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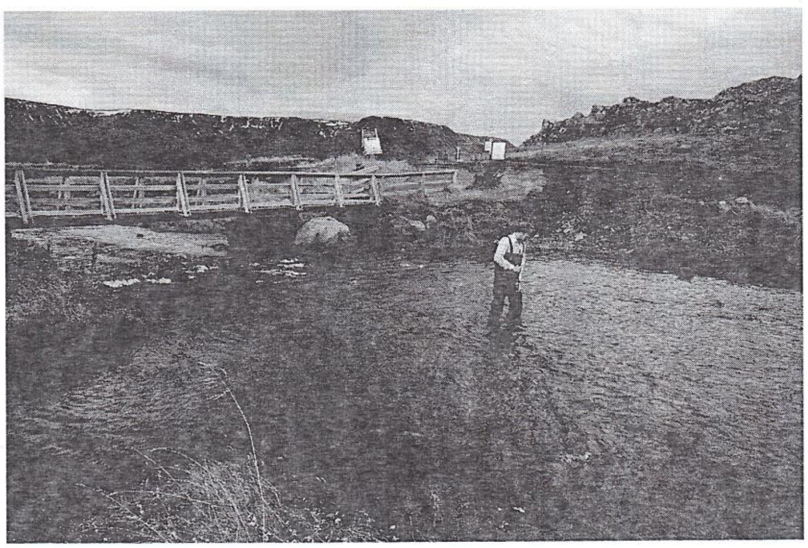

[ICELANDIC RIVERS CLASSIFICATION AND FLOW REGIMES]

This paper describes the classification of Icelandic rivers and the main factors that influence flow and channel morphology of these rivers.

Cover photo: Kristinn A. Guðjónsson 2005

1.0 Classification of Icelandic rivers

Rivers can be classified based on different criteria. Some classifications are basec on channel morphology while others look at factors such as flow regimes anc dynamics. The Icelandic classification system is based on two main factors – the origin of the water and the flow regime. These factors further dictate the flow dynamics, channel morphology and sediment load.

Flow variations within rivers are due to different reasons. Glacial rivers display a radical diurnal as well as annual variation in flow while other rivers are characterisec by constant and even flow throughout the year. Before continuing further it is important to define some key terms that relate to hydrology.

2.0 Discharge

Discharge is simply the amount of water that a river carries to the ocean during a certain time frame. It is normally measured in cubic meters per second (m^3/s). Wher the discharge is said to be 50 m^3/s then 50 m^3 of water flows past the observatior point every second. If that point is at the mouth of the river (were sucl measurements are often conducted) then 50 m^3 of water flow into the ocean every second. Since the density of water is 1000 kg/m^3 it is easy to convert this to mass thus we find that in this particular river 50 tons of water make it to the ocean every second of flow.

The discharge can very through the course of a day or year. It is not uncommon tha flow in glacial rivers increase 10 times from morning to evening during a clear sunn summer day. Going from next to nothing in the early morning when snow melt is at a minimum on the glacier to much greater amounts in the evenings when the melt is a its greatest. These same glacial rivers will dry up during the winter months when a the precipitation that falls on the glacier is snow.

2.1 Discharge in Icelandic rivers

Table 2.1 shows the mean annual discharge of some large rivers in Iceland. It als includes the size of the catchment area and the discharge in litres per second pe km^2. One would assume a strong relationship between catchment size and mea annual discharge. Undeniably that is the case when comparing catchments in simila geological settings e.g. within the same type of bedrock. The porosity of the bedrock can however vary from one area to the other thus greater or lesser amount of the precipitation that fall within the catchment becomes groundwater flow and never reached the river channel (see more on that later).

