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ANALYSIS OF LAND USE EFFECTS ON THE DISCHARGE OF THE RIVER FNJÓSKÁ

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ABSTRACT

The study was conducted to analyse the impact of land use on a river discharge and to explore the sensitivity of a hydrological model by testing the effects of different land use data and soil characteristics of a specific watershed. The study area was the watershed of the River Fnjóská, which is located in the Fnjóská valley in the north of Iceland. The WaSiM model applied in this study was initially calibrated with the discharge at the water gauge, and the outcome of the model simulation reflected the discharge well. After the initial calibration of the River Fnjóská watershed, five fictional land cover scenarios were imported into the calibrated WaSiM model to analyse the effects and sensitivity of different land covers on the river flow. ArcGIS spatial analyst tools were applied to process the watershed delineation and establish the five fictional different land use scenarios. The alternate land covers included in the watershed were: grassland, wetland, barren land, moss and heath land, forest and shrubs. The simulated discharge with different land covers was compared with the outcome of the calibrated model. The simulated discharges for grassland, moss and heath land, and observed discharges revealed a similar behaviour of distribution. However, the runoff from the barren land cover was quite distinctively different, often returning the highest discharge. The outcome of the model reflects well that the condition and type of land use contribute significantly to the runoff and are accompanied by predicted scenarios of land cover and soil type changes. This work on the overall results determined that simulated land cover change had a significant impact on the discharge distribution of the River Fnjóská through barren land covers. Subsequent research in the Fnjóská watershed should investigate land use and climate change effects on sediment transportation.

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1. INTRODUCTION

By definition a watershed is the area where all of the surface water draining off it runs into the same catchment area. Upper highland areas from streams and rivers collect water and recharge groundwater aquifers. Watersheds can vary immensely in size from a small river to embracing networks of rivers, streams, and lakes and the land area surrounding them. The watersheds have the prominent role in a water supply and human activities are highly dependent on river systems. Unfortunately, various forms of degradation, including exacerbated runoff and erosion, can interfere with the health of the watershed. Therefore, restoration of watersheds is important in water management, achieving natural hydrological balance and maintaining river ecosystems.

Disturbance of the ecological balance of watersheds is very frequently the result of human activities, e.g. by grazing and agricultural cultivation, and removing the forest cover in the mountainous regions. Also, the foothills and floodplain areas are often affected by urbanization and the control of the rivers around the floodplain, e.g. location of levees and ditches (Lalika et al. 2015; Paroissien et al. 2015). It is widely recognized that forest cover on slopes plays an important role in the formation of runoff and the moisture retention of soil (Guzha et al. 2013). The rapid pace of industrialization in the world resulting, among other things, in removal of forest cover has indeed led to increased erosion of the surface of the upper watershed areas in a number of areas throughout the world. These actions can have a strong influence on the characteristics of an area and the hydrological regime of the rivers. Furthermore, the speed of erosion is increased by global climate changes and alteration in land use (Sarma et al. 2013).

According to Routschek et al. (2014), change in climatic conditions enhances the land use changes and can speed up the changes in the properties of the land such as content of organic carbon, porosity, and vegetation cover and density. In his research Ouyang observes that the land use on watershed areas in north-east China, freeze-thawing areas increased from 23.5% to 62.1% in the simulations, and in addition that during the ten years about half of dryland was altered to paddy land (Ouyang et al. 2015). In this way all these drivers, human enhanced and natural processes, are interacting, causing strong synergistic effects and affecting the condition of the surface runoff and the change in sedimentation rates within the river (Smith & Wilcock 2015).

An increase in rainfall and its intensity due to climate change will also lead to accelerated soil erosion (Marshall & Randhir 2008). This can result in flooding in the rivers at lower altitudes and increased transport of sediments. The influence of land use and the shifts in the hydrological regime of the Namnam Stream in the Koycegiz Watershed, Turkey, indicate that climate change will increase mean annual flow by 5–60%, because the impervious surface was increased to 0.1–50% (Baloch et al. 2015). The changes in soil are mainly caused by erosion and the utter exhaustion of nutrients. The depleting nutrients in the soil and its fertility are the main reason that new land is transformed to enable further food production (Bahadur 2012). This is a repetitive process that is important to understand in order to stop the chain reaction so the resource can be used sustainably.

