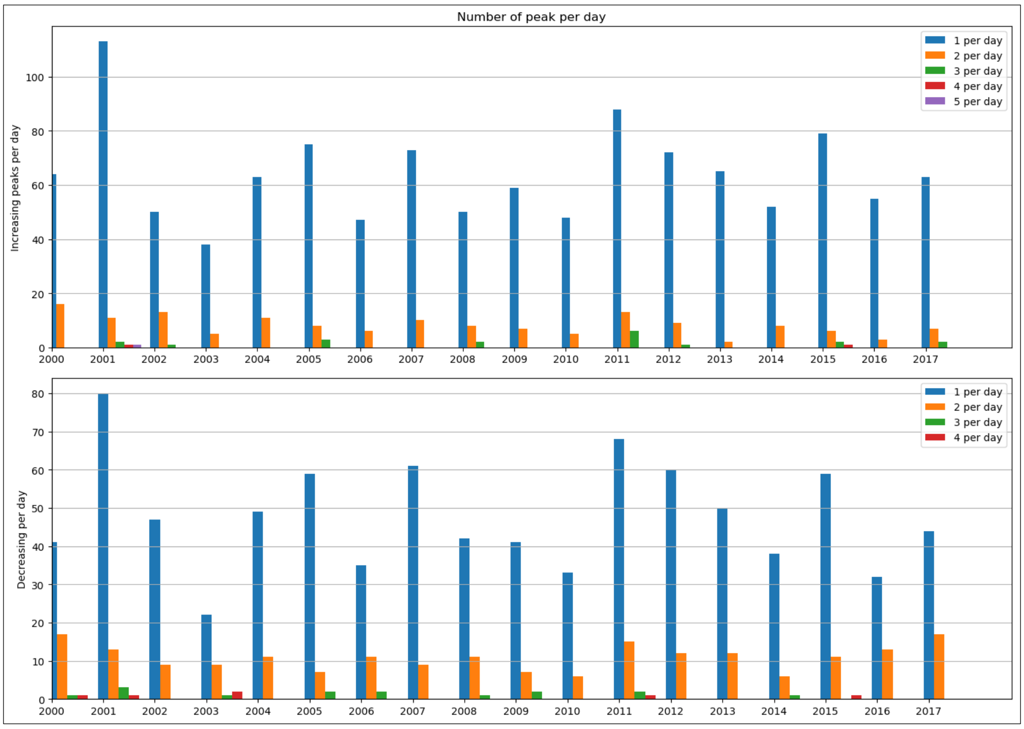

Figure 134. Tørrisdal. Number of peaks per day- Discharge

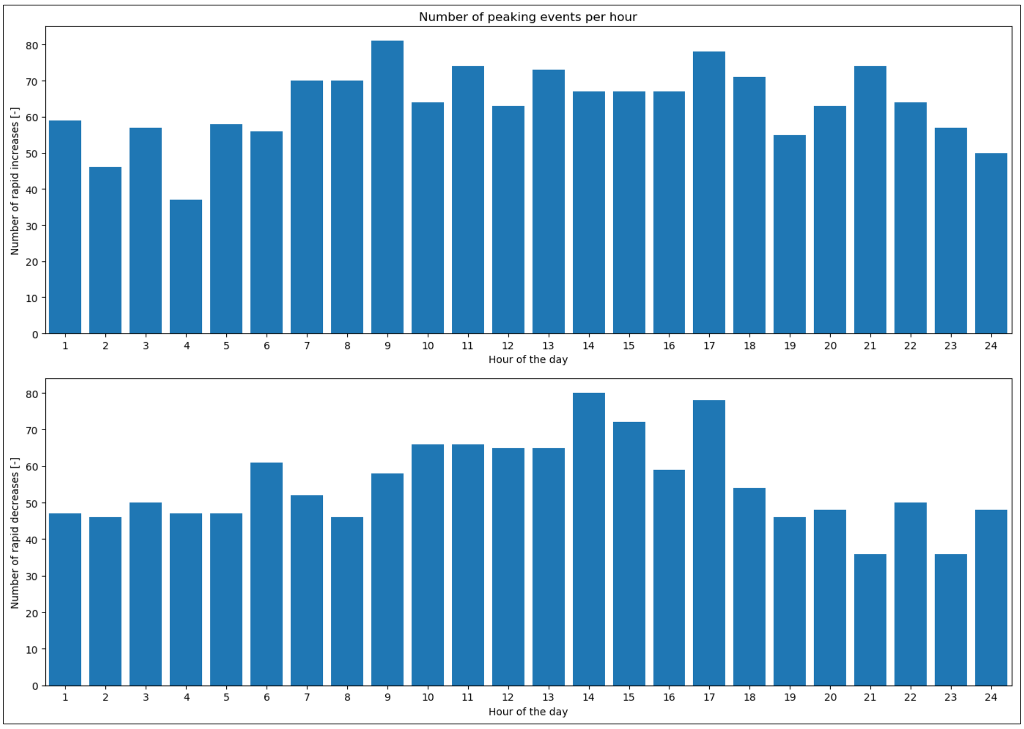

Figure 135. Tørrisdal. Number of peaks per hour - Discharge

1.23.2 Water level

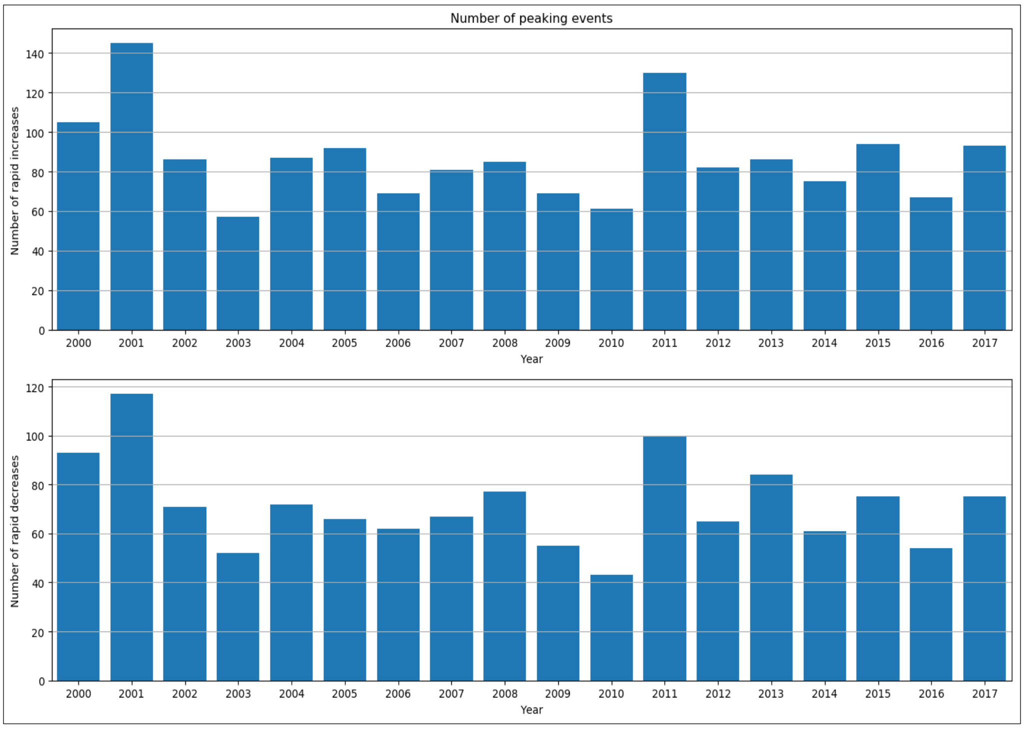

Figure 136. Tørrisdal. Number of peaks per year - Water level

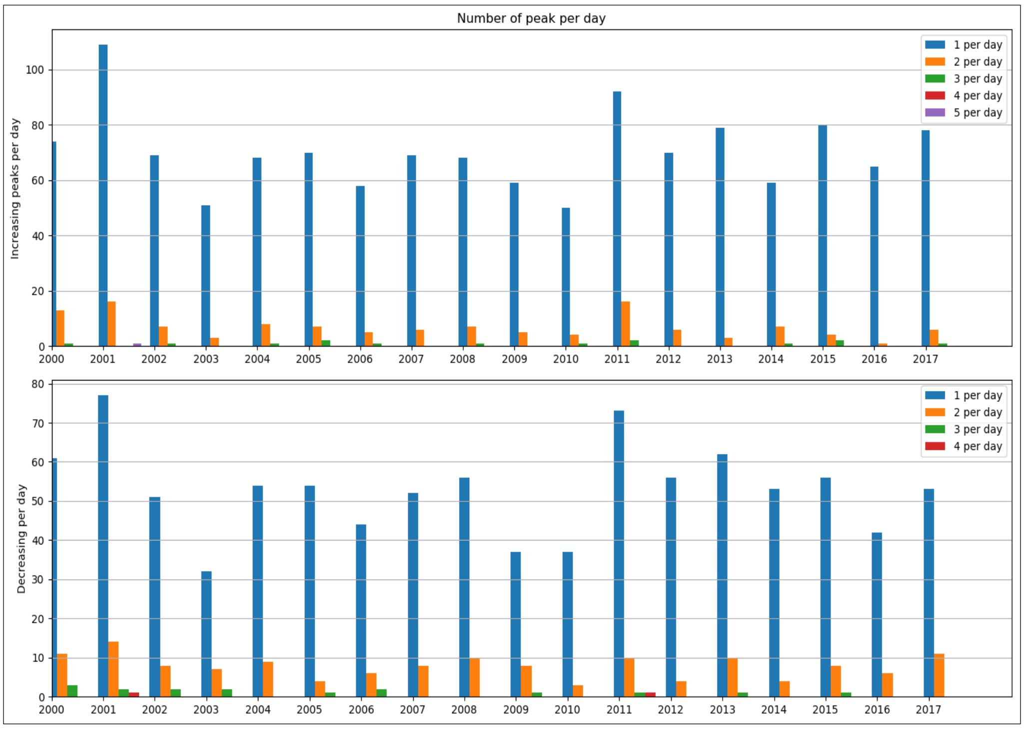

