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# ASSESSING THE ECOLOGICAL STATUS OF THE HRÓARSLÆKUR CREEK, A TRIBUTARY OF THE YTRI-RANGÁ RIVER IN SOUTHERN ICELAND

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## ABSTRACT

The ecological status of rivers is of major importance for the surrounding aquatic and terrestrial ecosystems. In order to identify potential threats to the ecology of rivers, it is important to assess and monitor the status of the ecology of rivers. In the present project, a river classification method was applied to a case study in southern Iceland. The method has been used in Austria and Switzerland and accordingly had to be adapted to Icelandic conditions. For this purpose, four categories of ecological status have been developed and all river sections of the case study categorised accordingly. Hróarslækur Creek close to the town of Hella was used as a representative case study to test the method. Besides classifying the creek sections, electrical conductivity and water temperature were measured to assess some preliminary water quality observations. The study concluded by assessing the overall ecological status of the Hróarslækur Creek. The weighted ecological evaluation of all creek sections of the Hróarslækur fall into the highest ecological class defined, indicating the good ecological condition of the creek.

Key words: ecology, ecomorphology, river classification, water quality, Iceland

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# TABLE OF CONTENTS

# 1 INTRODUCTION

## 1.1 General setting of the study

The fast growing population and theirs anthropogenic activities are a threat to the sustainable functioning of ecosystems and the services they provide to the society (Millennium Ecosystem Assessment 2005). Ecosystem services can be classified in two categories: i) direct services, such as crop production and ii) indirect services such as nutrient retention, organic matter breakdown, and habitats for fauna and aquatic animals. Water bodies are an example of ecosystems which are jeopardised by the increasing pollution due to anthropogenic activities.

Rivers present habitats for a large part of the world biodiversity. Nevertheless some rivers are highly threatened by human activities (UNEP 2007). Serious impacts of pollution on water supply may subsequently also affect human health. This has brought lawmakers and water managers to focus their efforts on the water quality and eco-morphological conditions of water bodies (Moss 1998). The eco-morphological assessment of water bodies focuses in particular on channel form, water flow, and surrounding vegetation (Elosegi et al. 2012).

Physical river impairment threatens the benefits these ecosystems provide to the society (Elosegi et al. 2010). The interaction between the flow of water, the channel form (or hydro morphology) and the ecological status is called ecomorphology (also Ecological morphology). The assessment of the ecomorphology is essential to river condition and also impacts the water quality, biodiversity and river ecosystem functioning (Boix et al. 2010). A good ecomorphological status of a water body is an essential part of a sustainable management of river ecosystems. Understanding the main principles underlying the importance of channel forms and water flow for river ecosystems (including their biodiversity) are thus essential to design strategies for river classification, which was the aim of the present study.

The present study presents the methods and results of the assessment of the ecological status of a river in Iceland. This study was carried out as part of training at the United Nation University Land Restoration Training programme (UNU-LRT) in Iceland, which aims at building capacity in the field of land restoration and sustainable land management in developing countries. The case study was located in Southern Iceland, but the methods used within this project can be adapted and applied anywhere in the world. As the methods may also be applied in Niger Republic (the home country of the author), the next section presents background information on Niger Republic. In the subsequent section the following topics are presented: i) the case study investigated in Iceland, ii) reviews of relevant literature, iii) materials and methods, and iv) the results and discussion of the assessment. The study concludes by classifying all river sections of the selected case study into four different ecological classes.

## 1.2 Background information on Niger Republic

Niger Republic is a Sahelian country located in the very heart of the Sahelo-Saharan zone (ADB [African Development Bank] 2011). It is situated between latitudes 12° and 23° North and longitudes 00° and 16° East. It covers a surface area of 1,267,000 $km^2$ (CPM [Cabinet of Prime Minister] 2009). Three quarters of its surface area are desert and the southern band which represents a quarter of the total area is shelter for ¾ of the total population (Seyni

2006) and constitutes the agro-pastoral zone where agriculture and animal rearing are possible.

Niger faces recurrent food crises due to erratic and insufficient rainfall and has observed frequent droughts and desert encroachment where a grain deficit occurs about every three years (ADB 2011). The population of Niger was estimated at more than 16 million in 2011(FAO 2013) with a birth rate of 3.45%, one of the highest in the world (Tidjani 2008). More than 83% of this population live in rural areas and their principal activity is agriculture (FAO 2013). The soil is mostly sandy and therefore very sensitive to wind and water erosion (Zakari et al. 2011). Niger has various untapped fossil aquifers and multiple surface water bodies which in most cases are shared among multiple users such as industries, domestic water users, farmers, herders, aquatic life, and others. These water basins receive little rainfall due to the frequent droughts but withstand strong anthropogenic pressure affecting surface water courses. The rainfall pattern analysis shows a chronic deficit of rainfall after the wet years of 1950s over almost a continuous period of more than 25 years (Botonie & Chris 2009) which has affected the whole Sahel region, though mainly the western part. The country has two seasons: a rainy season from June to September and a lengthy dry season from October to May. The rainfall varies from south to north. The Soudano-Sahelian zone receives up to 800 mm of rainfall per year while more than half of the country receives less than 100 mm per year throughout the rainy season (Tidjani 2008).

As in various parts of the world, the surface water bodies in Niger Republic are facing serious challenges: decreasing water quality due to waste water released into the water bodies, degraded river morphology such as channelization, and intense farming activities close to the river banks which can lead to eutrophication (Finger et al. 2012), to name just the most important challenges. Up to the present day an adequate water policy which addresses the key issues is still lacking (Zakari et al. 2011).

Freshwater ecosystems of rivers, lakes and other water bodies are threatened by the construction of dams and irrigation systems that divert water to farmers' fields and city water supplies (UNESCO 1996). Dams and channelization destroy the habitats of local flora and fauna, cut rivers off from floodplains and alter natural flow on which plants and animals depend. The spreading of invasive plant species may be enhanced due to eutrophication (Elosegi et al. 2012). Climate change, pollution from agricultural land, domestic and industrial wastes discharged into water bodies impair the ecomorphological status and water quality of rivers. The strong population pressure of 75% of the population on a quarter of the total surface area of the country, with its competitive uses of natural resources along rivers provokes a deep ecological imbalance among the riparian systems and can lead to damaged ecosystems (Tidjani 2008).

The challenges cited above are waiting for solutions when I return home. The experience learned working on the case study in Iceland will be very valuable to help face the situation of the Niger River, the longest in West Africa (4200 km) and the third longest river in Africa. The Niger River is shared by 9 countries and approximately 100 million people live along its watershed (Zakari et al. 2011). This natural treasury is seriously threatened.

## 1.3 Objectives

The overall goal of this study is the classification of the Hróarslækur Creek, a tributary of the Ytri Rangá River in Southern Iceland.

The main objectives of the study were:

1. To identify sections with similar ecomorphology and classify all creek sections of the Hróarslækur Creek according to their ecological status;
2. To assess the integrated ecological quality of the Hróarslækur Creek;
3. To describe the ecomorphology of the Hróarslækur Creek.

To reach the objectives sections of the Hróarslækur creek were classified from its source to the conjunction with the Ytri Rangá into four categories: 1) natural parts where no human activities have impacted the river morphology and the water quality, as well as the environmental status of the riparian area, 2) light anthropogenic impacts with minor changes of the ecomorphology of the river, 3) restored river sections characterized by restoration activities, and 4) river sections highly affected anthropogenically characterized by channelling or degradation of water quality due to intense farming around the river. The aim of classifying the river into these four categories was to assess the ecological status of the river sections into "very good condition", "moderate or good condition", "poor or fair condition" and "bad condition" (Borja et. al 2010). Besides classifying the river sections, the following research questions were asked and answered: i) Can restoration activities prevent river degradation? ii) Do anthropogenic activities, such as supply of thermal water from close-by farmsteads, increase water temperature? iii) Does vegetation cover enhance the protection of river integrity?

The following research hypotheses were postulated:

- Anthropogenic activities impact on the river morphology and subsequently affect the ecological status of the creek.
- Land restoration activities improve the ecomorphology of the creek and subsequently enhance the overall ecological condition of the creek.

In order to classify the creek sections, electrical conductivity, water temperature and river ecomorphology were assessed along the creek to determine the overall ecological status of the Hróarslækur Creek.

The methods and model used to assess the water quality and environmental status of the Hróarslækur Creek in Southern Iceland could help to set up a similar evaluation of rivers, lakes and other surface water bodies anywhere in the world. The assessment and monitoring of the water quality and ecological status of rivers is of major importance for local residents in Niger. Accordingly, this study has also been building capacity for institutions in Niger as the knowledge will be shared among other researchers to improve research on river ecology. The results will help policymakers in designing surface water management programmes.

### 1.4 The case study of Hróarslækur Creek

The case study was carried out in a small tributary called Hróarslækur Creek that runs into the Ytri Rangá River located in southern Iceland. In the following section, the Ytri Rangá is described and then a focused description of Hróarslækur Creek is presented.

### *1.4.1 The Ytri (West) Rangá River*

The Ytri (West) Rangá river is mainly located within the municipality of Rangárþing Ytra and drains into the ocean on the south-western coast of Iceland (
Figure 1). It is about 100 km from the city of Reykjavik and 35 km east of the town of Selfoss. Its source is located north of the Hekla volcano and the town of Hella is on its east bank (
Figure 2). About 10 km downstream, the Ytri Rangá joins the river Þverá to become the Hólsá River. The distance from the source of the Ytri Rangá to the sea is about 70 km. From the Hólsá junction with the Eystri (East) Rangá River to sea is about 10 km (
Figure 1).