Table 2.1 - Discharge in some large rivers in Iceland measured at the mouth of the rivers

Name of river	Catchment size km^2	Discharge m^3/s	Discharge $l/s/km^2$
Ölfusá	6100	440	72
Þjórsá	7530	387	51
Kúðafljót	2400	220	92
Jökulsá á Fjöllum	7750	212	27
Jökulsá á Dal	3700	205	55
Hvítá í Borgarfirði	3880	190	49
Lagarfljót	2900	130	45
Héraðsvötn	3650	108	30
Hólsá	1860	100	70
Skjálfandafljót	3860	95	25

It is important to note that summer discharge is often twice the mean annual discharge and in typical spring floods the flow can easily be 3-10 times the average annual flow. Catastrophic floods are common in Icelandic rivers. They are usually a result of a sub-glacial eruption, geothermal activity or due to other glaciological processes such as glacial surges. The highest discharge ever measured in Hvítá river in south Iceland, is 2000 m^3/s or 10 times the mean annual flow of that river. The volcanic eruption at Gjálp in the Vatnajökull glacier in 1996 triggered a catastrophic flood in Skeiðará river which peaked at 60.000 m^3/s which is 200 times the mean annual flow for that river. By far the largest floods are associated with volcanic eruptions in Katla, south Iceland. It is located underneath the Mýrdalsjökull glacier and is estimated to have produced flood with discharge as high as 800.000 m^3/s in the past.

3.0 Catchment and discharge

The area from where the river gets its water from is referred to as a catchment area or basin. The outer boundary of the catchment area is called a watershed (figure 3.1). The Watershed follows the highest ridges around the river. As stated earlier there is a relationship between the size of the catchment and the discharge of the river. The bigger the catchment, the greater is the collection area for the water thus resulting in greater discharge.

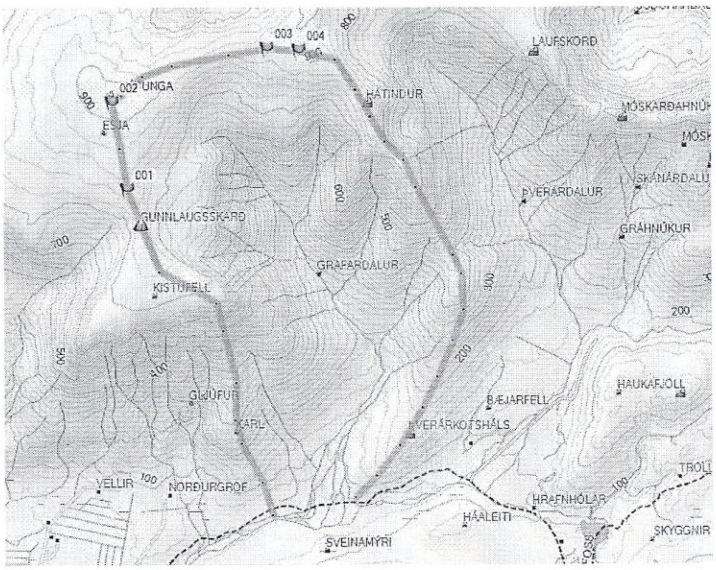

Figure 3.1 A figure that shows the basic components of a river system. The red line denotes the watershed and the area within the red line is the catchment for the river in question and all its contributories. The catchment is the basic unit in hydrology (Map: Kristinn A. Guðjónsson).

3.1 Factors that influence flow.

Other factors also affect the flow of a river. If we have two rivers with identical catchment size but one is located in a dry region and the other in a wet region it stands to reason that the one located in a wet region will have greater discharge. In addition we can have two rivers with identical catchments and precipitation but one is in a warm region and the other in a cold one. Here the one in the warm region will have less flow since greater amounts of the rain that falls will evaporate and therefore not contribute to the discharge. Finally two catchments may be of the same size, experience the same temperature and precipitation but one has porous bedrock and the other sits on impermeable bedrock. The one with impermeable bedrock will display greater discharge since overland flow is greater in that catchment (figure 3.1)