Figure 137. Tørrisdal. Number of peaks per day - Water level

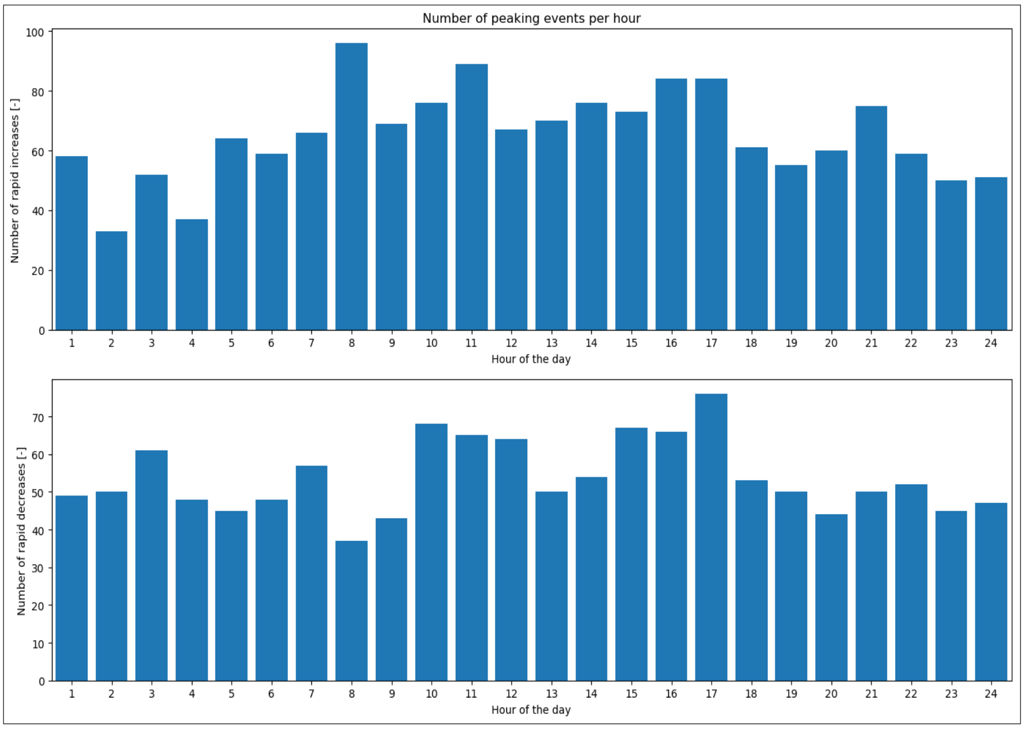

Figure 138. Tørrisdal. Number of peaks per hour- Water level

2 UNREGULATED STATIONS

2.1 *MASI*

2.1.1 Discharge

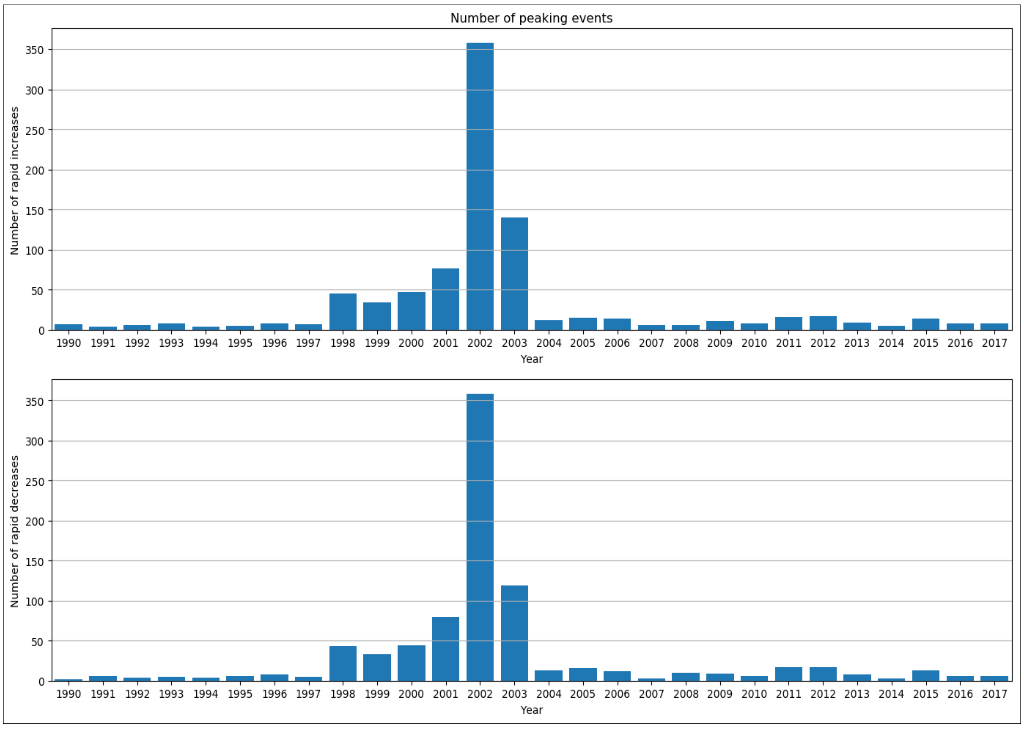

Figure 139. Masi. Number of peaks per year - Discharge

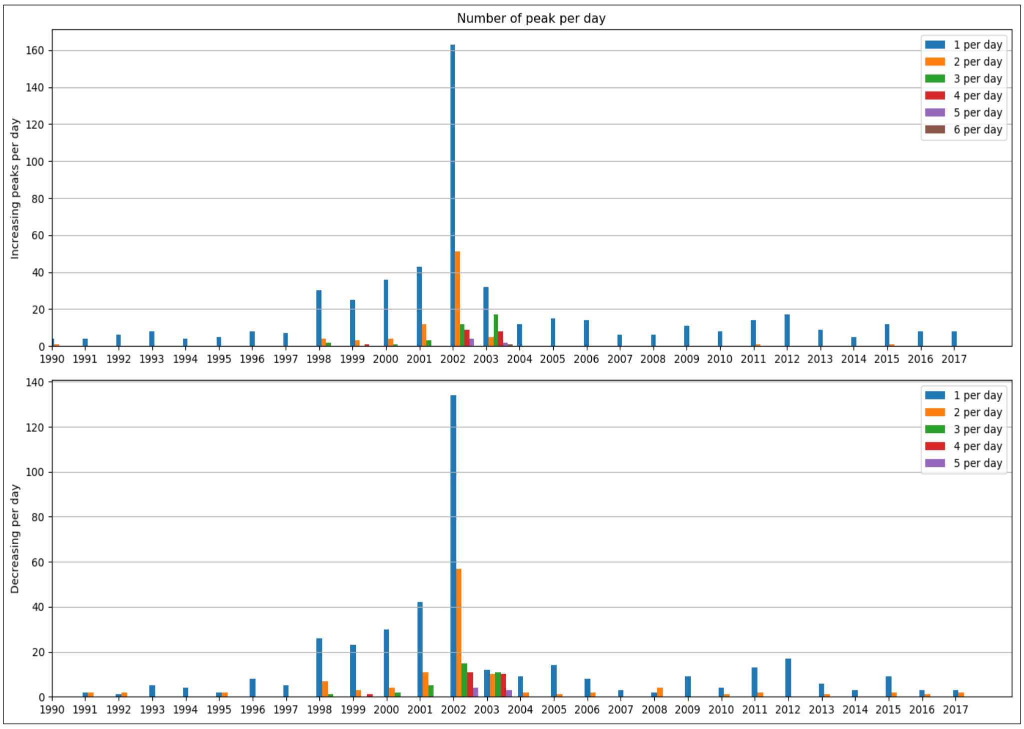