1.1 Goal

The main goal of this project was to analyse the impact of land use change on discharge, and explore the sensitivity of the hydrological model simulating river discharge patterns, to different scenarios of land use.

1.2 Objectives

- To gain experience and training in using GIS to delineate a watershed and to extract land use and soil classifications of the watershed;
- To analyse and compare runoff sensitivity, using a hydrological model, by applying different land use data and soil characteristics of a watershed.

2. LITERATURE REVIEW

The hydrological functions of the watershed depended on the current condition of interrelated characteristics of basic components such as land cover, topography and climate (Brooks et al. 2003; Stewart 2013). Discharge from watersheds and their capability to capture moisture depends to a high degree on climatic factors, which in turn are prominent with respect to available water supply. Related environmental consequences of impacts influence changes in the hydrological regime of water flows (Fan & Shibata 2015). Spatial hydrological models are used to study changes in land use in watersheds. Hypothetical land cover scenarios allow describing the various hydrological processes which are based on the current condition of the catchment area.

El-Khoury et al. (2015) used the SWAT model for a Canadian watershed as a tool to demonstrate how land use impact on water quality and quantity could be reduced. The calibrated model can simulate possible effects on the watershed of altering the projection of land use. The authors assume a rapid urbanization in areas, but include also a scenario where small forest areas have disappeared and replace them with arable land around the watershed. The results show that the variability in quality and quantity of water caused by the shift in land use is in the same direction as the influences of climate change.

Fan and Shibata (2015) examined influences of land use and climate change by manipulating different conditions of the water and nutrient cycles. They used SWAT as a hydrology and nutrient model and an empirical land use change model CLUE (Conversion of Land Use and its Effects) for a river catchment area in Japan. Their research established that the climate changes increased surface runoff and ground water recharge. Furthermore, changes in the hydrological processes as well as application of fertilizers and changes in the nutrient cycle increased total N and P yields. Concurrently, all combinations of effects together with the climatic changes were more powerful than land use changes. Paroissien et al. (2015) developed a method to estimate soil resistance to erosion under climate and land use changes by using the land use change model CLUE-S and the soil erosion model STREAM. Their results, as shown by to the hydrologic processes, revealed that the alteration of peaks in flooding, along with the increase in water level, also increased nutrients and sediment in the runoff.

Jasper et al. (2004) use the grid-based catchment model WaSiM-ETH (Water Flow and Balance Simulation Model) to analyse the impacts of climate change on the hydrological regime of mountainous Alpine river basins. Differed projection results of selected scenarios of runoff showed in an increase in evapotranspiration and reduction in the extent and length of the snow cover. The tendency to change was especially found in the summer season exhaustion of soil moisture and alteration in the temporary expression of runoff, with preliminary and diminishing maxima in consequence of the melting of the fallen snow. According to Jasper et al. (2004) the estimation of the impact of climate change on the hydrological regime of river catchments in mountain regions requires knowledge of geographical location and geometric features of the land and also of land use.

Krause et al. (2007*a*) made a quantitative assessment of groundwater and surface water and their interaction of the Havel river basin in a North German lowland floodplain by applying hydrological models. They used WaSiM-ETH to simulate percolation fluxes in the unsaturated zone and estimate vertical soil water dynamics, and MODFLOW for modelling flow in the glutted area. Results showed considerable interim and dimensional variability between surface water and groundwater in the explored area. Furthermore, the authors studied differences in the kind of alteration structure inflow and outflow to and from the groundwater. Krause et al. (2007*b*) simulated the impact of land use and water balance in drainage systems of floodplain sinks in north-east Germany. In this modelling the alteration of land use by using land use change scenarios illustrated the influence of evapotranspiration and vertical recharge of groundwater. According to Krause et al. (2007*b*) the cause of change in land use structures is a change in the vertical groundwater water balance interactions of surface water and groundwater flows. These results emphasize the influence of land cover and drainage intensity of channel nets. This should also be reflected in the management and planning of land use of wetland and floodplain areas.