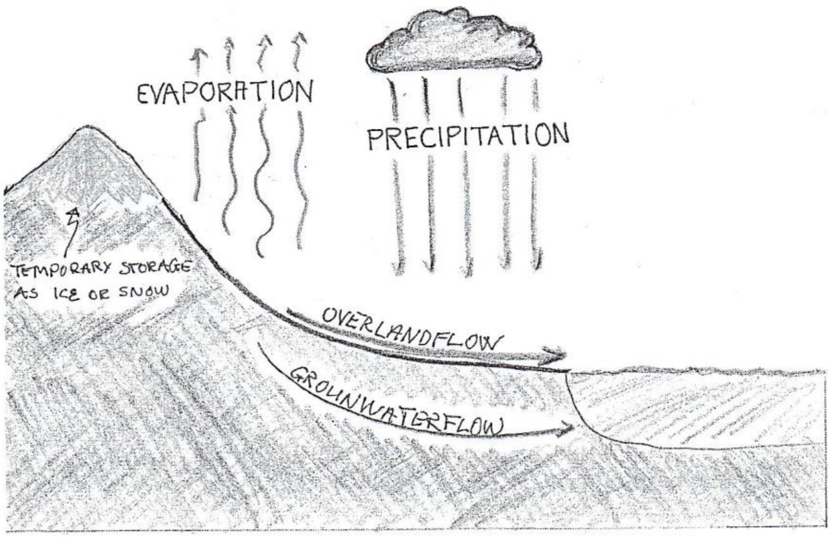

Figure 3.1: The hydrological crossroads. Precipitation that falls on the surface follows three possible routes or paths. It can run across the surface as overland flow, it can evaporate or it can seep into the ground and be carried away as groundwater. It is the type of bedrock, amount of precipitation, temperature and the porosity of the bedrock that determines the different routes (Diagram: Kristinn A. Guðjónsson)

Iceland is a wet and cold temperate environment were for most parts precipitation is geographically evenly distributed. Mountain areas tend, however, to get greater amounts of precipitation and some area in the shelter of larges mountain ranges fall within precipitation shadows. Therefore the main factor that dictates discharge in Icelandic rivers beside catchment size is bedrock type. We find that in the geologically older areas in the west, north and east of the island the permeability of the rock is high thus encouraging overland flow but the opposite is true for the porous bedrock of the volcanic areas in the south and central island.

4.0 Flow rates

Flow rates refer to how rapidly the water flows in the channel. They are typically measured in m/s. Flow rates are dictated by channel width and depth and discharge rates. High discharge usually means higher flow rates – we have more water that needs to get to the ocean and therefore it needs to move more rapidly. Channel morphology is also of importance since water flows more rapidly in narrow channels than wider ones.

While discharges remain relatively the same along a certain segment of the channel flow rate can vary radically as the channel widens and narrows. Discharge tends however, to increase slowly down the river as contributories add more water to the main channel.

The carrying capacity of the river refers to the size of the particles that it can lift. It is exponentially related to flow rates. If the flow rates are doubled the carrying capacity increases 6 times. If a river can lift a rock with the mass 1 kg at flow rates of 10 m/s then the same river has the capacity to lift a 6 kg stone if the rates increase to 20 m/s and a 36 kg stone if they increase to 30 m/s.

5.0 River load

Rivers carry with them materials of different kinds. We refer to this material as river load. Several factors influence the amount of material that a particular river carries. The most important is availability. This is best seen in glacial rivers were the glacier provides great amounts of silts and clays. Secondly the flow rate determines the carrying capacity and thirdly the discharge dictates the amounts.

We classify river load into three main categories:

1) **Suspended load:** This refers to all the fine grained material that remains for most parts suspended within the water column. Usually the grain size is clay and silt but it can be greater if the flow rate is high. This is the dominant part of the load of glacial rivers. Measurements show that the total amount of suspended sediments transported annually by rivers in Iceland is 50 million tons.
2) **Dissolved material:** When water gets into contact with bedrock it partly dissolves the rock. Salts are carried in dissolved form to the rivers and with them to the oceans. This is referred to as the dissolved load of the river. It is the greatest in rivers that are fed by groundwater. In those cases the water has been in contact with bedrock for long period of time (often hundreds of years). On averages the amount of dissolved materials in groundwater is about 70 mg/L in Iceland. If this water has a geothermal component the dissolved material may be as high as 500-1000 mg/L
3) **Bed load:** While the fine grained material stays in suspension in the water column coarser particle role along the channel floor. This material is called

bed load. Annually 35 million tons of material is carried to the oceans ir Iceland in this manner. Bed load is the greatest in rivers with high flow rates.