Figure 140. Masi. Number of peaks per day - Discharge

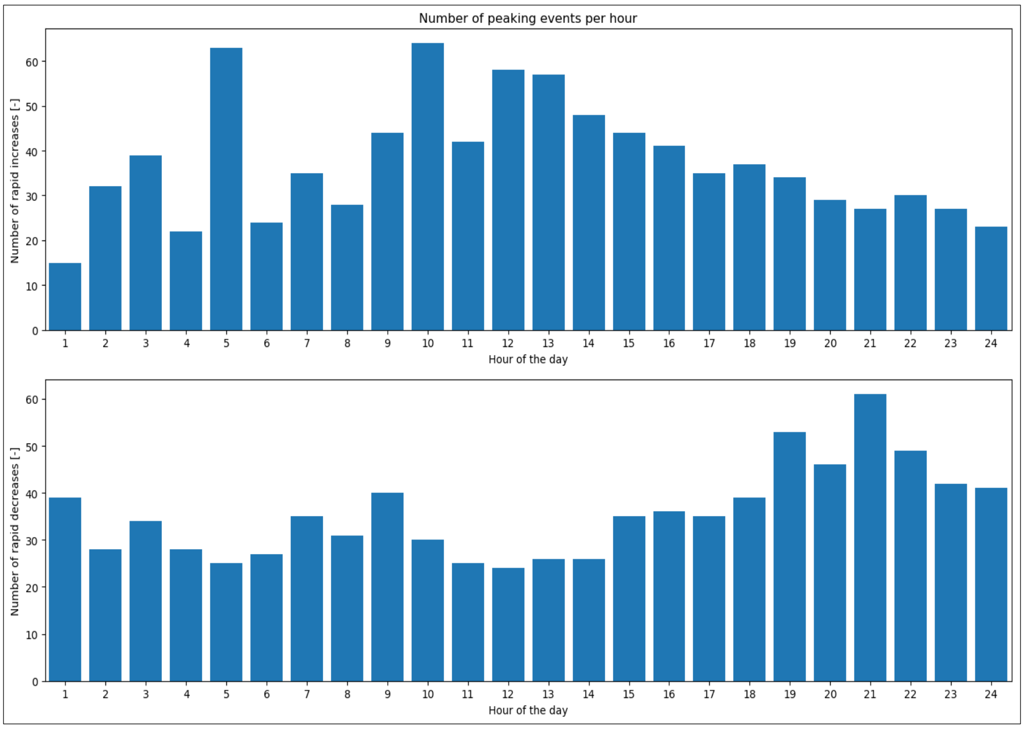

Figure 141. Masi. Number of peaks per hour - Discharge

2.1.2 Water level

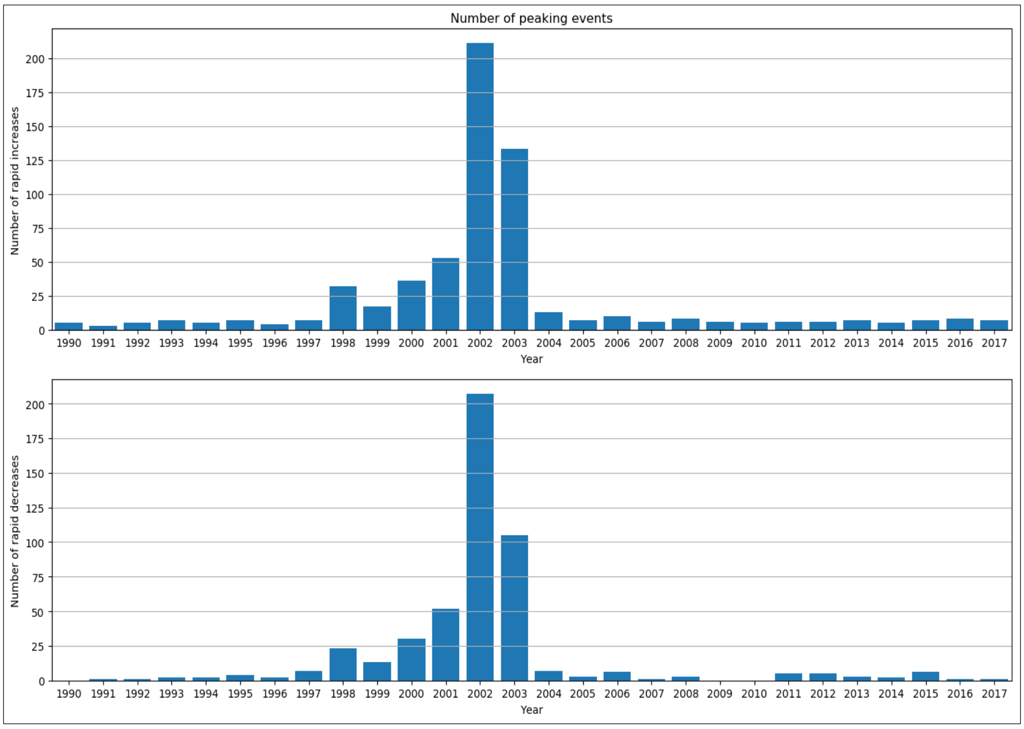

Figure 142. Masi. Number of peaks per year - Water level

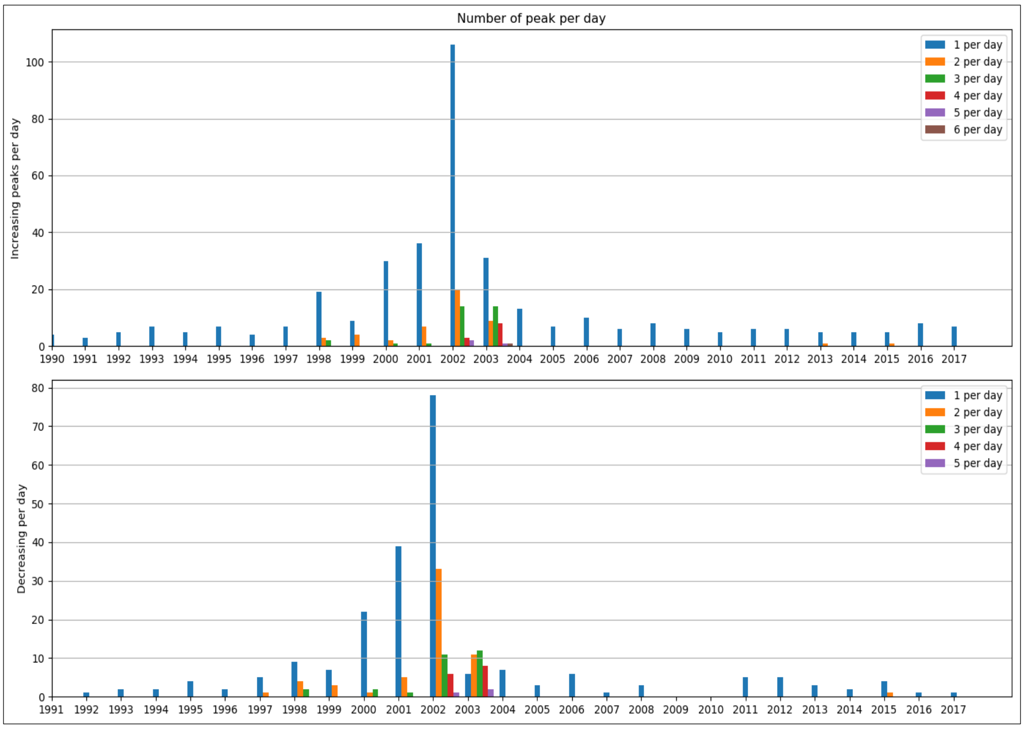

Figure 143. Masi. Number of peaks per day - Water level

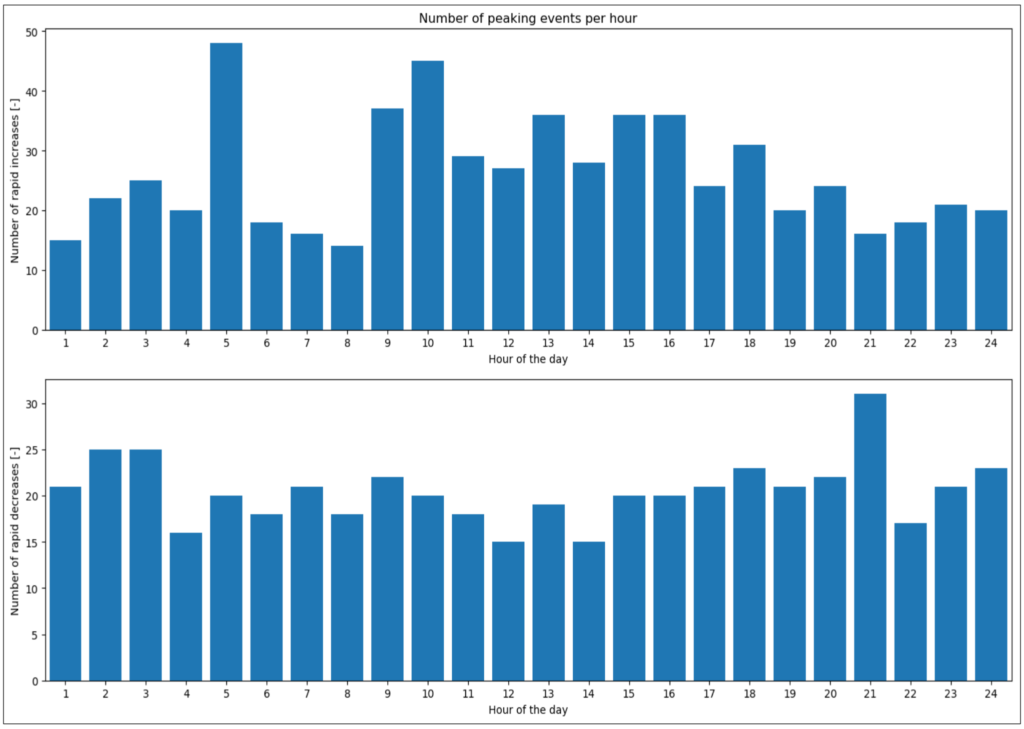