Using google earth, the average width of the Ytri Rangá River is estimated to be about 50 m and the average depth less than 2 m. The river bed consists mainly of black and grey volcanic sand (Federation of Icelandic River Owners 2014). The river is known for its fishing activities, the regional tourism activities and the fact that highway route no. 1 crosses it at the town of Hella. The most populated area within the watershed of the Ytri Rangá River is the town of Hella with 784 habitants (Statistical Yearbook of Iceland 2013). Hella's primary businesses are service for the agriculture and tourism industries (Statistical Yearbook of Iceland 2013). The studied creek and other tributaries discharge their water into the Ytri Rangá.

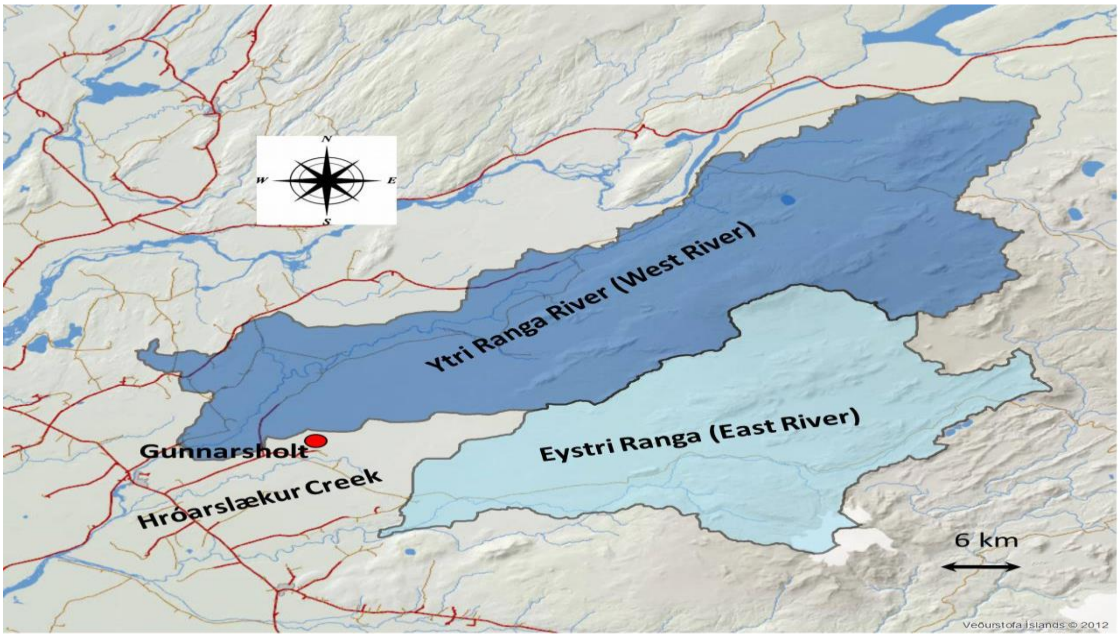


Figure 1. Overview of the study site: Hróarslækur Creek and its surroundings. The red point locates Gunnarsholt. The two blue coloured areas on the map show the drainage areas of two gauging stations in the Ytri Rangá (dark blue) and the Eystri Rangá Rivers (light blue) (Computed with Arc GIS based on a DEM provided by the Icelandic Meteorological Office 2014). The entire watershed of the two rivers extends several kilometres downstream to the Atlantic Ocean.

Figure 2. Photo shows the Ytri Rangá River (YR) and the town Hella (Source: Discover South Iceland n.d. 2012).

### *1.4.2 Description of Hróarslækur Creek*

This study focused on Hróarslækur Creek, a tributary of the Ytri Rangá River located in southern Iceland. The Hróarslækur is located between the Ytri Rangá (West Rangá) and the Eystri Rangá (East River) (
Figure 3). The discharge in the Hróarslækur originates primarily from a spring in the lava field, situated north-east of the town of Hella, close to Hekla, one of Iceland’s most active volcanoes. The creek is about 25 km long according to the field measurement.

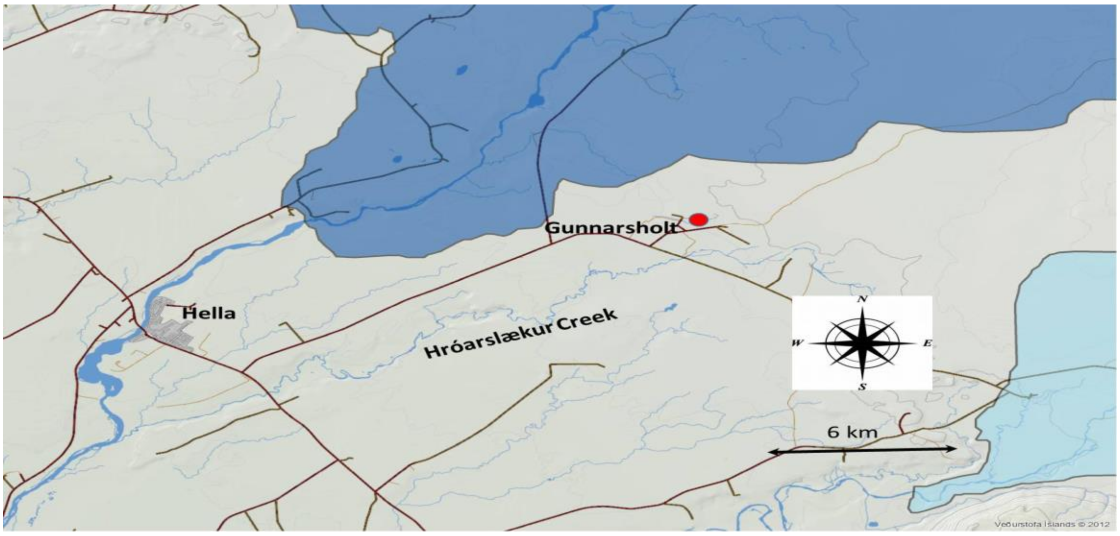


Figure 3. Map shows Hróarslækur Creek from the source to its estuary in the Ytri-Rangá River. The red point locates the Soil Conservation Service of Iceland (SCSI) headquarters. The dark blue area illustrates the water basin of a gauging station of the Ytri Rangá and the light blue area illustrates water basin of a gauging station in the Eystri Rangá River (Source: Iceland Meteorological Office).

# 2 LITERATURE REVIEW

## 2.1 River ecology

Rivers are complex systems of flowing waters draining a particular land area which can be defined as a watershed (UNESCO 1996). In many areas rivers are the main sources of freshwater for human beings (UNESCO 1996). In the past freshwater availability has been identified as a millstone for socioeconomic and political development and stability of the human community living within the watershed (UNESCO 1996). The growing demand for ecosystem services by human beings threatens the sustainability of natural resources (Elosegi et al. 2012). In some areas of the world the threshold of sustainable use of natural resources has been exceeded. In developing countries as well as in developed countries, rivers play an important role in economic health regulations for countries (rivers are used for hydropower production, agriculture, rural and urban water supply, and recreation, which are potential sources of revenue) and biodiversity conservation. A UNEP report (2007) stated that the rivers provide key services to society such us hydroelectricity production, crop production through irrigation, water supply for human consumption, fishing activities, recreational activities such as tourism and cultural activities like worshipping.

In the policy context of the Water Framework Directive (WFD) of the European Union (EU) water managers aim to achieve and maintain good water quality through biological, physicochemical and hydro-morphological assessments (Trent 2003). Nevertheless, rivers are facing serious challenges due to natural and anthropogenic factors (Baattrup-Pedersen et al. 2011). This has endangered biodiversity throughout the world (Spanhoff et al. 2012).

Serious effects of pollution on water quality and subsequent impacts on human health have drawn the attention of policy-makers and water agencies to water quality issues besides the other aspects of river condition (Elosegi et al. 2010; Moss 1998). One main concern in many areas of the world is eutrophication of fresh water, due to an oversupply of nutrients (Finger et al. 2012). These anthropogenic factors in combination with weak policies and environmental factors have endangered the resilience of ecosystems and contributed to the degradation of global rivers. Finally, effective ecological restoration leading to ecosystem resilience can only be achieved if the sustainable management of water and soil resources is in line with the aims of the local societies (Petursdottir & Finger 2014).

## 2.2 Rivers and human activities

Different human interventions such as sediment mining, channelization, dams, deforestation and control works have been identified as the causes for channel modification (Comiti 2010). According to Elosegi (2010) the channel form and hydraulics of a river provide the structural environment for ecological processes, important for river biodiversity and functioning. The channel form and water flow are key components for the ecological status of a river (Elosegi 2010). Accordingly, the river morphology plays an important role in the benefits that ecosystems provide to the society (Elosegi et al. 2012; Gurnnell 2009). The conservation of aquatic habitats and the preservation of natural flow regimes impact on biodiversity and the functioning of river ecosystems. Nevertheless, the relationships between these components are often complex (Elosegi et al. 2010) and their interaction has to be assessed in order to achieve a sustainable management of rivers (Elosegi et al. 2012). The degradation of riparian areas has an adverse effect on river water quality. The environmental objectives include the achievement of good surface water status and prevention of deterioration of existing status (Trent 2003).

The classification of the ecological status of rivers is the basis for the future sustainability of the management of natural water resources (Spanhoff et al. 2012). The WFD sets the guidelines for an integrative assessment of the ecological status of all rivers across Europe (Spanhoff et al. 2012). Furthermore, the WFD of the EU aims to achieve and maintain good water quality through Integrated River Catchment Management (Trent 2003).

## 2.3 Anthropogenic impact on rivers

The characteristics of rivers within a given water basin are related to a number of features (Murray 2008) such as the size, the topography, the geological characteristics and the climatic conditions which determine the quantities of water drained by the river network in the entire watershed (UNESCO 1996; Murray 2008).

Nevertheless, human activities around river systems could have a negative effect on rivers and its surroundings that could lead to a decrease in water quality, vegetation destruction and habitats lost through agricultural activities, road construction and mining.