6.0 Classification of Icelandic rivers

This chapter deals with classification of Icelandic rivers. In short they are divided intc three categories based on the origin of the water that flows within them. These categories are: ***spring fed rivers***, ***runoff rivers*** and ***glacial rivers***. The followinc chapters describe each river type. They describe the channel morphology, flow regimes, geographical distribution and sediment transport of each category.

6.1.0 Runoff rivers

When it rains on impermeable surfaces the water flows over the surface forminc small creaks that unite in ever bigger creeks and rivers - a runoff river is formed Runoff rivers therefore have no fixed point of origin but develop from many smal source their water is either rain water or, in colder regions, snow melt. The smalle

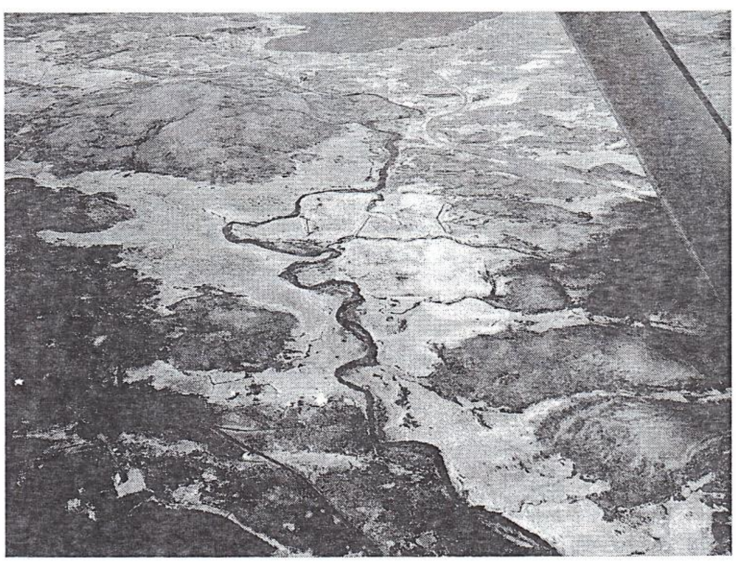

Figure 6.1 A section of a meandering river channel (Photo: Kristinn A Guðjónsson)

rivers that flow into the main channel are called contributories. In the upper reaches of the river this network of channels forms a dendritic pattern (see figure 3.1). On relatively flat land in the lower reaches of the river the channel usually meanders (figure 6.1). Wear these river enter the ocean or lakes they form moderately large deltas.