Elfert and Bormann (2010) investigated the sensitivity of the WaSiM-ETH to the changes in land use for the catchment of the Northern German lowland Hunte River. Three different land use scenarios were applied and their analysis showed the WaSiM-ETH to be quite sensitive to the choice of land cover. Consideration of three land use change scenarios included alteration from agricultural land. The first alteration from the agricultural land was into forest, the second was into an urban area, and third was into forest and an urban area in equal proportions. In terms of agricultural land use shifted into an urban scenario, results found an increase in runoff and decrease in evapotranspiration. The reverse effect appeared for the scenario where agricultural land shifted into forest. The third scenario had a minor increase in these parameters. River discharge increased groundwater by the interaction of rivers and aquifers and WaSiM-ETH reacted highly sensitively to the supposed land use changes.

3. MATERIALS AND METHODS

3.1 Study area

The study area was the River Fnjóská watershed in northern Iceland. The river has an approximate length of 117 km and it flows through various types of terrain from a rocky canyon valley bottom to meandering vegetated floodplains. The river's watershed extends approximately between 65° and 66° north latitudes and 19° and 17° west longitudes, as presented in Figure 1.

The area of the Fnjóská watershed is about 1094 km^2. The average annual precipitation is 355.2 mm. Climate conditions are characterized with large temperature fluctuations, the average max being 16°C in summer and the low -26°C in winter (data from the Icelandic Meteorological Office [IMO]). The Fnjóská watershed includes grassland, wetland, moss and heath, forest and shrub land, and barren types of land cover. The soil classes in the Fnjóská watershed used in the map which determine by WaSiM value are Histosol (H), Histic Andosol (HA), Gleyic Andosol (WA), mixed Brown Andosol (BA) and Gleyic Andosol (WA), and Cambric Vitrisols (MV). The original soil data were provided from an Icelandic soil map published in 1998. The hydrological regime of the River Fnjóská is most pronounced with flood peaks in the middle of June in the annual hydrological variation and snowmelt discharge generated largely in spring and summer. The average annual discharge was about 46 m^3/s for the 27 years observed by the Icelandic Meteorological Office (IMO). In the study area runoff accumulates from snow melt and the infiltration excess from saturated areas. Discharge as input data for the WaSiM model was available in from the water-level gauging station VHM200 in the lower part of the River Fnjóská (Fig. 1).