In order to assess the anthropogenic impact on rivers, several classification methods have been developed to assess the ecological condition of rivers. In Austria, the ecological status of rivers was identified using a four grade classification method depending mainly on the ecomorphology of a given river (Werth 1987). In Switzerland the federal Office on Environment classified all Swiss rivers using a similar method described by Heinimann et al. (1998). To my knowledge up to the present no classification method for Icelandic conditions has yet been established. However, as rivers in Austria and Switzerland are usually fed by snow melt, glacier melt, groundwater and rain runoff, the two methods may be adapted to classify Icelandic rivers.

Frequently anthropogenic activities also impact on water quality. For example, sewage release to streams, overuse of fertiliser on agricultural fields and untreated waste water from households can lead to eutrophication of rivers and lakes (Finger et al 2013; Cheng et al. 2006; Gulati et al. 2002). Exact monitoring of water quality requires extensive water sampling and laboratory analysis of pollutants in river water. The simplest way of getting an idea of the amount of dissolved substances in a water sample is by measuring the electrical conductivity in the water. Conductivity monitoring is widely used in industrial and environmental applications as a reliable way of measuring the ionic content in a solution (Gulati et al. 2002). The conductivity of an electrolyte solution is a measure of its ability to conduct electricity. Accordingly, conductivity is directly linked to the total dissolved solids in a solution (Cheng et al. 2006). This is why conductivity was used in this study to detect changes in the concentration of dissolved substances in the Hróarslækur Creek. However, when melt- or rainwater flows through mineral rich ground, natural minerals may also dissolve into the water. This leads to a natural increase in electrical conductivity which is not a sign of anthropogenic pollution.

## 2.4 Socioeconomics

### *2.4.1 Socioeconomic importance of Hróarslækur Creek*

<u>History of Hróarslækur Creek</u>

Hróarslækur Creek has a long history. Its name was mentioned in Landnáma, which describes the Icelandic settlement. In earlier times people at each farm who owned land on its bank named the creek according to the farm name. Accordingly, Hróarslækur Creek has been given up to 13 different names (S. Runolfsson, 25th July 2014, Soil Conservation Service of Iceland, and personal communication). A map drawn by the Danish cartographer Olaf Nicolas Olsen in 1844, based on the mapping of the Icelander Björn Gunnlaugsson, shows that a lake called Reyðarvatn of about 1.02 $km^2$ was located along the river (**Error! Reference source not found.**). However, due to overexploitation of the land the area around Hróarslækur Creek became almost completely unvegetated by the end of the 19$^{th}$ century. This led to some dramatic changes in the morphology of the creek. Strong winds and sandstorms blowing from the north-east in the 19$^{th}$ century lead to tremendous sand drift, gradually filling up the lake with sand. By 1882 the lake was completely filled up with drifting sand. The sand accumulated also on the right shore of the creek looking downstream. Reports from local residents indicate that before the dramatic sand drifts the creek was populated with brown trout and very likely arctic char (S. Runolfsson, 25th July 2014, Soil Conservation Service of Iceland, personal communication).

Thirty years ago the sewage from the Akurholl Alcoholic Sanitorium and the farmstead Gunnarsholt was indirectly drained into Hróarslækur Creek through several leaky septic tanks. Today the septic tanks have been renewed and all sewage is collected by road tankers and properly disposed of (S. Runolfsson, 12$^{th}$ August 2014, Soil Conservation Service of Iceland, personal communication).

According to Mrs Drífa Hjartardóttir, the former Mayor of the Rangárþing Ytra municipality, who has lived in Keldur for many years, a farm within the vicinity of the creek, the whole area has undergone changes due to erosion control and land restoration (Mrs Drífa Hjartardóttir, 24$^{th}$ July 2014, former Mayor of Rangárþing Ytra). In addition to restoration activities, summerhouses have been constructed in the surroundings of the creek since the mid-1980s. The first summerhouse was built around 1985 and most of them soon after that (S. Runolfsson, 12th August 2014, Soil Conservation Service of Iceland, personal communication). Today, more than 10 summerhouses have been constructed along the creek and several more houses are planned in the neighbourhood.

For many summer houses the creek is used as the source of drinking water. Drinking water is primarily obtained from little nearby springs.

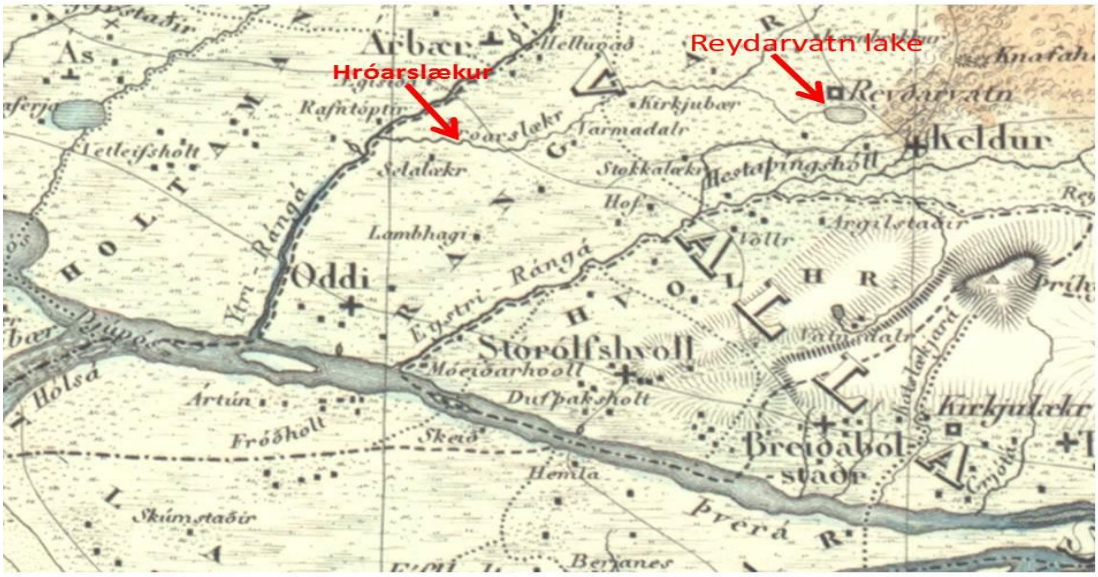


Figure 4. Map of Hróarslækur Creek showing Reyðarvatn Lake in 1844 before the sandstorms filled the lake with sand. Map drawn by Olaf Nicolas Olsen 1844 (Source: Böðvarsson 1996).

<u>Economic importance of the creek</u>

Along the creek two dams were constructed for hydropower production but the power plants are currently not in use anymore. The discharge of the creek into the Ytri Rangá at the point of confluence measured by Jonsson and Johannsson (2013) is about 5 $m^3$ per second.
Since the 1990s fingerlings have been released into different water logs of the creek, as shown in **Error! Reference source not found.**. The purpose of these efforts was to improve c atching in the creek.

The number of salmon caught in the creek currently varies between 250 and 400 annually. According to Jonsson et al. (2013) the fish catches have been increasing during recent years ( Figure 5). In addition to salmon, arctic char and brown trout are also caught but not as much as salmon in quantity. The increasing number of salmon caught is still below expectations, especially in regard to the huge quantity of fingerlings introduced into the creek since 1992.

**Table 1.** Number and type of fingerlings released into Hróarslækur from 1992 to 2013 (Source: Jonson and Johannsson 2013).

| Year | Number released | Type |
|---|---|---|
| 1992 | 9240 | Salmon |
| 1993 | 4000 | Salmon |
| 1994 | 4000 | Salmon |
| 1995 | 1500 | Salmon |
| 1996 | 3000 | Salmon |
| 1996 | 2000 | Char |
| 1997 | 5000 | Char |
| 1997 | 1000 | Trout |
| 1997 | 3000 | Salmon |
| 1998 | 3000 | Salmon |
| 1998 | 5000 | Char |
| 1998 | 1000 | Salmon |
| 1999 | 10000 | Salmon |
| 2000 | 15000 | Salmon |
| 2005 | 70000 | Salmon |
| 2006 | 70000 | Salmon |
| 2007 | 70000 | Salmon |
| 2008 | 70000 | Salmon |
| 2009 | 70000 | Salmon |
| 2010 | 70000 | Salmon |
| 2011 | 35000 | Salmon |
| 2012 | 30000 | Salmon |
| 2013 | 35000 | Salmon |

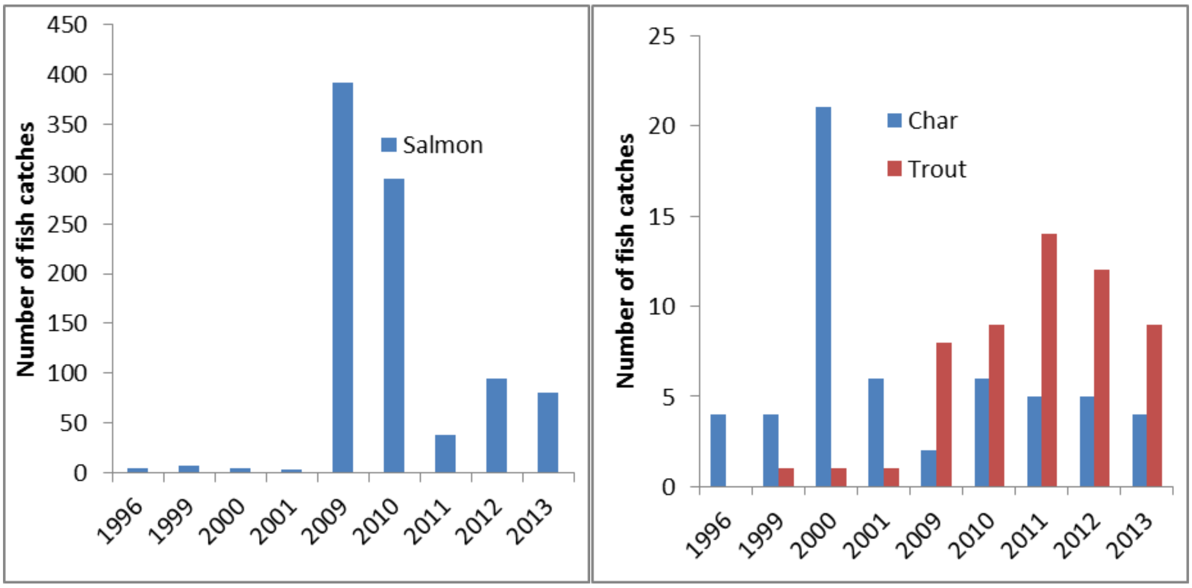


Figure 5. Fish catches in Hróarslækur Creek (Data from Jonson and Johansson 2013).