Figure 144. Masi. Number of peaks per hour - Water level

2.2 STRYNSVATN

2.2.1 Discharge

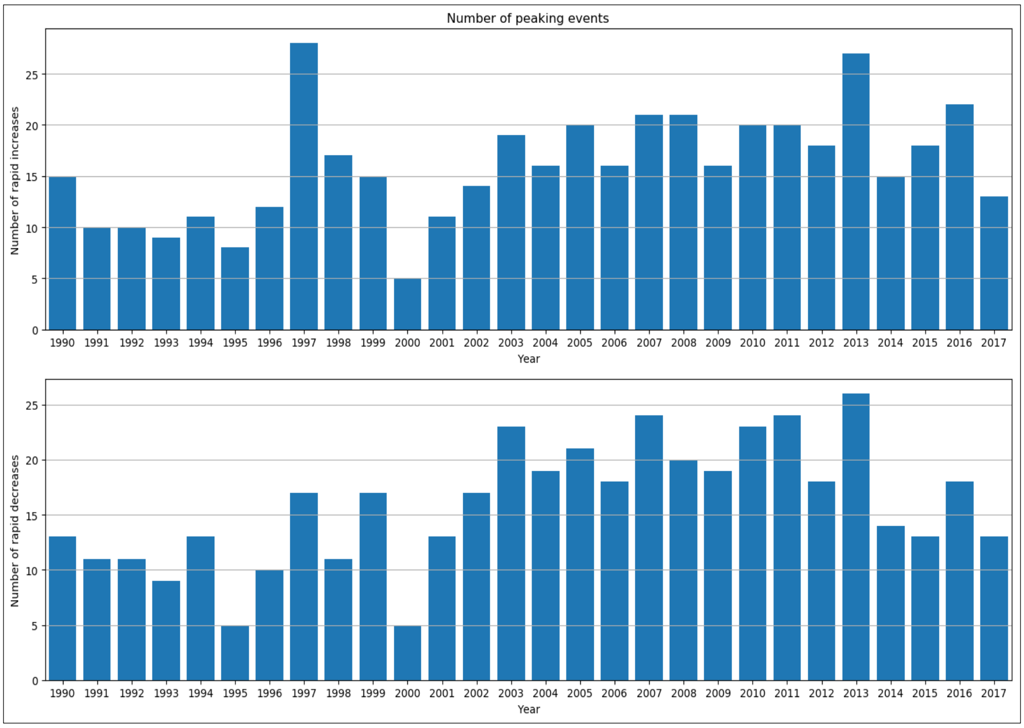

Figure 145. Strynsvatn. Number of peaks per year - Discharge

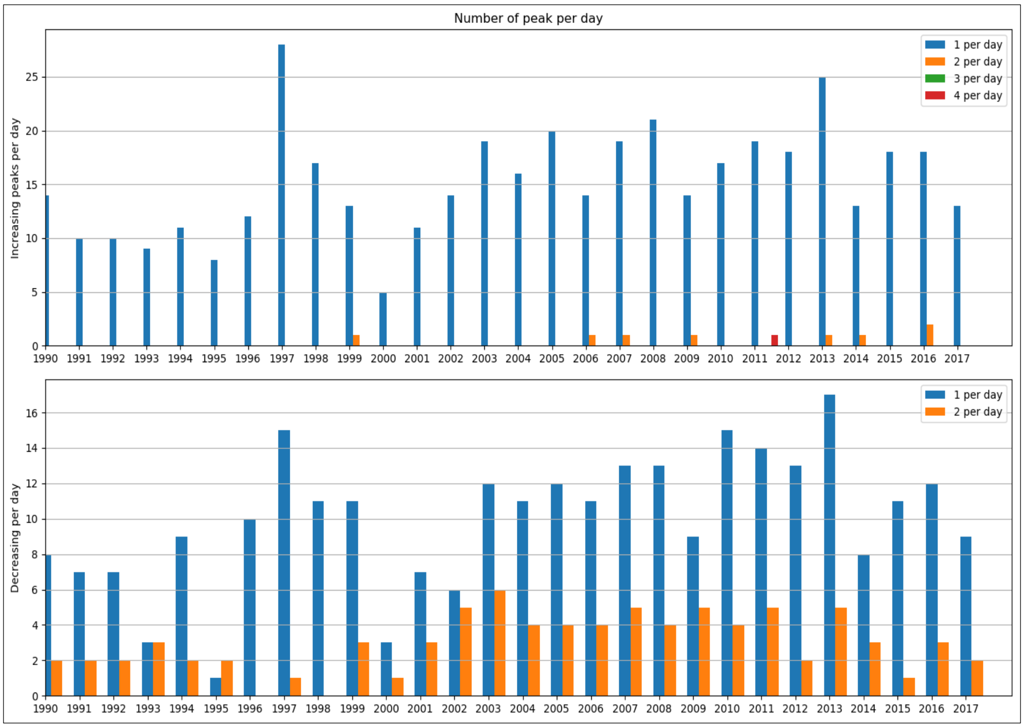

Figure 146. Strynsvatn. Number of peaks per day - Discharge

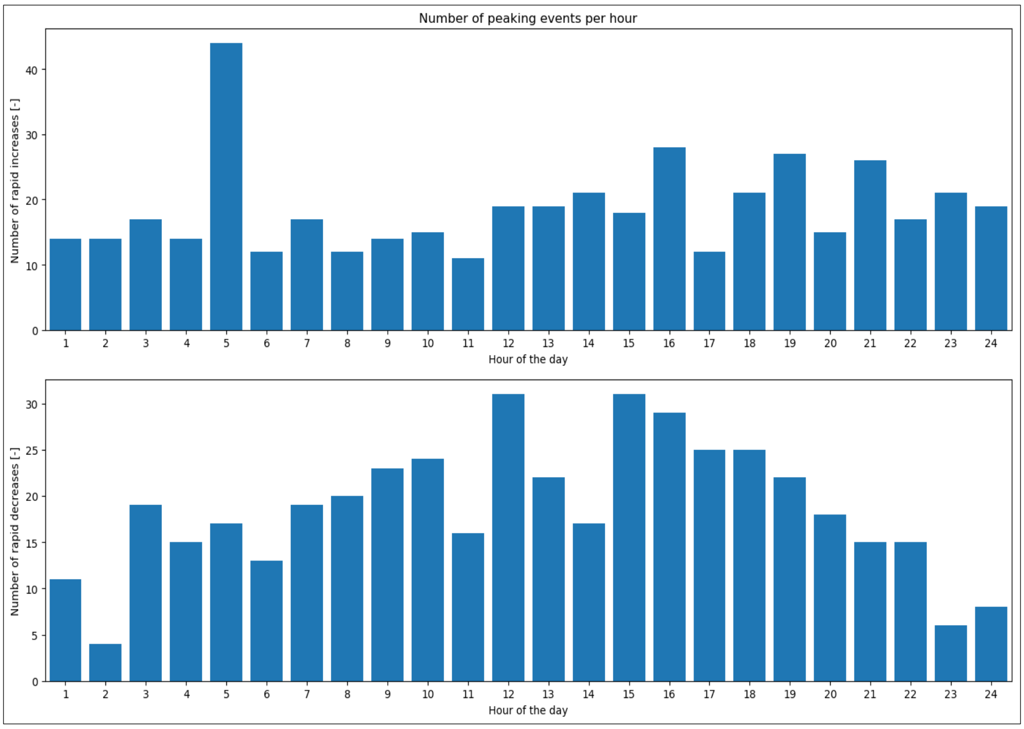