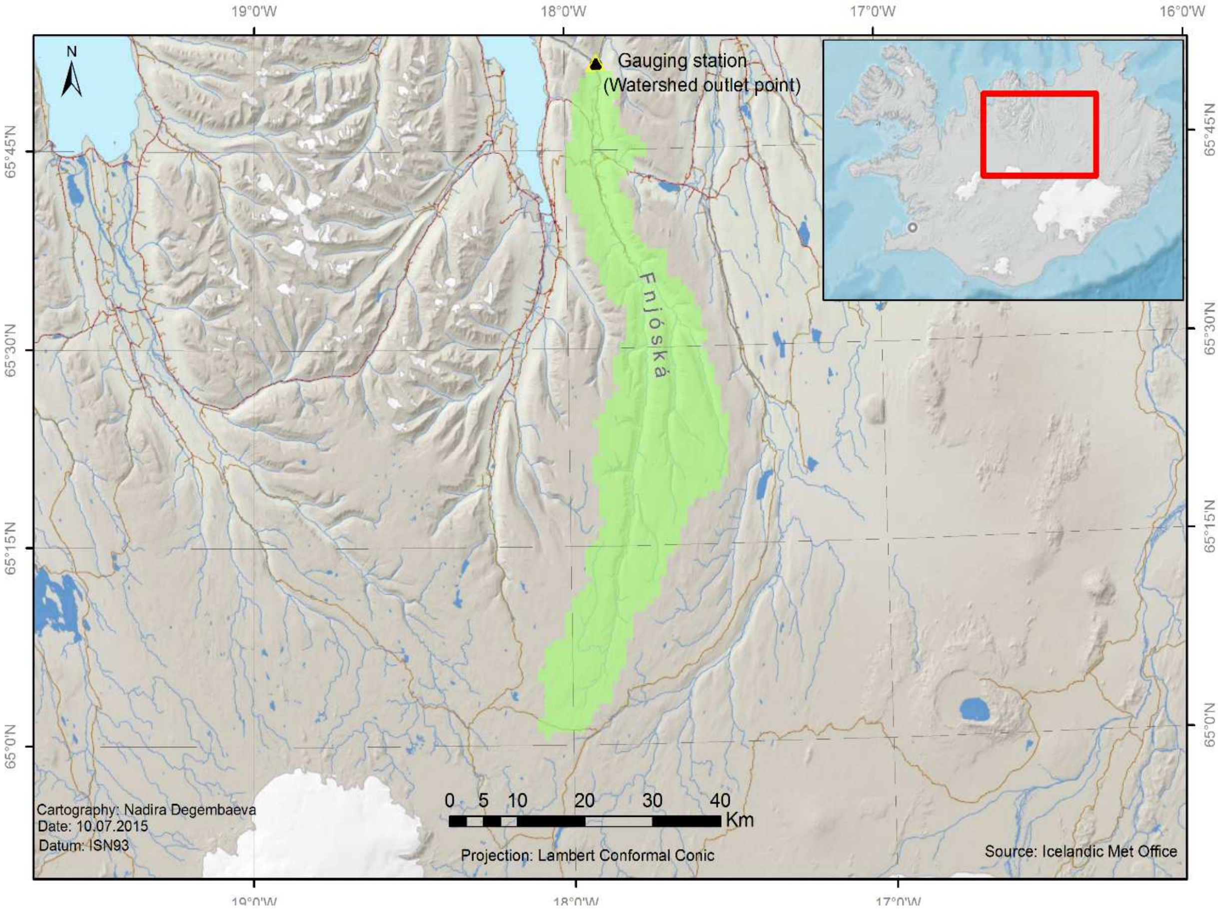


Figure 1. Overview of the Fnjóská watershed. The watershed is located in the north of Iceland, as is shown on the insert map.

3.2 Methodology

The accuracy of topographic representations of digital elevation models (DEMs) depends on their quality and resolution. The WaSiM model as operated at the IMO uses input grids with 1 km x 1 km grid cell resolution. Watershed delineation depends on the flow direction and flow accumulation grids prepared from a DEM by using ArcGIS. An acquired DEM of the study area must be resampled to conform to the same grid cell size as used as input into the WaSiM model at the IMO. The DEM needs to be processed in the correct order with the correct tools in the GIS. Therefore, the project consisted of two components, the first including GIS data gathering, its preparation, processing and manipulation of land cover and soil data, and the second involving analysing the resulting discharge data from model runs.

The next step after creating the flow direction and flow accumulation grids was to consider the pour point of the watershed (watershed outlet point). The geographic location of the watershed pour point for this study was where the gauging station is located (VHM200), at 17°53’51” W longitude and 65°51’04” N latitude. For the creation of the pour point feature class in ArcGIS, the location needed to be recalculated in decimal degrees and then projected onto the Icelandic Projection Coordinate system ISN93. Analysis of the impact of the land use change to discharge was implemented by extracting the existing land cover and soil classes within the watershed boundaries and also to change the land cover and soil class to input into WaSiM. Information on land use and soil classes of the Fnjóská watershed were adjusted to the WaSiM model required data format and grid size.

The sensitivity analysis was executed by comparing the simulated discharge series using the original land cover and soil data with the simulated discharge series using different land cover scenarios and soil classes. For analysis the different types of land use and soil class data were compared by manipulating land use scenarios with discharge series. The watershed consisted of five land cover types; grassland, barren land, moss and heath land, wetlands, forest and shrub land, classified based on the attribute column “Flokkur”, which is Icelandic for class. It was necessary to reclassify land cover and soil class data in order to fit the format of the WaSiM input data. The general processing methodology is presented in Figure 2.

Each land use scenario was compared to the calibrated version of the WaSiM model run. The parameters compared were annual, seasonal and long-term runoff. Also for comparison, the mean, maximum, minimum and peak of the flows simulated discharges were determined. The difference means of simulated discharges were checked by using the deviation coefficient and regression analysis was calculated in SAS (SAS 2013).