# 3 MATERIALS AND METHODS OF STUDY

## 3.1 Materials

For this study an electrical conductivity meter was used to measure the temperature and conductivity of the water during the field days. The geographic coordinates and the elevation above sea level of each measuring location were taken with a GPS map S62 device. The complete list of materials used is given in Appendix I.

## 3.2 Methods

### *3.2.1 Preliminary water quality assessment*

Due to time constraints the water quality assessment in this study was limited to measuring the electrical conductivity and temperature of creek water along the entire creek. Measurements were performed along the entire creek in order to identify locations of potential waste water input, fertilizer outwash from the surrounding fields or other dissolved substances sources. The IMO provided for each field investigation an EC meter. Unfortunately, during the two field days it was not possible to use the same EC meter. Accordingly, two different EC meters were used during each field day

Figure 6 shows the electrical conductivity (EC) meter which measures the electrical conductivity in a solution. It is used in hydroponics, agriculture and freshwater systems to monitor the amount of nutrients, salts or impurities in the water (Cheng et al. 2006).

Figure 6. Conductivity meter used in this study (type: Cond 315i SET) produced by the German company Wissenschaftlich-Technische Werkstätten GmbH (WTW).

As the conductivity is temperature dependent, conductivity and temperature should always be measured simultaneously. The WTW - Cond 315i EC meter corrects the measured conductivity automatically to a reference temperature of 25°C. Accordingly, conductivity in this thesis refers always to conductivity corrected for a reference temperature of 25°C.

### *3.2.2 Creek morphology investigations*

Up to the present no systematic method for classifying Icelandic rivers according to their ecology has been developed. Accordingly, within this study river classification methods from other geographic settings were used to inspire a new classification method for Icelandic rivers. The methods used, for example, in Austria or Switzerland are only partially suitable for Iceland or the Niger Republic, as vegetation composition, the types of agricultural activities or even the aims of the classification itself are to some extent very different. Accordingly, in this study the classification of Heinimann et al. (1998) and Werth (1987) were combined to generate a more suitable method for Icelandic conditions. The method of Heinimann et al. (1998) focuses on the following properties (see Appendix V for a more detailed description):

- ✓ Variability of water level depth
- ✓ Composition of the river sole
- ✓ Variation of the river width
- ✓ Condition and variation of the shoreline

Werth (1987) classified rivers sections in Austria by considering the following parameters:

- ✓ Stream lines and flow behavior of the river (See APPENDIX V for a more detailed description)
- ✓ Condition of the benthic zone (sole) of the river
- ✓ Interaction between water and land
- ✓ Vegetation, shrubs and condition of the littoral zone
- ✓ Vegetation of the embankment and the shore

For the classification of Hróarslækur Creek sections the criteria defined by Werth (1987) and Heinimann et al. (1998) have been combined into four criteria suitable for Icelandic rivers. The defined criteria are summarized in Table 2.

**Table 2.** Summary of four criteria for the ecological classes.

| | **Class 1 (Grade 0-1) Poor condition** | **Class 2 (Grade 1-2) mediocre condition** | **Class 3 (Grade 2-3) fairly good condition** | **Class 4 Grade (3-4) Very good condition** |
|---|---|---|---|---|
| **Benthic zone** | Concrete or sandy sole | Muddy | Gravel and sand | Gravel and rock |
| **Flow line** | Channelized and concrete benthic zone | Channelized with sandy benthic zone | Straight not channelized | meandering |
| **Littoral zone** | Concrete walls or tube | Eroded | Vegetated with sign of erosion | Very well vegetated |
| **Surrounding Vegetation** | No or little vegetation | Sparse grass and single trees or shrubs | Grass and sparse trees or shrubs | High density of trees, shrubs and grass |

In order to quantify the overall ecological status of every creek section, numbers from 1 (poor condition) to 4 (very good condition) were assigned for all four criteria. This numbering allows calculating the average ecological condition considering all four criteria. Finally, the overall ecological status of the creek can be computed by averaging the grade of all creek sections. The criteria summarized in Table 2 are explained below in more detail.

- Benthic zone: This is the bottom of the creek. The benthic zone is called the sole in accordance with Werth (1987). The sole of the benthic zone may be composed of sand, gravel, rock and mud or a combination of sand and gravel, rock and gravel or sandy-mud. In the developed method, if the benthic zone is very heterogeneous and composed of gravel and rock it is graded “4”. It is graded “1”if the benthic zone is sandy or constructed with concrete, mainly because sand is a sign of erosion. If the benthic zone is muddy, it is ranked “2” because mud is better than sand. If the benthic zone is composed of gravel and sand then it is graded “3”.
- Flow line: The flow line can be meandering or channelized. If a river is in a natural condition, meandering flow lines are frequent, but make it also difficult for farmers to use the surrounding areas. Channelized rivers allow for a better cultivation of surrounding areas. Accordingly, the flow line is graded “4” if it is meandering. If the flow line is channelized with both banks and the benthic zone constructed with concrete then it is graded “1”.
- Littoral zone, called also river banks: In Werth (1987) the littoral zone is called “shore”. The littoral zone is graded “4” if it is very well vegetated without any sign of human impairment or degradation due to grazing or wind erosion. If the littoral zone is dammed with concrete or rock it is then graded “1”.
- Surrounding vegetation: In the developed method, the surrounding vegetation was defined as an additional criterion for the ecological status of the creek. The vegetation around the creek is composed of trees, shrubs and grass mainly. If the surrounding vegetation of a given section is densely composed of trees, shrubs and grass it is graded “4”. If there is no vegetation on a particular section or if it is completely degraded then it is graded “1”.

The average of the “grades” for every criterion gives the overall evaluation of a section. The overall classification of the entire creek is then calculated by computing a length weighted average of all sections, as indicated in the following equation:

$$G_{overall} = \frac{1}{N}\sum_{s=N}^{s=1}\frac{L_s}{L_{tot}}G_s$$

where:
$G_{overall}$: Overall grade for the entire creek
$G_s$: aggregated grade for a creek section
N: total number of sections
S: section number
$L_s$: length of section
$L_{tot}$: total length of the creek

# 4 RESULTS

## 4.1 Sections of Hróarslækur Creek

As described in the method section, Hróarslækur Creek was divided into creek sections with distinct characteristics in creek morphology, the vegetation cover, littoral condition and benthic zones. In the Table 3 below the geographic coordinates of every creek section identified, the dates of the investigations and the names of the investigators are summarized.

**Table 3**. Section number coordinates of creek sections and dates of investigation are shown in the following table. The investigators were: Saidou Amadou Moussa (SAM) and David Finger (DF); ER stands for Eystri Rangá and YR stands for Ytri Rangá sampling locations.

| | **Start** | | **End** | | **Date of investigation** | **Investigators** |
|---|---|---|---|---|---|---|
| Sections | X | Y | X | Y | | |
| 1 | 20.1151 | 63.8329 | 20.11733 | 63.83285 | 26.6.2014 | SAM & DF |
| 2 | 20.11733 | 63.83285 | 20.1203 | 63.83271 | 26.6.2014 | SAM & DF |
| 3 | 20.1203 | 63.83271 | 20.12639 | 63.83205 | 26.6.2014 | SAM & DF |
| 4 | 20.12639 | 63.83205 | 20.13782 | 63.83693 | 26.6.2014 | SAM & DF |
| 5 | 20.13782 | 63.83693 | 20.14114 | 63.84038 | 26.6.2014 | SAM & DF |
| 6 | 20.14114 | 63.84038 | 20.14024 | 63.84399 | 26.6.2014 | SAM & DF |
| 7 | 20.08993 | 63.50993 | 20.09108 | 63.51046 | 28.06.2014 | SAM |
| 8 | 20.09108 | 63.51046 | 20.09353 | 63.51164 | 28.06.2014 | SAM |
| 9 | 20.09353 | 63.51164 | 20.15538 | 63.85538 | 28.06.2014 | SAM |
| 10 | 20.15538 | 63.85538 | 20.15639 | 63.85649 | 28.06.2014 | SAM |
| 11 | 20.15639 | 63.85649 | 20.15915 | 63.85742 | 28.06.2014 | SAM |
| 12 | 20.15915 | 63.85742 | 20.16306 | 63.85682 | 28.06.2014 | SAM |
| 13 | 20.18287 | 63.85378 | 20.18287 | 63.85378 | 28.06.2014 | SAM |
| 14 | 20.19296 | 63.85665 | 20.20158 | 63.85537 | 28.06.2014 | SAM |
| 15 | 20.20158 | 63.85537 | 20.20386 | 63.85467 | 28.06.2014 | SAM |
| 17 | 20.22083 | 63.85201 | 20.23013 | 63.85026 | 05.07.2014 | SAM |
| 18 | 20.23013 | 63.85026 | 20.24018 | 63.84767 | 05.07.2014 | SAM |
| 19 | 20.24018 | 63.84767 | 20.25302 | 63.84207 | 05.07.2014 | SAM |
| 20 | 20.25302 | 63.84207 | 20.26653 | 63.84204 | 05.07.2014 | SAM |
| 21 | 20.26653 | 63.84204 | 20.2948 | 63.83875 | 07.07.2014 | SAM |
| 22 | 20.2948 | 63.83875 | 20.29742 | 63.83535 | 07.07.2014 | SAM |
| 23 | 20.29742 | 63.83535 | 20.29977 | 63.83461 | 07.07.2014 | SAM |
| 24 | 20.29977 | 63.83461 | 20.30216 | 63.83474 | 07.07.2014 | SAM |
| 25 | 20.30216 | 63.83474 | 20.33427 | 63.8269 | 07.07.2014 | SAM |
| 26 | 20.33427 | 63.8269 | 20.33558 | 63.82802 | 07.07.2014 | SAM |
| 27 | 20.33558 | 63.82802 | 20.35413 | 63.82081 | 09.07.2014 | SAM |
| 28 | 20.35413 | 63.82081 | 20.36814 | 63.81853 | 09.07.2014 | SAM |
| 29 | 20.36814 | 63.81853 | 20.39056 | 63.81382 | 09.07.2014 | SAM |
| 30 | 20.39056 | 63.81382 | 20.40039 | 63.81256 | 09.07.2014 | SAM |
| 31 | 20.40039 | 63.81256 | 20.41285 | 63.80812 | 09.07.2014 | SAM |
| ER | 20.40222 | 63.83732 | | | 29.07.2014 | SAM & DF |
| YR | 20.25 | 63.75 | | | 29.07.2014 | SAM & DF |