Figure 147. Strynsvatn. Number of peaks per hour - Discharge

2.2.2 Water level

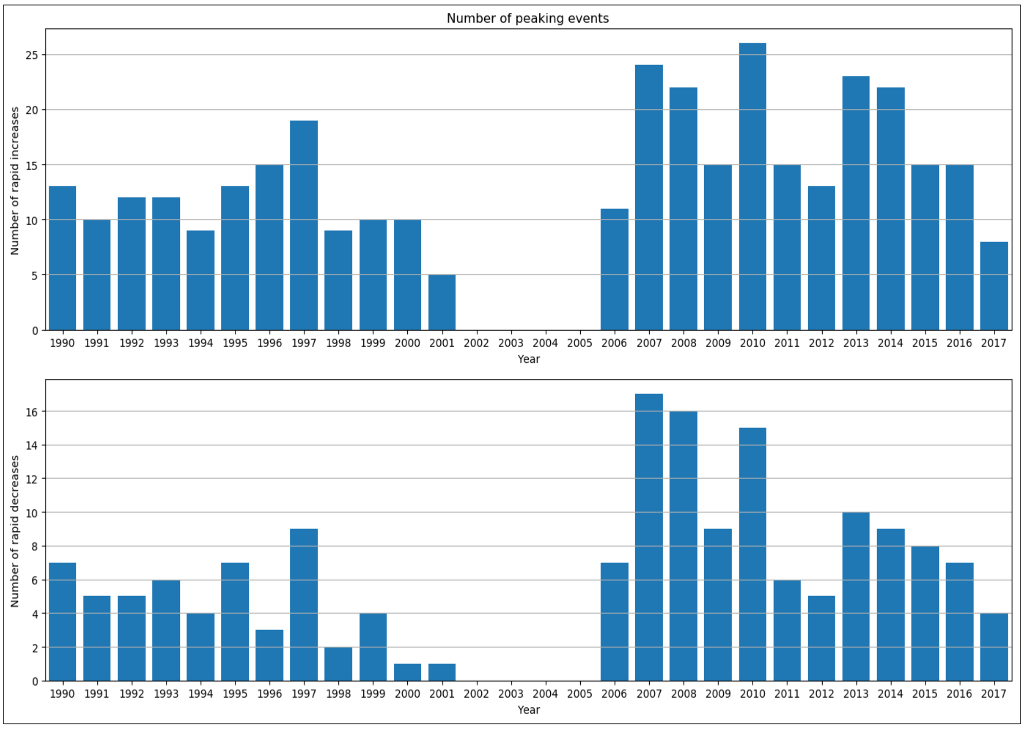

Figure 148. Strynsvatn. Number of peaks per year - Water level

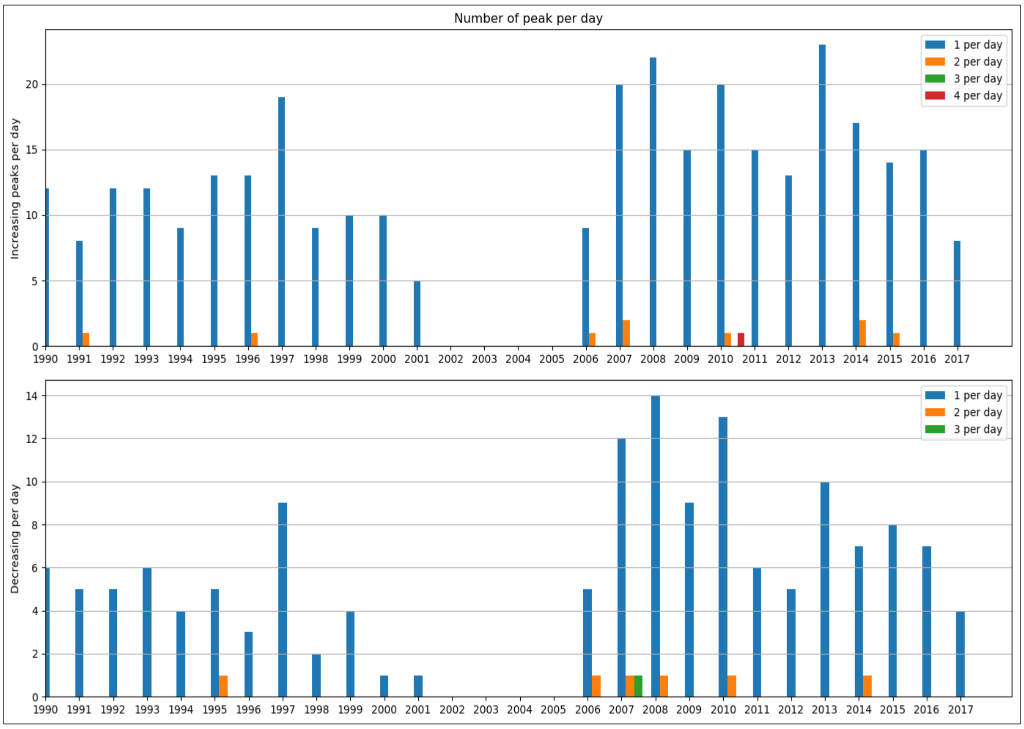

Figure 149. Strynsvatn. Number of peaks per day - Water level

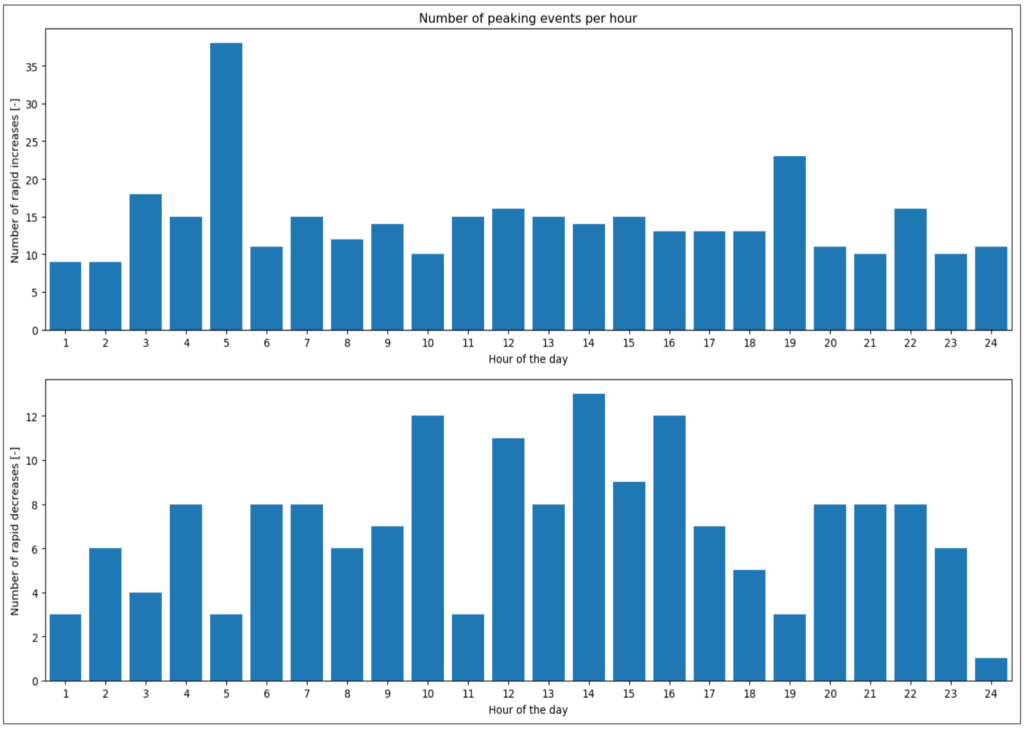

Figure 150. Strynsvatn. Number of peaks per hour - Water level