3.3 Digital Elevation Model (DEM) selection, acquisition and preparation

The features of the watershed area such as ridges, valley bottoms and channel properties are identified by using a digital elevation model. The main necessary condition in hydrological modelling is acquisition and preparation of a digital elevation model (DEM) in order to calculate from this the flow direction (frd) and flow accumulation (fac) processes by using ArcGIS tools. Resolution and quality of the DEMs determine the accuracy of topographic information of the researched area. In this case the quality is represented in the elevation data and equates to accuracy, in terms of resolution expressed in elevation and spacing of surface information

(Environmental Systems Research Institute Redlands 2000). In the preparation process of DEM it is important to understand the morphology of the study site and to realize which features may be factual or real, such as sinks that can influence the flow of water on the surface in the watershed area. Also there is a need to identify and avoid features which are merely errors in the data. The United States Geological Survey (USGS) server provides public applications for different DEM data. For the selection DEM, two datasets are compared which properly cover the study area under consideration, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Emissivity Database and NASA's Shuttle Radar Topography Mission (SRTM). The land cover resolution used at the IMO (Icelandic Meteorological Office) for input data to the WaSiM model is a grid of 1 x 1 km cells. The same resolution was used when other land cover types were tried in the model.

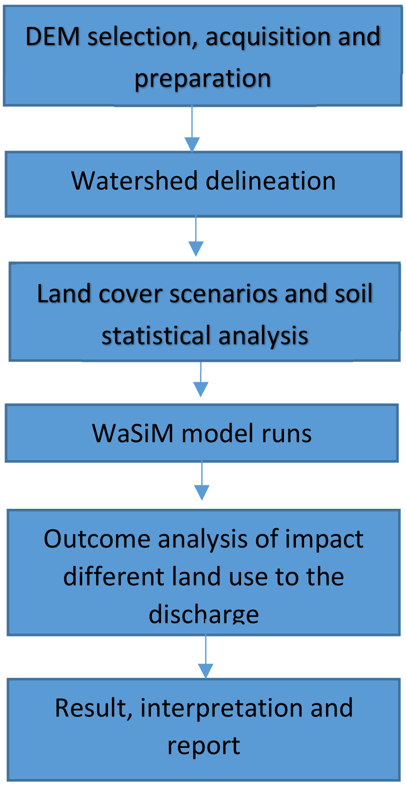


Figure 2. The sequence of general methodology.

Ascertaining exact watershed boundaries from DEM depends on accuracy in the digital replication of receiving stream networks. Comparison of display images of surface features was executed into 1-arc-second DEM areas for ASTER Global Emissivity Database the Advanced Spaceborne Thermal Emission and NASA Shuttle Radar Topography Mission (SRTM) over the study area. The second type of satellites through extension distance not covered our considered region from these investigated DEMs. Therefore I selected ASTER which allows a high quality output of DEM, measured over approximately 30 m by 30 m grid cells. As an appropriate output format of the DEM for use in ArcGIS processed into vertical value which is 16 bit unit GEO tiff and was downloaded with WGS84/EGM96 Geo-reference. The clipped study area was projected into the Icelandic Projected Coordinate system ISN 1993 Lambert from WGS84. The main requirement input data for DEM were that each grid should be compatible with the grid dimensions and coordinates of the actual model run. Thus the original ASTER DEM was converted from Geotiff to ARC grid cells and resampled from 30 m by 30 m to 1 km by 1 km grid cells. The resampled 1 x 1 km DEM versus the original is presented in Figure 3.