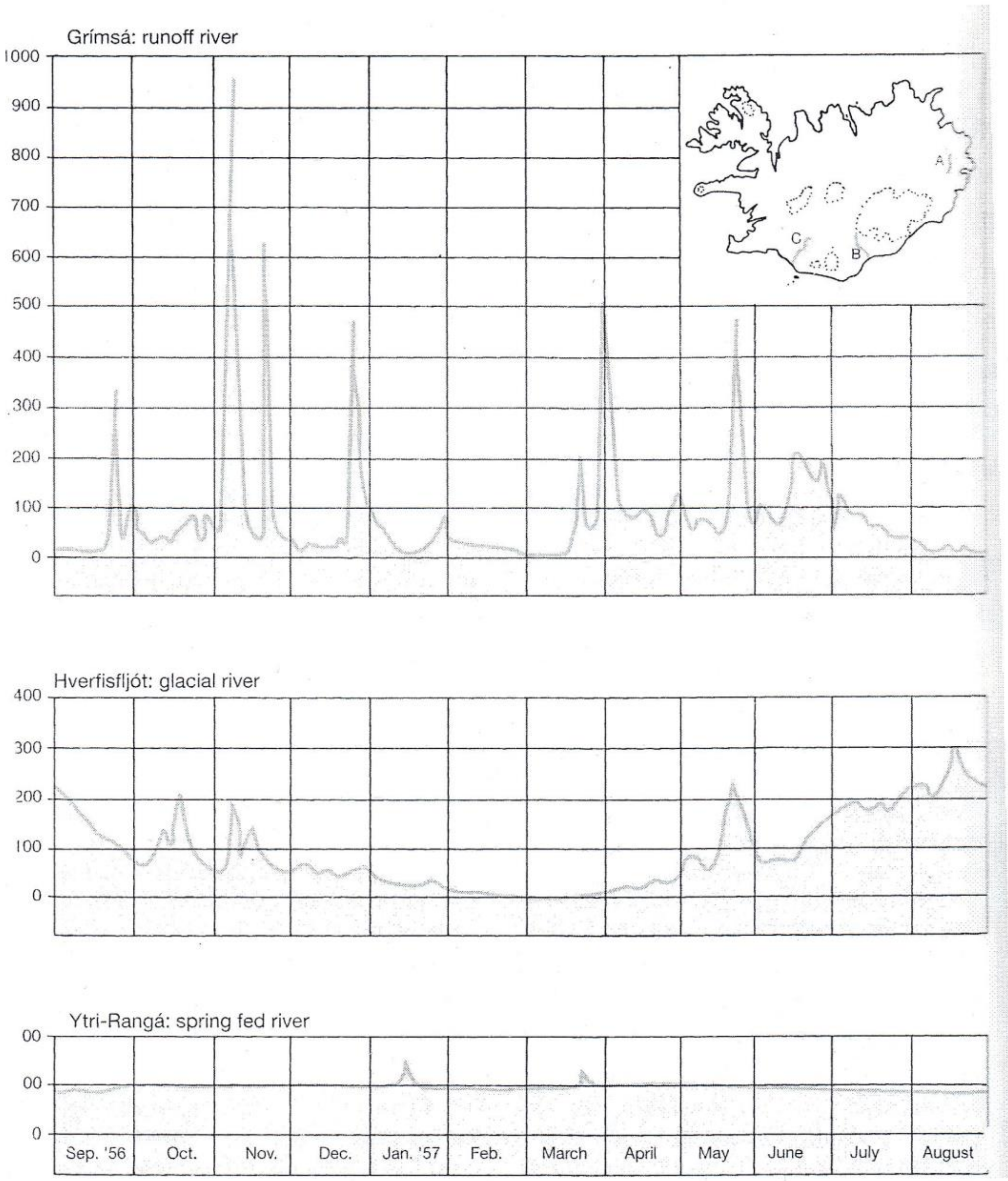

Figure 6.2 Flow regimes of three river types. At the top a typical runoff river. Note the discharge peak during spring melt and fall rains. Winter discharge close to zero and summer discharge reflecting precipitation. The glacial river (central graph) freezes up during winter with minor discharge peaks during fall rains and spring melt and progressively increasing discharge as summer progresses. Finally the spring fed river with constant discharge during the year. Note small discharge peaks in winter time when surface runoff is generated as rain falls on frozen ground (Þorleifur Einarsson, 1992).

6.1.1 Flow regimes of runoff rivers

In warm and temperate areas the flow reflects precipitation. In dry periods the discharge is low but high during the rainy seasons. Such flow regimes are called ***pluvial regimes***. In arctic areas the flow reflects snow melt rather than precipitation (which mostly falls as snow). Such flow regimes are called ***nivial regimes***. In cold temperate areas like Iceland the flow regime is a mixture of these two and is referred to as ***pluvial-nivial***. In pluvial rivers the water temperature reflects the ambient temperature but is much lower in nivial regimes (figure 6.2).

Winter discharge in pluvial-nivial regimes is usually low but is rejuvenated during winter warm spells which trigger snow melt. Spring floods are typical and occur when most of the snow in the basin is melting. Summer flow reflects precipitation.