3 RELATIONS SEN’S SLOPE

3.1 SEN’S SLOPE VS DISTANCE STATION- POWER PLANT OUTLET

3.1.1 Discharge:

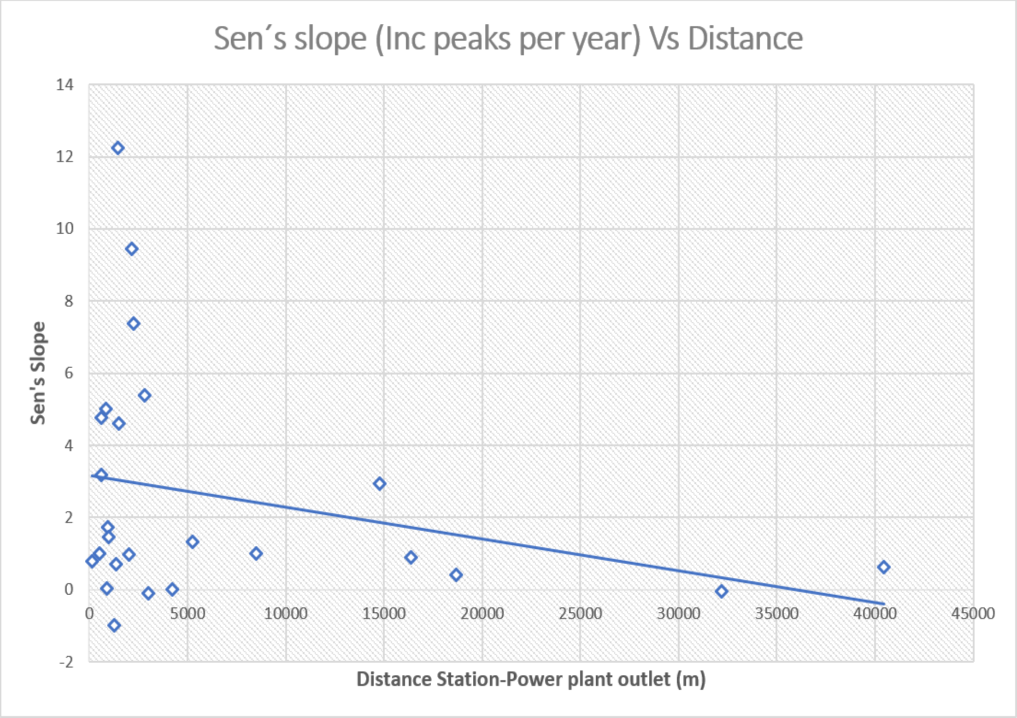

Figure 151. Relation Sen's slope Vs Distance (Inc peaks per year) - Discharge

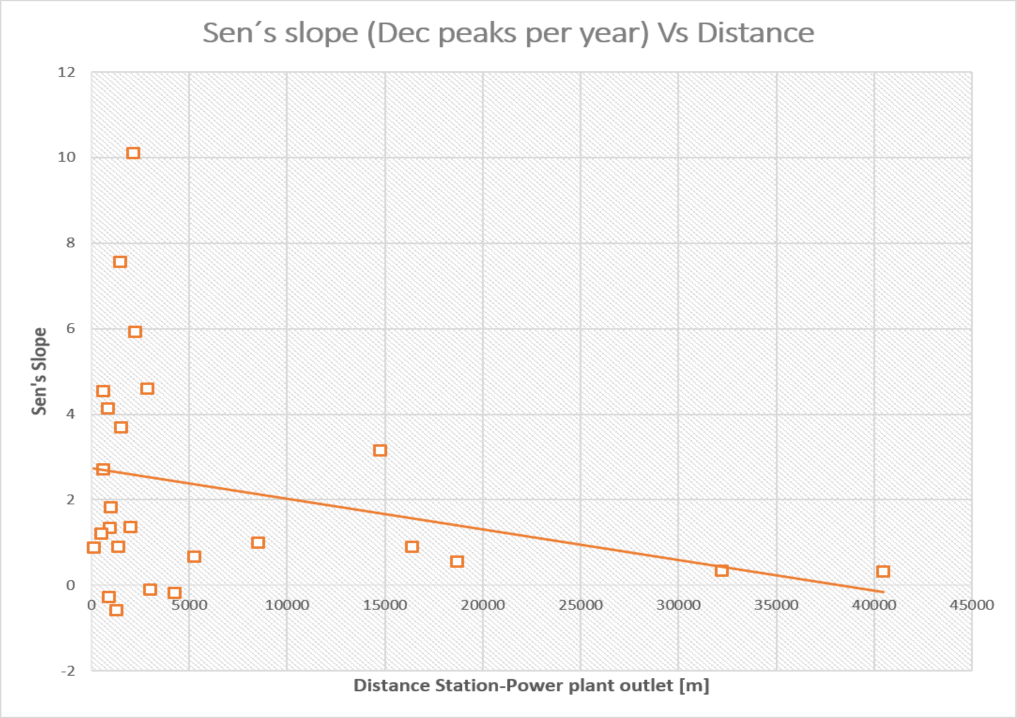

Figure 152. Relation Sen's slope Vs Distance (Dec peaks per year) - Discharge

3.1.2 Water level