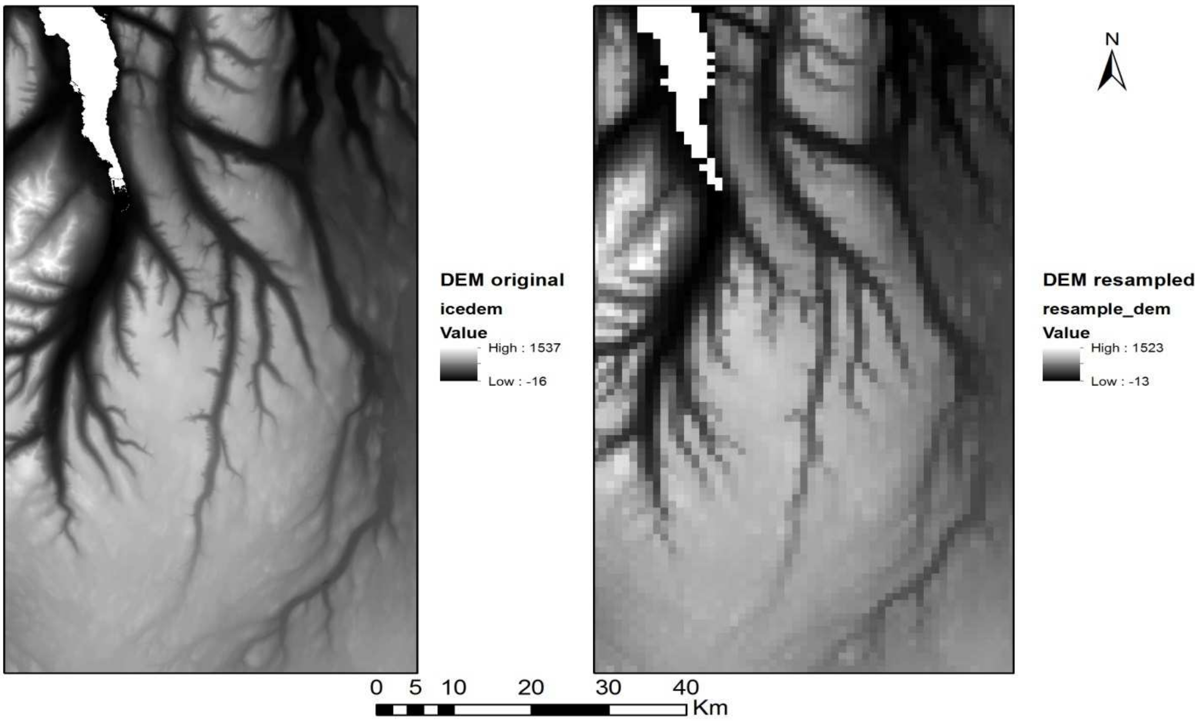
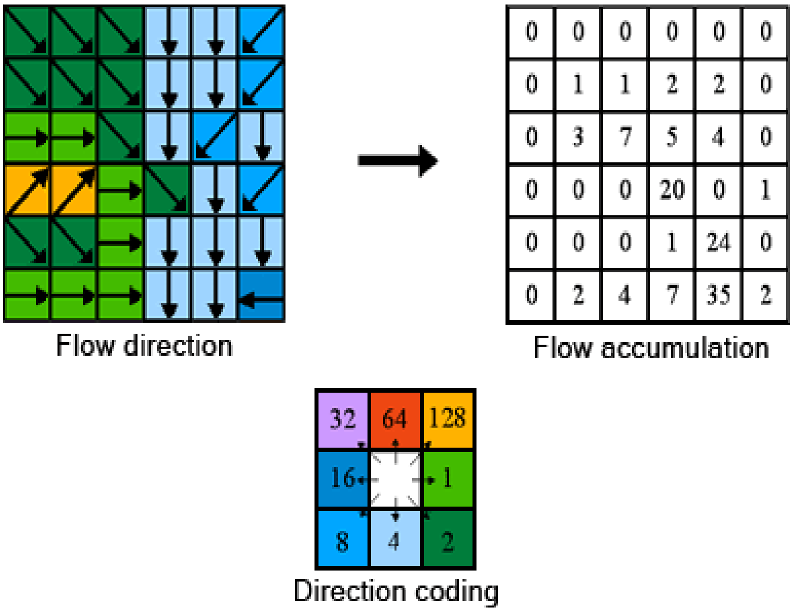


Figure 3. Original and resampled DEM of River Fnjóská watershed.

3.4 Flow Direction, flow accumulation grid processing

The goal was to define the direction of flow from every cell in the study area using a flow direction tool. Using the valid output directions with the eight-direction (D8) model the direction of each cell in relation to the eight adjacent neighbour cells was computed. As Figure 4 shows, the accumulated weight (number count of cells) from all cells flowing downward was calculated with the flow accumulation tool. Watershed delineation in GIS uses two types of grids, which are created from digital elevation model data in order to present in the flow direction (fdr) and flow accumulation (fac). Information about the watershed boundary was determined by the direction of flow of each cell and how many of them flowed into any downstream cell. For correct delineation of a watershed the fdr and fac grids for the study area DEM were built in the correct order and with flow direction and flow accumulation tools using ArcGIS. The ASTER DEM model in Iceland has a 30x30 m resolution, but the WaSiM model in the Fnjóská area has a 1x1 km grid resolution. Hence, the initial step was to resample the more exact information in the DEM model into 1x1 km resolution by using the ArcGIS spatial analyses tool. Figure 5 shows a flow chart of the preparations and processing involved.