6.1.2 Sediment load in runoff rivers

The amount of dissolved materials within runoff rivers is small. This is water that has been in short and limited contact with the bedrock thus the water has not had time to react with rocks. Most of the transport is in the form of suspended sediments but the quantities are usually not great but can depend on the availability of lose material in the area that is being flushed. However, during floods the load can go up drastically.

6.1.3 Channel morphology of runoff rivers

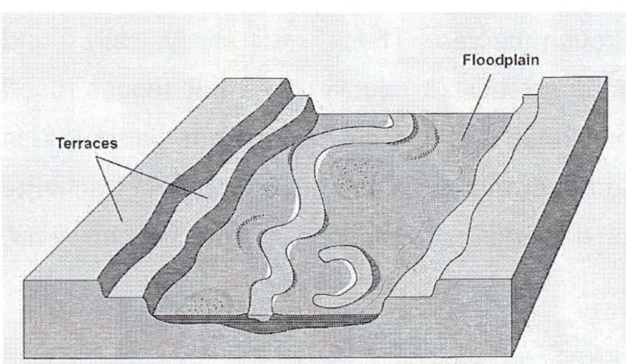

Figure 6.3 Channel transect. During normal flow the water is confined to the main channel. Bordering the main channel is the flood channel (flood plain). If foods are frequent for example seasonal the flood channel will be poorly vegetated.

As stated earlier these channels tend to be dendritic in form at the source of the rive (figure 3.1.). They are confided to deep ravines or gullies where the slope is stee but meander on relatively flat areas. In such areas the flow is confined to the mai channel but on either side of it is a poorly vegetated area which goes under wate during floods. This is called the flood channel (figure 6.3). In larger rivers the term flood plain would be more appropriate than flood channel.. Bars are common in the meandering parts of the rivers channel.

The estuary or delta area is moderately big although that does depend on the availability of sediments within the catchment.

6.1.4 Geographical distribution of runoff rivers

Runoff rivers are the dominating river type in the tertiary bedrocks of Iceland (figure 6.4). This is the geologically oldest section of the island and the bedrock therefore the most impermeable. In the more permeable bedrock of the volcanic zones water will not flow along the surface thus preventing runoff rivers from forming.

6.2 Spring fed rivers

In areas where the surface cuts the groundwater table or where groundwater is forced to the surface through other processes (e.g. by aquicludes) springs are formed. Rivers that are fed by such springs are called spring fed rivers. Contrary to runoff rivers spring fed rivers have a clear point of origin. All rivers that drain lakes display the same flow characteristics as spring fed rivers.

6.2.1 Flow regimes of spring fed rivers

Discharge rates remain continues through the year. These rivers are typically found within areas of porous bedrock so heavy rainfall usually does not trigger runoff events since most of the water infiltrates the ground. Long-term variations in precipitations can raise or lower the groundwater table and therefore affect discharge rates over long time period. Seasonal or diurnal variations in flow are, however, minor.

Figure 6.4 The geographical distribution of two river types in Iceland. The runoff rivers are found on the impermeable bed rock outside of the active volcanic zone (blue on map). The spring fed rivers are mostly found within the volcanically active zone of Iceland where the bed rock is permeable and surface flow rarely occurs (Map: Kristinn A. Guðjónsson)

?.2 Sediment load in spring fed rivers.

ıce the water in the channels of spring fed rivers is groundwater it is clear and free suspended sediments. The water has been in contact with the bedrock for long riods of time (in some cases hundreds of years) therefore the load is mostly solved materials.

?.3 Channel morphology of spring fed rivers.

oods are unusual in these rivers therefore the banks are grass grown down to the ter table (figure 6.5). Rivers bars are uncommon and deltas are small or non isting. On flat areas the rivers meander.

?.4 Geographical distribution of spring fed rivers.

vers in this category are found on the permeable bedrock of the volcanic zones o eland. In such area groundwater flow is immense and springs are common (figure 4). Spring fed rivers often originate from underneath modern lava fields. All of the ecipitation that fall on the lava infiltrates into the ground and flows along the sub rface until it reaches the outer margin of the lava field (figure 6.5).