## 4.2 Ecomorphology of the creek sections

### *4.2.1 Section 1*

Section1 includes the source of the Hróarslækur Creek. It is densely vegetated with trees, shrubs and grass (Figure 7). It is fenced off against the crossing of any animals such as horses or sheep. Drinking water intake for the adjacent summerhouses is located here. There is also an unused watermill wheel located in this section, which is however made of wood and does not affect the ecological status of the creek in any way. This section contains also one of the sources of the river where water comes from spring in the lava. The water depth is 10 to 20 cm and the width is about 5 m but very irregular. The banks of the creek at this point were desert in 1980 but vegetation has been restored by the summerhouse owners and the bank is now well covered with native Icelandic vegetation, for example birch trees (*Betula pubescens*). The benthic zone is sandy with stone and earth.

Figure 7. One of the sources of the creek (left) and an unused hydropower wheel (right) in section 1. Photos were taken on 26 June 2014.

Classification of section 1 according to the criteria defined in the method section:

| | |
|---|---|
| Flow Line | 4 |
| Benthic zone | 3 |
| Littoral zone | 4 |
| Vegetation | 4 |
| Overall $G_s$: | 3.75 |

*4.2.2 Section 2*

This section is characterized by grass without trees but numerous shrubs grow along the creek banks. The benthic zone is composed of sand and the flow line is meandering. The creek bank is eroded on the right side bank of the creek (not visible in the picture) when moving downstream and the vegetation cover less dense than in section1 at the left of the creek, as shown in Figure 8. A summerhouse is located at about 100 m distance from the creek. The surroundings are mainly characterized by prairie and horse grazing areas.

Figure 8. Picture showing vegetation cover and summerhouse of section 2. Photo was taken on 26 June 2014.

Classification of section 2 according to the criteria defined in the method section:

Flow Line: 4
Benthic zone: 3
Littoral zone: 4
Vegetation: 3
Overall $G_s$: 3.5

### *4.2.3 Section 3*

Section 3 of the creek is characterized by a sandy benthic zone covered in some areas by small rocks and gravel. The slope of the banks is steep and partially eroded. The vegetation is mostly grass with single trees. Further along the creek widens, as shown in Figure 9. The vegetation is composed of grass and shrubs.

Figure 9. Section 3 of the creek. Photo was taken on 26/06/2014.

Classification of section 3:

Flow Line: 4
Benthic zone: 1
Littoral zone: 2
Vegetation: 2
Overall $G_s$: 2

### *4.2.4 Sections 4, 5 and 6*

These three sections all have a meandering flow line. The benthic zone is composed of earth and mud. The difference between the three sections resides in the vegetation composition and littoral zones. The vegetation of section 4 is mostly shrubs and grass on both sides (Figure 10) while at section 5 vegetation is composed of grass with sparse shrubs. Section 6 has steep banks more than one meter high (
Figure 11). The creek is quite large but very shallow.

Figure 10. Vegetation cover of section 4 with grass and shrubs. Photo was taken on 26 June 2014.

Classification of section 4 (refer to Table 6 for the classification of sections 5):

Flow Line: 4
Benthic zone: 3
Littoral zone: 3
Vegetation: 3
Overall $G_s$: 3

Figure 11. Photo of section 6 shows vegetation cover with single shrubs. Photo was taken on 26 June 2014.

Classification of section 5 and 6:

Flow Line: 4
Benthic zone: 2
Littoral zone: 3
Vegetation: 2
Overall $G_s$: 2.75

*4.2.5 Sections 7 and 8*

Sections 7 and 8 are meandering in flow line. The benthic zone of section 7 is sandy with little mud while the section 8 benthic zone is essentially muddy. Both sections have well vegetated creek banks on the left of the creek but the right side section 8 is eroded with no vegetation cover. The vegetation around the creek for these two sections is mostly grass with sparse shrubs, as shown in Figure 12 and Figure 13, respectively.

Figure 12. Photo shows littoral zone vegetation cover of section 7. Photo was taken on 26 June 2014.

Classification of section 7:

Flow Line: 4
Benthic zone: 3
Littoral zone: 4
Vegetation: 3
Overall $G_s$: 3.5

Figure 13. Photo showing eroded right side bank of section 8. Photo was taken on 28 June 2014.

Classification of section 8:

Flow Line: 3
Benthic zone: 2
Littoral zone: 2
Vegetation: 2
Overall $G_s$: 2.25

*4.2.6 Sections 9 to 12*

The sections have the same flow lines. The difference results in benthic and littoral zones and vegetation composition. The river bed of section 9 is muddy while sections 10 and 11 have respectively rocky and sandy benthic zones. Section 12 has a sandy river bed. The vegetation cover is mostly grass with more or less shrubs. The left side littoral zone of section 9 is well vegetated by grass while the right side is composed of sparse shrubs and eroded up to five meters away from the river, as shown in Figure 14. The benthic zone is covered with perennial plants *(Stuckenia filiformis).*

Figure 14. Photo shows the section 9 vegetation cover with sparse shrubs and eroded zone five meters away from the creek and perennial plants (*Stuckenia filiformis)* in the benthic zone. Photo was taken on 28 June 2014.

Classification of section 9 (refer to Table 6 for the classification of sections 10, 11 and 12):

Flow Line: 4
Benthic zone: 2
Littoral zone: 4
Vegetation: 3
Overall $G_s$: 3

*4.2.7 Sections 13 to 19*

These sections are different from the previous sections by the presence of Hróarslækur Hotel in section 13 (Figure 15). From the discussion I had with the former mayor of Rangárþing Ytra municipality and the SCSI Director, hotels in Iceland are not granted an operating licence unless they use proper septic tanks and comply with environmental protection measures. Nevertheless, an open pit was discovered during the field work (Figure 15). After the discussion with the Director of Hróarslækur Hotel, it was found out that the water in the pit is the excess of geothermal water that the hotel releases. Preliminary conductivity measurements in this section did not reveal increased electrical conductivity (see also section 4.3). In sections 18 and 19 the creek flows in proximity to the SCSI headquarters in Gunnarsholt, where restoration activities have been ongoing since early in the last century (Fig. 16). The river then passes a road where the river has been channelized (Figure 17). Close to the Hróarslækur Hotel there is a small pond and the vegetation is composed of grass, shrubs and trees and *Stuckenia filiformis* in the benthic zone. The flow line is straight at section 14 then meanders in sections 16 and 17.  Close to the SCSI headquarters in section 18 the vegetation is mainly composed of trees, shrubs and grass (Figure 16). The creek banks are walled in section 15 due to the construction of a culvert on the extension of road 264, as shown in Figure 17.

Figure 15. Hróarslækur Hotel with a pipe releasing an excess of geothermal water from the hotel in an open pit close to creek section 13. Photo was taken on 28 June 2014.

Figure 16. Vegetation cover composed of trees, shrubs and grass on restored land close to the SCSI headquarter section 14 (left) and upper dam built in 1953 used for hydropower production for Gunnarsholt (right). Photos were taken on 28 June 2014.

Classification of section 14 (refer to Table 6 for the classification of sections 13, 16, 17, 18 and 19):

Flow Line: 4
Benthic zone: 3
Littoral zone: 4
Vegetation: 4
Overall $G_s$: 3.75

Figure 17. Photo of section 15 shows a channelized section of the creek due to the construction of the culvert. Photo was taken on 28 June 2014.

Classification of section 15:

Flow Line: 1
Benthic zone: 1
Littoral zone: 1
Vegetation: 0
Overall $G_s$: 0.75

*4.2.8 Sections 20 to 26*

The flow lines of these sections are meandering. The difference resides in the banks and benthic zone of the river. The vegetation cover of sections 20, 21, 23, 24 and 25 is essentially composed of grass with single shrubs in section 22 (Figure 18). The benthic zone of section 21 is composed of rock and gravel and section 24 has a sandy-gravel benthic zone. The littoral zone of all the sections is well vegetated except for sections 24 and 26 which are eroded, as shown in Figure 19 and 20. The creek has been modified by the construction of a hydropower dam in section 26, as shown in Figure 21Figure **21**, which is no longer in use.