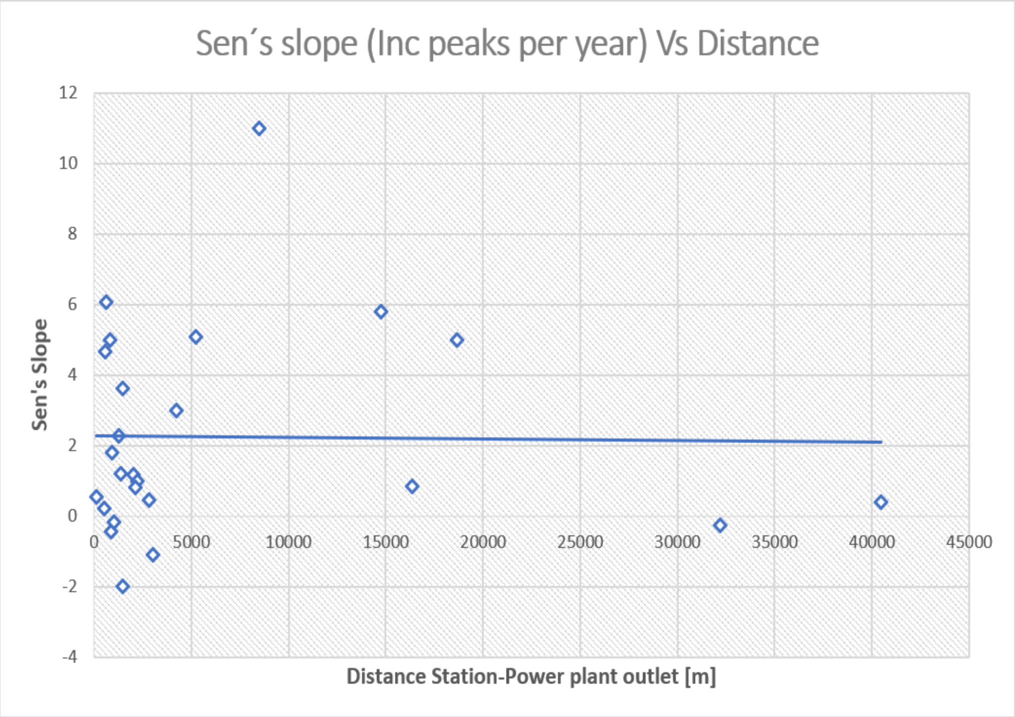

Figure 153. Relation Sen's slope Vs Distance (Inc peaks per year) - Water level

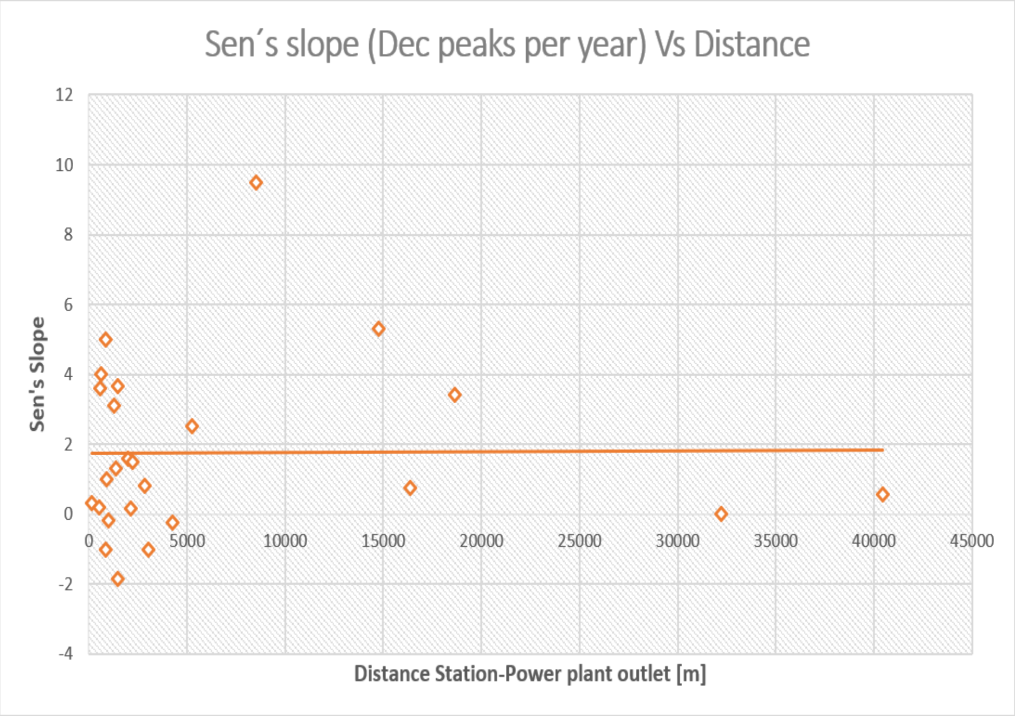

Figure 154. Relation Sen's slope Vs Distance (Dec peaks per year) - Water level

3.2 SEN’S SLOPE VS DOR

3.2.1 Discharge

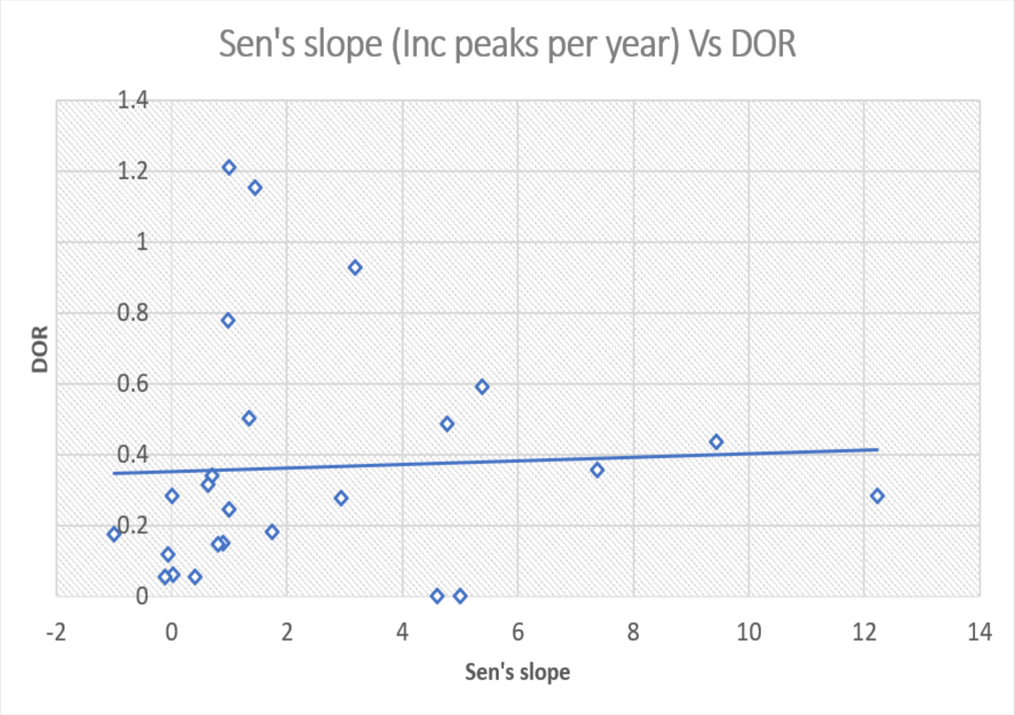

Figure 155. Relation DOR Vs Sen's slope (Inc peaks per year) – Discharge