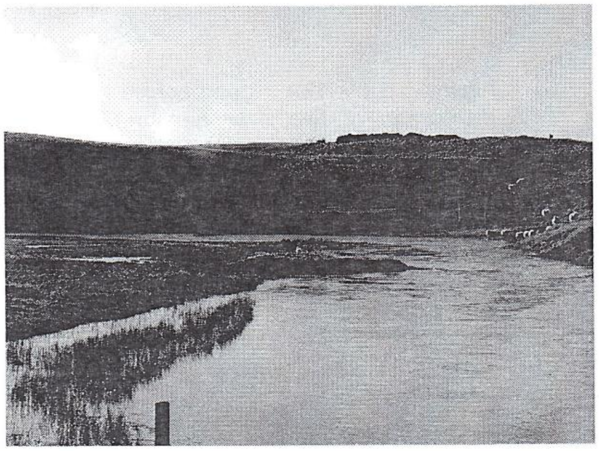

Figure 6.5 Spring fed river at point of origin The river comes from underneath a moder lava in the background of the photo and th flow is continues throughout the year. Th banks are grass grown down to the wate table. Floods almost never occur. Lon term variations in flow my take place bu they reflect long term variation i precipitation within the area (Photo: Kristin A. Guðjónsson)

6.3 Glacial rivers

Rivers that flow from glaciers are called glacial rivers. The water within the originates for most parts from snow or ice melt on the glaciers. Some water m additionally come from the areas bordering the channel.

6.3.1 Flow regimes of glacial rivers.

Flow in glacial rivers displays great variability. Such rivers can dry up during wint months when the glacier freezes up. Flow often starts with spring floods due to m within the basin. Once summer discharge has started it reflects both temperature a precipitation. Warm and wet days produce the greatest melt while cool and dry da produce the smallest amount. As the sub glacial drainage system develops throu the summer month's flow rates tend to go up. Early in summer the glacier acts as filling reservoir since the melt water has difficulty finding its way through the ice b once the drainage system has developed this temporary reservoir is depleted th resulting in greater flow (figure 6.2). This reservoir effect is most apparent in lar glaciers.

Superimposed on these variations are diurnal variations in flow. The snowm reaches a peak at solar noon but the river flow lags behind two to six hou depending on the size of the glacier. In a similar fashion the melt is at a minimum early morning. This effect is very apparent on clear sunny days in the summertir (figure 6.6). In short glacial river display the highest discharge shortly after solar no and the lowest early in the morning.

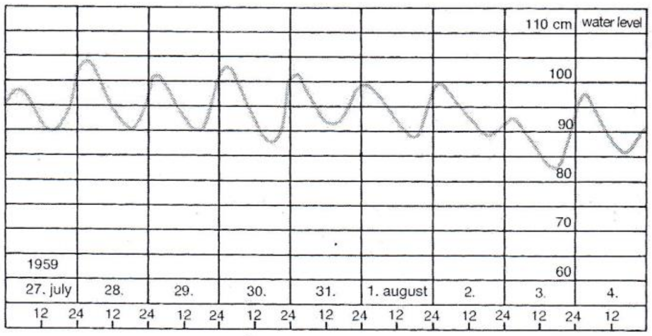

Figure 6.6 Diurnal variations in the discharge of a glacial river. In this case the lag time is almost 12 hours. The peak flow is typically around midnight but the minimum flow around noon (Þorleifur Einarsson 1992).

6.3.1.1 Jökulhlaup

In addition to the variability stated above catastrophic floods are also common. Such floods are called jökulhlaup (this in fact is the Icelandic term for this phenomena) The reasons for these floods vary but they distinguish themselves from other floods in size. Flow rates during jökulhlups can be many thousand times the average flow rates. In fact these are the biggest catastrophic floods on earth. Jökulhlaups can be triggered by different mechanisms but the most common are the following.

Jökulhlaups triggered by volcanic eruptions: When volcanoes erupt underneath glaciers they cause extremely rapid melt. The water is carried along the sub-surface towards the glacier margin. Such eruptions very commonly produce jökulhlaups with discharge rates as high as 50.000-300.000 m^3/s. Some studies indicate that jökulhlaups associated with eruptions in the volcano Katla on the south coast of Iceland may have had rates as high as 800.000 m^3/s.