Figure 18. Photo shows isolated shrubs in section 22. Photo was taken on 5 June 2014.
Classification of section 22 (refer to Table 6 for the classification of sections 20, 21 23 and 25):

Flow Line: 4
Benthic zone: 2
Littoral zone: 3
Vegetation: 2
Overall $G_s$: 2.75

Figure 19**.** Photo shows eroded littoral zone of section 24. Photo was taken on 7 June 2014**.** During field data collection I found horses grazing around this section. Fences can be seen protecting the next section of the creek in the photo. The littoral zone is well vegetated.

Classification of section 24:

Flow Line: 4
Benthic zone: 3
Littoral zone: 1
Vegetation: 2
Overall $G_s$: 2.5

Figure 20. Photo shows the steep eroded littoral zone of section 26. Photo was taken on 7 June 2014**.**

Classification of section 26:

Flow Line: 4
Benthic zone: 3
Littoral zone: 2
Vegetation: 2
Overall $G_s$: 2.5

Figure 21. Photo shows the lower dam built in 1947, from unused hydropower station section 26. Photo was taken on 7 June 2014**.**

*4.2.9 Sections 27 to 31*

These sections differ from the previous sections by their proximity to the town of Hella. The traffic is very high around section 27 close to the ring road (main highway of Iceland, also called Route 1). The vegetation covers, benthic and littoral zones differ from section to section, and likewise the flow line. Section 27 is channelized at the bridge on the ring road, as shown on Figure 22. The right side vegetation cover of section 28 is composed of trees, shrubs and grass (Figure 23) with only grass on the left side.

Figure 22. Photo shows channelized river section 27 under a bridge on Route 1. Photo was taken on 9 June 2014.

Classification of section 27 (refer to Table 6 for the classification of sections 29 and 30):

Flow Line: 1
Benthic zone: 2
Littoral zone: 1
Vegetation: 1
Overall $G_S$: 1.25

Figure 23. Photo shows right side vegetation composition of section 28. It is composed of trees, grass and single shrubs with recreational area. Photo was taken on 9 June 2014. The left side is composed of grass only.

Classification of section 28:

Flow Line: 4
Benthic zone: 2
Littoral zone: 3
Vegetation: 3
Overall $G_s$: 3

The confluence of Hróarslækur Creek with the Ytri Rangá River at section 31 is eroded. The vegetation cover is mainly grass. The benthic zone is sandy with a little gravel. The littoral zone is eroded and the flow line is meandering, as shown in Figure 24 below.

Figure 24. Photo section 31 shows the junction of the creek with the Ytri Rangá River. Photo was taken on 9 June 2014.

Classification of section 31:

Flow Line: 2
Benthic zone: 2
Littoral zone: 2
Vegetation: 2
Overall $G_s$: 2

### *4.2.10 Overview of all sections*

The results of all the observations described above are summarized in the following (Table 4).

**Table 4.** Ecological status of all sections of Hróarslækur Creek including the ecomorphology of every section based on the criteria described in Table 2. R&L stands for right and left creek bank side in flow direction (upstream to downstream).

| Sections | Flow line | Benthic zone | Littoral zone | Vegetation |
|---|---|---|---|---|
| 1 | meandering | sandy/gravel | Natural/grass (R&L) | Very veg. (Grass, trees and shrubs) |
| 2 | meandering | sandy | Natural/grass (R&L) | Very veg. (Grass, trees and sparse shrubs) |
| 3 | meandering | more sandy | Eroded and sandy bank | Few shrubs (L&R), grass |
| 4 | meandering | sandy/little rock | Grass (R&L) | Grass, shrubs |
| 5 | meandering | muddy | Grass (R&L) | Shrubs, grass |
| 6 | meandering | muddy | Grass (R&L) | Grass |
| 7 | meandering | sand & muddy | Natural/grass & sparse shrubs | Grass & sparse shrubs |
| 8 | small lake | muddy | Eroded on the right/natural, on left | Grass & sparse shrubs |
| 9 | meandering | muddy with vegetation | Natural/grass | Grass |
| 10 | meandering | sand | Natural | Prairie |
| 11 | meandering | bedrock | Natural/shrubs & grass | Prairie |
| 12 | straight | stone & gravel | Natural/grass | Trees, shrubs and grass |
| 13 | meandering | sand | Eroded | Sparse grass |
| 14 | meandering | rock | Natural/grass | Trees, shrubs, grass |
| 15 | meandering | dammed | Culvert | Road |
| 16 | meandering | stone & gravel | Eroded left, shrubs and grass right | Grass & shrubs |
| 17 | meandering | sand & gravel | Natural | Grass |
| 18 | meandering | stone & gravel | Eroded steep left & flat right | Grass left & grass, shrubs right |
| 19 | meandering | stone & gravel | Eroded very steep slope 5 m left & grass right | Grass |
| 20 | meandering | gravel | Very steep slope | Grass, shrubs and trees |
| 21 | meandering | rock | Walled | Grass + trees |
| 22 | meandering | rock, gravel | Channelized with rock(R), natural (L) | Grass |
| 23 | lake | muddy + sand | Grass | Grass |
| 24 | meandering | sand + gravel | Eroded | Grass |
| 25 | Meandering divided | muddy | Grass | Grass |
| 26 | Meandering | muddy | Eroded steep slope, bank length 5m | Grass single shrubs |
| 27 | Straight | dammed | Walled with bridge on top | Road |
| 28 | Meandering | muddy | Grass | Grass + single shrubs |
| 29 | Meandering | muddy | Natural with steep slope | Trees at the right + grass and only grass at the left |
| 30 | Meandering | muddy | Grass + single shrubs | Prairie + summer houses |
| 31 | Junction with Ytri Rangá River | sand + gravel | Steep bank slope and flat eroded at the junction with Ytri Rangá | Degraded commons for animal grazing |

## 4.3 Hydrological properties

The water quality investigation was limited to measuring the electrical conductivity and the temperature of the water at different points. The results of these observations are summarized in Table 5.

**Table 5**. Water temperature, conductivity, width and depth of the creek section of Hróarslækur Creek and the measurements from section 1 to section 13 were performed on 26.06.2014 (a cloudy and rainy day). The other measurements were performed on 29.07.2014 (a sunny and dry day). ER stands for Eystri Rangá measuring location and YR stands for Ytri Rangá measuring location; both measurements were performed for comparison reasons.

| Sections | Conductivity (μS/cm) | Temperature (°C) | Width (m) | Depth (m) |
|---|---|---|---|---|
| 1 | 205 | 3.7 | 15 | 0.3 |
| 2 | 210 | 3.6 | 10 | 0.3 |
| 3 | 210 | 3.7 | 12 | 0.4 |
| 4 | 210 | 4 | 11 | 0.5 |
| 5 | 207 | 5.6 | 14 | 0.5 |
| 6 | 208 | 6.4 | 13 | 0.5 |
| 7 | 209 | 7.1 | 14 | 0.3 |
| 8 | 208 | 7.2 | 45 | 0.35 |
| 9 | 211 | 7.0 | 15 | 0.15 |
| 10 | 210 | 7.2 | 12 | 1.3 |
| 11 | 209 | 7.3 | 20 | 1 |
| 12 | 210 | 7.5 | 10 | 0.6 |
| 13 | 210 | 8.0 | 20 | 0.3 |
| 14 | 229 | 8.2 | 15 | 1 |
| 15 | 230 | 8.2 | 15 | 1 |
| 16 | 228 | 8.1 | 21 | 0.19 |
| 17 | 227 | 8.3 | 15 | 0.29 |
| 18 | 230 | 8.5 | 30 | 0.4 |
| 19 | 229 | 8.9 | 10 | 0.6 |
| 20 | 228 | 9.0 | 20 | 0.7 |
| 21 | 228 | 9.1 | 15 | 0.5 |
| 22 | 229 | 9.1 | 40 | 0.3 |
| 23 | 230 | 9.3 | 18 | 0.4 |
| 24 | 226 | 9.2 | 20 | 0.3 |
| 25 | 230 | 9.7 | 16 | 0.6 |
| 26 | 229 | 9.7 | 12 | 0.5 |
| 27 | 230 | 9.9 | 25 | 0.3 |
| 28 | 230 | 10.1 | 15 | 0.5 |
| 29 | 229 | 10.2 | 15 | 0.4 |
| 30 | 229 | 10.3 | 20 | 0.3 |
| 31 | 229 | 10.5 | 20 | 0.3 |
| ER | 123 | 8.7 | | |
| YR | 212 | 9.5 | | |

**Error! Reference source not found.** and Figure 26 show the trend of both electrical conductivity and temperature. The variation of electrical conductivity from section 1 to section 13 was between 208µS/cm and 210µS/cm. Nevertheless, it can be seen that the EC increased from section 14 to section 29 and reached 229µS/cm and continued to rotate around 229µS/cm and 230µS/cm (Figure 25).

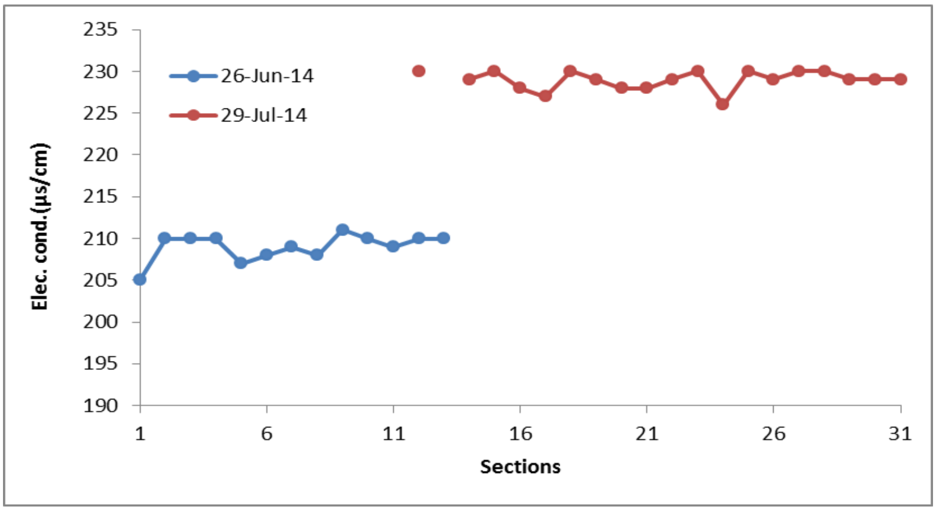


Figure 25**.** Electrical conductivity variation along the Hróarslækur Creek. The label in the figure indicates the date when measurements were performed.