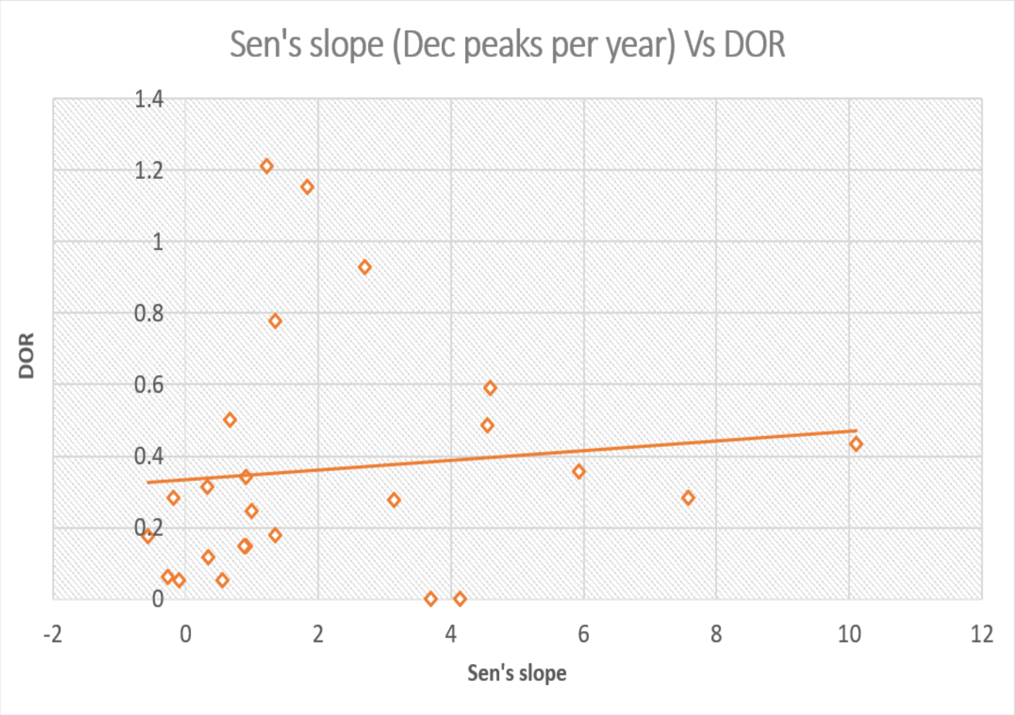

Figure 156. Relation DOR Vs Sen's slope (Dec peaks per year) – Discharge

3.2.2 Water level

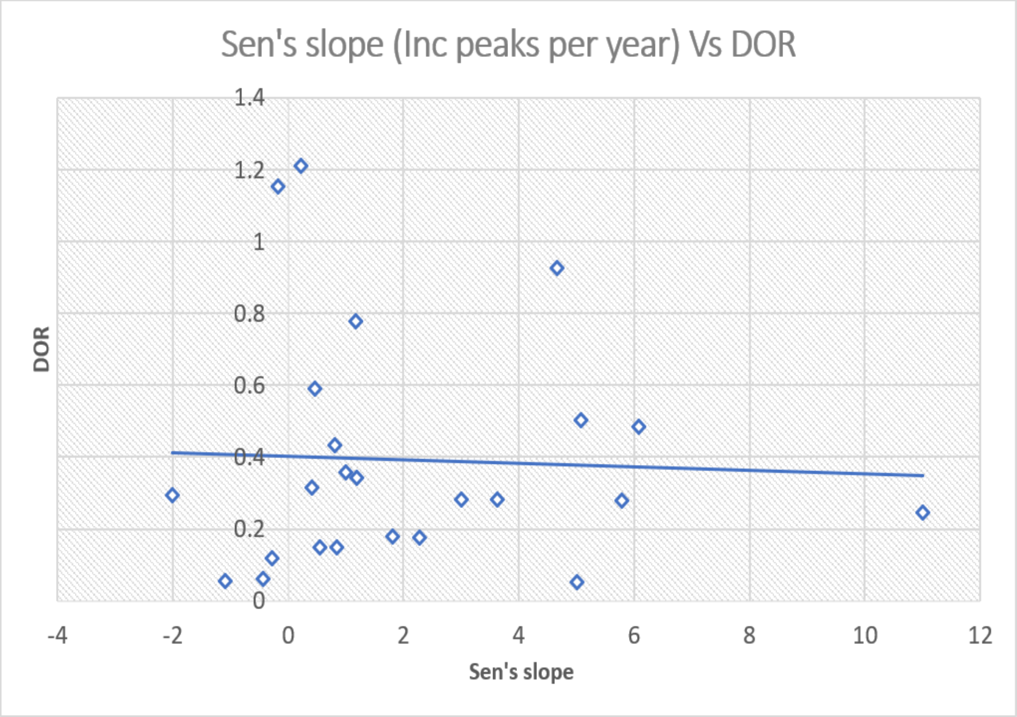

Figure 157. Relation DOR Vs Sen's slope (Inc peaks per year) - Water level

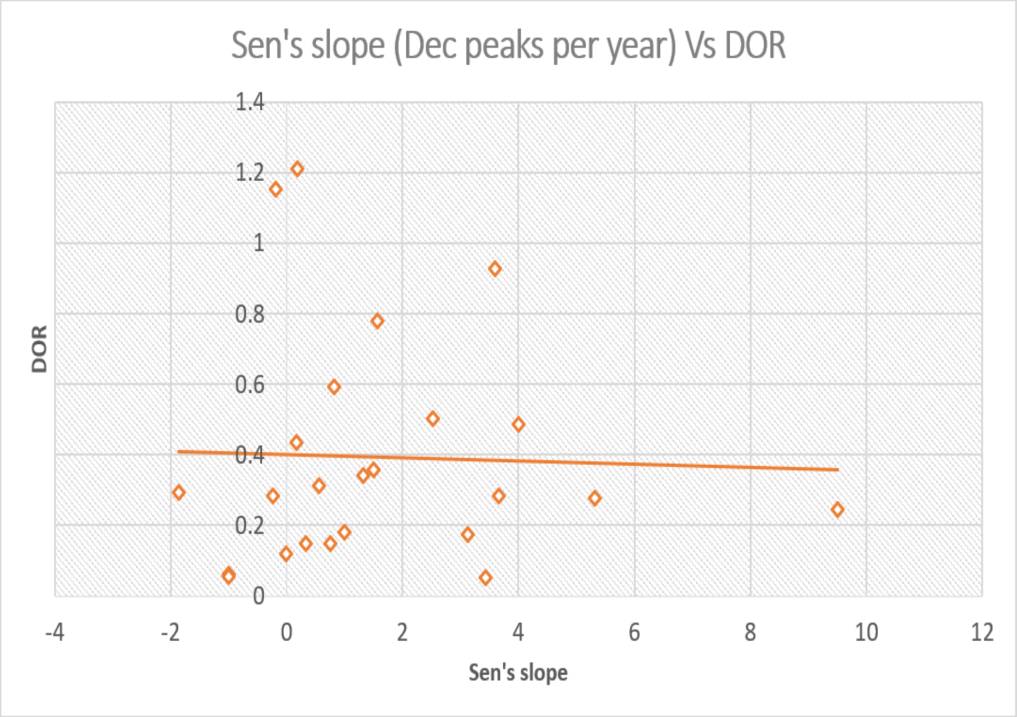

Figure 158. Relation DOR Vs Sen's slope (Dec peaks per year) - Water level