Jökulhlaups triggered by geothermal activity: Geothermal areas underneath glaciers cause continues melt of the ice. The water collects in sub-glacial basins to form sub-glacial lakes. As the water level increases within the lakes the ice is lifted and eventually the lake drains and a jökulhlaup is triggered at the glacial margin These types of jökulhlaups are triggered at relatively regular intervals the length of which is determined by the ice thickness. The greater the thickness the longer is the interval and the bigger is the flood.

Jökulhlaups triggered by draining of marginal lakes: Lakes are common next to the glacier margins. This is especially true next to retrieving glaciers. Glacial outlets can also dam side valleys thus turning them into lakes. These lakes can empty swiftly causing floods in glacial rivers. The draining of the lake can occur when the lake water becomes deep enough to lift the ice dam or when the flow finds a new outlet path at a lower elevation than the previous river outlet. Many catastrophic floods of this type occurred in front of the large ice sheets of N-America and Europe during the late glacial period. Landforms like the Grand Canyon were formed during such events.

6.3.2 Sediment transport of glacial rivers

Glacial rivers transport tremendous amounts of materials from the glaciers to the oceans. The glaciers are active in mechanical weathering of the underlying bedrock and this material is carried by melt water to the river channels. Most of the material is silt that is carried in suspension in the water column but bed load is also a very important component of the overall load. The typical greyish colour of glacial rivers is due to the amount of silt in suspension.

6.3.3 Cannel morphology of glacial rivers

The river originates from a point source where it comes from underneath the glacier. On steep surfaces they dig deep and broad canyons. Normal flow is confined to central cannel but the flood channel is much broader. The bed material of the flood channel is large (boulders and rocks) and the river bars are usually composed of coarse grained materials.

Were the surface is flat the rivers become braided and can flow in thousand of channels. The sediment load is high so a particular section of the cannel fills rapidly forcing the river to create continuously new channel sections. With time west outwash plains are formed which are called sandur. This is the case with the glacial rivers on the south coast of Iceland (Mýrdalssandur, Skeiðarársandur). The jökulhlaups are important contributors to these outwash plains.

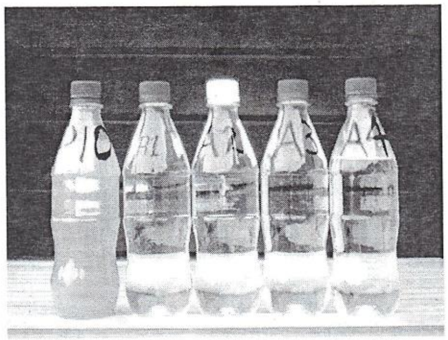

Figure 6.7 Samples from five different rivers. One is a spring fed river, three are runoff rivers and the one is a glacial river. Can you guess which the glacial one is? The samples had been standing on the table for two days when the photograph was taken (Photo: Kristinn A. Guðjónsson)

6.3.4 Geographical distribution of glacial rivers

Large glacial rivers are associated with large glaciers. Most of them are in the south and south east of Iceland. Many important and big glacial rivers drain the northern margins of these glaciers and flow towards the northern coast of the island.

7.1 Mixed rivers

Figure 7.1: Two river types meet. To the far left is Sogið Iceland's largest spring fed river and to the far right the sediment laden glacial river Hvítá, Iceland second largest glacial river. Further down the waters of these two rivers become completely mixed.

In reality few rivers can be defined as pure glacial rivers or pure runoff rivers. A typical runoff river often has a spring fed component. Spring fed rivers can join glacial rivers and so on. Most rivers are therefore mixed rivers. Their characteristics can therefore be a mixture of many river characteristics the importance of each depends on the size of the rivers that contribute to the total flow. If 80% of the water is glacial and 20% is spring fed then glacial characteristics dominate during summer but those typical for spring fed rivers become apparent during wintertime when flow from the glacier stops.