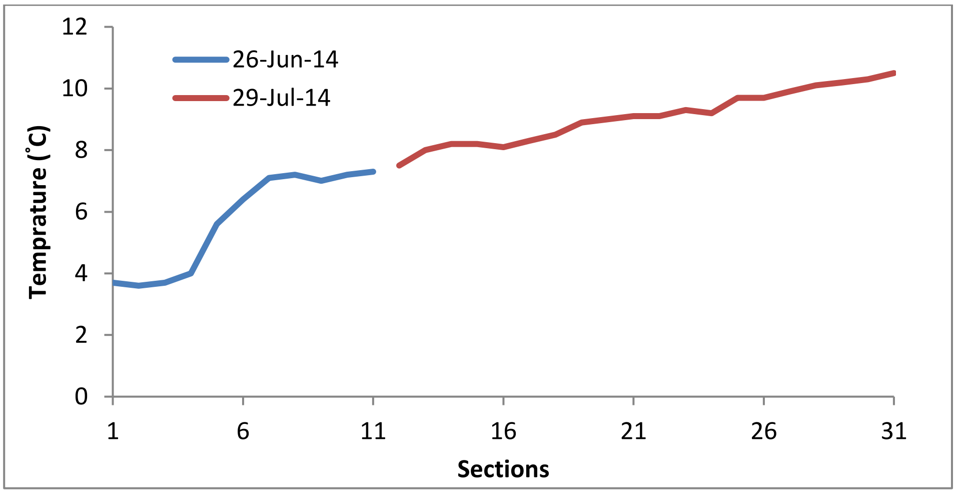


Figure 26. The figure shows the evolution of the water temperature along Hróarslækur Creek from upstream to downstream. The label in the figure indicates the date when measurements were performed.

### 4.4 Surroundings

The creek is surrounded from the source to the confluence point with the Ytri Rangá River by horse pastures and farming land. Furthermore several summerhouses are located around the creek. The SCSI headquarters and the Hróarslækur Hotel are near the creek. From the source of the creek to the conjunction with the main river there are two unused dams constructed originally for hydropower production, one culvert on the extension of Road 264 and one bridge close to the town of Hella.

## 4.5 Ecological evaluation of the creek

The classification was made based on the ecomorphological status of the creek as described in section 4.2.4. The overall evaluations of the different sections of the creek are given in Table 6.

**Table 6.** Creek sections classification based on the criteria of Table 2 (1=very bad quality, 2=bad quality, 3=good quality, 4 =very good quality). Ls stands for length of the section.

| Sections | Ls (m) | flow line | Benthic zone | Littoral zone | Vegetation | Overall | Classes |
|---|---|---|---|---|---|---|---|
| 1 | 325 | 4 | 3 | 4 | 4 | 3.75 | Very good |
| 2 | 229 | 4 | 3 | 4 | 3 | 3.50 | Very good |
| 3 | 147.5 | 4 | 1 | 2 | 2 | 2.25 | Fair |
| 4 | 575.64 | 4 | 3 | 3 | 3 | 3.25 | Good condition |
| 5 | 954 | 4 | 2 | 3 | 3 | 3.00 | Good condition |
| 6 | 173.38 | 4 | 2 | 3 | 2 | 2.75 | Fair |
| 7 | 1241.88 | 4 | 3 | 4 | 3 | 3.50 | Very good |
| 8 | 100.53 | 3 | 2 | 2 | 2 | 2.25 | Fair |
| 9 | 553.86 | 4 | 2 | 4 | 3 | 3.25 | Good condition |
| 10 | 98.25 | 4 | 1 | 4 | 2 | 2.75 | Fair |
| 11 | 629.4 | 4 | 3 | 4 | 3 | 3.50 | Very good |
| 12 | 198.125 | 3 | 4 | 4 | 4 | 3.75 | Very good |
| 13 | 955.1 | 4 | 2 | 3 | 2 | 2.75 | Fair |
| 14 | 1218.7 | 4 | 3 | 4 | 4 | 3.75 | Very good |
| 15 | 11.43 | 1 | 2 | 1 | 1 | 1.25 | Bad condition |
| 16 | 390.92 | 4 | 4 | 3 | 3 | 3.50 | Very good |
| 17 | 352.59 | 4 | 3 | 2 | 2 | 2.75 | Fair |
| 18 | 119.02 | 4 | 4 | 1 | 2 | 2.75 | Fair |
| 19 | 408.43 | 4 | 4 | 1 | 2 | 2.75 | Fair |
| 20 | 2569.17 | 4 | 3 | 2 | 4 | 3.25 | Good condition |
| 21 | 501.5 | 4 | 3 | 1 | 3 | 2.50 | Fair |
| 22 | 260.8 | 4 | 2 | 3 | 2 | 2.75 | Fair |
| 23 | 189.7 | 3 | 2 | 4 | 2 | 2.75 | Fair |
| 24 | 593.43 | 4 | 3 | 1 | 2 | 2.50 | Fair |
| 25 | 5844.66 | 4 | 2 | 4 | 2 | 3.00 | Good condition |
| 26 | 2875.65 | 4 | 3 | 2 | 2 | 2.75 | Fair |
| 27 | 8.75 | 1 | 2 | 1 | 1 | 1.25 | Bad condition |
| 28 | 1337.19 | 4 | 2 | 3 | 3 | 3.25 | Good condition |
| 29 | 653.34 | 4 | 2 | 3 | 3 | 2.75 | Fair |
| 30 | 516.26 | 4 | 2 | 3 | 2 | 2.75 | Fair |
| 31 | 960.52 | 2 | 2 | 2 | 2 | 2.00 | Fair |

The total length ($L_{tot}$) of the creek is 24.95 km and the weighted average grade of all creek sections ($G_{overall}$) of Hróarslækur Creek is 3.01 (see the equation in section 0).

## 4.6 Creek mapping

Figure 27 shows the sections of the creek based on the ecomorphological status. The green, blue, yellow and red colours signify very good, good, fair and bad condition, respectively, according to the parameters defined in Table 6.

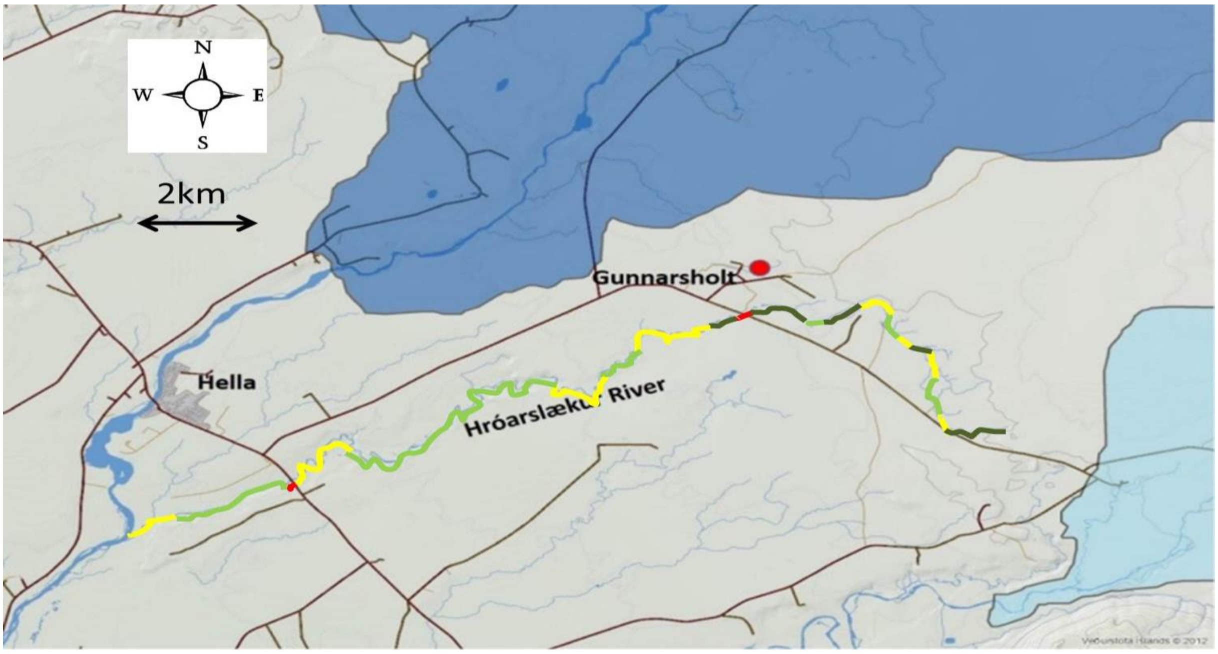


Figure 27. Classification of Hróarslækur Creek sections. The dark green colour indicates sections of the creek that are in "very good condition". The light green colour indicates the sections of the creek that are in "good condition". The yellow and red colours indicate the sections where the creek is respectively in "fair condition" and "bad condition".

# 5 DISCUSSION

## 5.1 Creek sections

Based on the following parameters — flow line, benthic zone, littoral zone and the vegetation — four classes have been defined.

- Class no. 4 is represented by the "dark green colour". In this section the vegetation is very dense and composed of trees, shrubs and grass. The creek is in its natural state with no anthropogenic activities impairing the ecological status. The benthic zone is composed of sand and gravel, the littoral zone is well vegetated and the flow line is meandering. Sections 1, 2, 7, 12, 14 and 17 fall into this category. Sections 7, 12, 14 and 16 are close to the Soil Conservation Service headquarters in Gunnarsholt. The plantation of trees and shrubs along the river has enhanced the ecological status of the creek.
- Class no. 3 is designated by a "light green colour". In this section, the vegetation is composed of either grass or shrubs without trees or trees and grass without shrubs less in number. The benthic zone is either muddy or mud and mosses. The littoral zone is steep with less vegetation on one side and well vegetated on the other side. More than 50% of the creek sections fall in this class, as shown on the map of Figure 27 above.
- In class no. 2, the vegetation is composed of grass only or grass and individual trees or shrubs. The littoral zone shows signs of degradation and the benthic zone is composed of sand. The presence of sand in the benthic zone shows that the river has undergone siltation due to wind erosion. Sections 3, 6, 8, 10, 17, 18, 19, 21, 23, 23, 24, 29 fall in this class.
- Class no. 1 is designated by a "red colour". In these sections there is very little or no vegetation cover. The littoral zone is walled or completely degraded and the benthic

zone is made up of concrete or sand. The section creek morphology is highly impaired. Sections 15, 27 and 31 fall into this class. The sections 15 and 27 are where the creek crosses the Route 264 and Route 1, respectively. Section 31 is the confluence with the Ytri Rangá River. At this point the benthic zone is made up of sand and some gravel. The vegetation cover is low grass only. The river bank is highly eroded due to the trampling of horses.

This is the first time that these classes have been established and applied to an Icelandic study site. Further discussion would be advisable in order to come up with better defined and more objective evaluation criteria. Nevertheless, this classification presents a first step as to how the ecological status of Icelandic rivers could be conducted. This could be an important step in the implementation of the EU WFD in Iceland even though the study classified a spring-fed river. The criteria used can be improved and adapted for glacier rivers and direct run-off rivers.

## 5.2 Hydrological observations

The observations presented in the result section (Figure 25 and Figure 26) call for a discussion on the observed changes along the creek. Regarding the electrical conductivity, there are four explanations to the observed variation along the creek:

1. The weather condition during the measurement: During the data collection the weather condition of the first day was rainy and cloudy throughout the day of investigation while during the second day of collection the weather was dry and sunny. Accordingly, it could very well be that rainwater with low conductivity mixed into the runoff, leading to temporarily lower conductivity in the creek.
2. Specification of the electrical conductivity meter: The EC meter used for the first measurement was not the same type as the EC meter used for the second measurement. The calibration and precision of the two pieces of equipment may have interfered with the readings.
3. Inflow of thermal water: A further explanation might also be that the variation in EC was due to the hot water (65°C) released into the creek from the thermal water supplied to Gunnarsholt (S. Runolfsson, 25th July 2014, Soil Conservation Service of Iceland, personal communication).
4. Sewage water from summerhouses might also temper the quality of water. Even though all of them have septic tanks, septic tanks may leak and polluted water may find its way into the creek flowing through a bed of gravel and soil.

It was not possible to clearly identify the reasons for the observed conductivity patterns within this project. However, conductivity levels did not indicate dramatic changes, and accordingly it is very probable that water quality is excellent.

The trend in temperature showed an increase in water temperature along the creek sections. The first readings of the temperature showed a slight difference in temperature from sections 1 to 6, as shown in Figure 26. These results are in line with the results obtained by Jonsson and Johannsson (2013). As the water coming from the source of the lava field is always very cold, the temperature increase along the creek is probably due to the warming from the ambient temperature.

From the discussion with the Director of the Soil Conservation Service of Iceland, Gunnarsholt sometimes releases an excess of geothermal water into the river at a temperature of less than 65°C. This could also have been a probable cause for the increase in water temperature in section 13 of the creek.

### 5.3 Fishing yields in the creek

Investigations of the number of fish catches over recent decades indicate that the ecological status of the creek may be continuously increasing. However, in the study carried out by Jonsson and Johannsson (2013), despite the huge quantity of fingerlings of salmon, trout and char released into the creek (**Error! Reference source not found.**), the fish catches have b een far below expectation. A detailed investigation of this topic would go beyond the scope of this report. Accordingly, it is not possible to come to a clear conclusion on this issue, as the fishing yields are still far below the common percentage of numbers of fish returning to the creek compared to the numbers of fingerlings released every year into the creek.

## 6 CONCLUSIONS AND RECOMMENDATIONS

Even though the surroundings of the creek are mostly farming land, horse pasture and improved land around summerhouses, the creek is well protected and fenced at some sections to prevent crossing by horses. The temperature of the water ranged between 3.5°C and 10°C and the EC varied around 225µS/cm. As stated above, the electrical conductivity does not indicate any major anthropogenic pollution. Most of the creek sections were classified between classes 3 and 4, i.e. “good” and “very good” ecological status. The overall weighted average of the Hróarslækur Creek was 3.01. This also indicated that the creek was ecologically in good condition.

From the field observation, a lot of birds were found where the density of shrubs and trees was high and also in grassland without trees and shrubs, as was also discovered by Gunnarsson et al. (2006). The vegetation has influenced the number of birds’ habitats.

Based on the results, restoration has had a positive impact on the ecological status of the creek and subsequently enhanced the overall condition of the creek.

The success in maintaining the creek in good condition can also be attributed to the effort of the environmental policy of the government of Iceland in general and the Rangárþing Ytra municipality particularly to prohibit the release of any kind of waste in the creek by all summerhouse owners living around the creek.

The following recommendations are formulated for further investigation:

- More areas of complete protection of the creek to allow growth of original Icelandic birch forest as currently the case only in section 1;
- Further study on the chemical water quality of the creek;
- Further investigation on the cause of low fish catches compared to the number of fingerlings released in the creek;
- Planting more trees and shrubs along the creek to enhance the ecological quality of the creek and create more habitats for wildlife.

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# APPENDICES

## APPENDIX I. List of materials used

The following materials were used for this study:

- Electrical Conductivity meter for water electrical conductivity and temperature measurement;
- pH meter;
- GPS unit for taking sections and point coordinates;
- Digital camera for taking photos;
- Google map for locating the area of study;
- Computer (Excel, ArcGIS) for data treatment and analysis;
- Meter for measuring the cross-section and the depth of the river;
- Boots for crossing the river;
- Block notes, pencils, eraser for data collection on the field.
- Bicycle for transportation.

## APPENDIX II. List of figures

## APPENDIX III. List of tables

## APPENDIX IV. Sigel and abbreviations

| AUI | Agricultural University of Iceland |
|---|---|
| **CPM** | Cabinet of Prime Minister |
| **EC** | Electrical Conductivity |
| **EU** | European Union |
| **FAO** | Food and Agricultural Organisation of the United Nations |
| **FOEN** | Federal Office for Environment Forest and Landscape |
| **GIS** | Geographic Information Systems |
| **IFAD** | International Fund for Agricultural Development |
| **SCSI** | Soil Conservation Service of Iceland |
| **TDS** | Total Dissolved Solids |
| **UNEP** | United Nations Environmental Programme |
| **UNESCO** | United Nations Education, Scientific and Cultural Organisation |
| **UNU LRT** | United Nation Land Restoration Training |
| **WFD** | Water Framework Directorate |

## APPENDIX V. Classification criteria used by Werth (1987) and Heinemann (1998).

### Class 1: natural

- Meandering, branched, strongly divided, possibly with old arms and outside
- Good relief sole
-Water depth very choppy
-Shore natural, shrub and trees, wide buffer zone

### Class 2: slightly impacted

Affected, but natural- impression of almost "natural" water
-Run anthropogenic influences, but close to nature

### Class 3: strongly impacted (influenced, monotone) - clearly evened and regulated

-Technical design dominates
-Trapezoidal profiles, grass berms
-Monotonous slope, uniform water depth

-Buildings made of smooth material (no opportunity for advancement for aquatic organisms)
-No buffer zones, traffic areas, settlement and land on the edge of the embankment
-Only occasionally shrubs

**Class 4: not natural**

-Installed, artificial
-Extremely technical installation: turf paving, concrete, corrugated steel profiles, sheet pile walls
-Strictly geometric profiles
-Asphalt, concrete or stone shops
-Fortified waters soles
-Monotone, unresolved water border
-No or only individual trees or shrubs

**Specific parameters for the classification (scoring with averaging**)

**(A) Lines and flow behavior**

A1 Natural change dynamics, very different lines
A2 Visible corrections, but irregular lines with impact - and nearly
A3 Evens; curved gradient, but with shore lead
A4 Monotonous, straight/straight, power stroke in the middle of the waterway, parallel flows

**(B) Sole**

B1 Strongly, flats and a deepened in quick succession, location-typical substrate
B2 Recognizable, unifies uniform particle sizes.
B3 Significantly uniform contact with underground single-sided substrate limited,
B4 Smooth, uniform and hard sole, no ground contact

**(C) Interaction between water and land, widths variability**

C1 Resolved strongly structured and variable water land boundary, such as T.
C2 Width evens, many side soon areas, but without extensions
C3 Uniform profile, slope foot determines the width differences
C4 No variability, smooth slope without niche

**(D) Embankment and shore**

D1 Strongly structured and organized, natural, material
D2 Unified structure, but with sporadic, irregular construction
D3 Uniformly and artificially designed
D4 Smooth and uniform, without spaces

**(E) Shore vegetation, shrubs**

E1 High number of species of shrubs and trees, several 10 m wide, often with
E2 Narrow hem, somewhat impoverished, partly only shrub vegetation
E3 Only individual trees or isolated groups of

E4 No shrubs

For example, the criteria of the Heinemann 1998 ("ecological morphology, level F"), focusing on the following properties are an alternative assessment after WERTH:

-Variability of water level width
-Engineering degree of the sole
-Control level of the slope foot
-Width and condition of the shore area