0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	2

Figure 4. Determination of flow accumulation. (Source: http://resources.arcgis.com/en/help/main/10.1/index.html#//009z00000063000000).

3.5 Watershed delineation

Runoff on the surface of the watershed area forms as small rivulets. Then several of these coalesce and form a branch of the river system that then merges in the river basin. The simple flowchart of processing of flow direction and flow accumulation shows the order of steps needed to accomplish a correctly delineated watershed grid (Fig. 5). The delineation of a watershed requires proper filling of sinks for inclusion of discontinuous drainage systems of the river in the basin under study. The computation of the flow direction by using watershed tools in ArcGIS delineates the area from a DEM. To do this a raster needs to be created with the flow direction tool. The cell values in the raster dataset are then used to determine the pour point. The result will be the output raster which shows the contributing watershed area in integer type. Figure 5 indicates the main GIS processing of watershed delineation.

3.6 Land cover and soil data preparation and processing

Land use and soil data need to be prepared as input to WaSiM in ArcGIS. When watershed delineation is complete data under the watershed polygon are extracted from the original land use and soil feature classes. Further, this vector soil and land data are converted in ArcGIS into the data format and grid size needed for the WaSiM model. In this analysis the WaSiM model required reclassification of the original land use raster from a classification system based on the attribute column “Flokkur”, which belonged to the original datasets. Reclassification of land cover categories is important to put data into the hydrologic model and its run and this methodology is presented in Figure 6. The soil data were produced by the Agricultural University of Iceland and Icelandic Institute of Natural History at the scale of 1:250000 of the soil map (Icelandic Soils, Rala 2004). The land cover data received from the source of the Vegetation Map of Iceland, first edition of 1998 (Guðjónsson & Gíslason 1998), which gives an overview of dominant vegetation communities in the study area. Figures 5 and 6 indicate the procedure of the flow chart and preparation of land cover and soil data of the Fnjóská watershed.

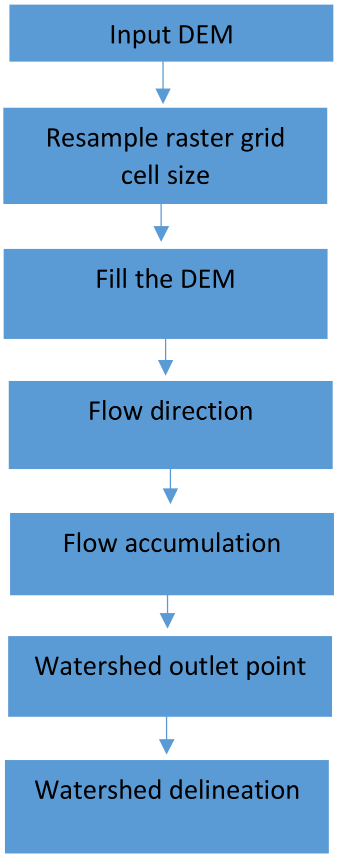


Figure 5. The watershed delineation procedure.

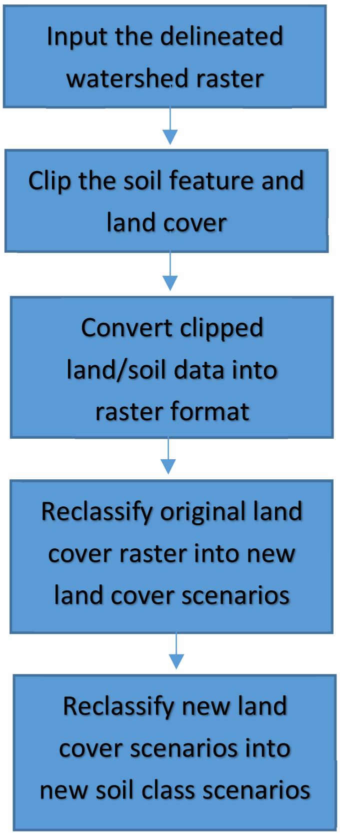


Figure 6. The land cover and soil data preparation procedure.

Sensitivity analysis of the hydrological model was obtained by comparing the altered land cover scenarios to the original. Land cover data input into WaSiM runs use the same categories of land cover but with different numbers (Table 1). The analyses of land use effects included land cover and soil class data which were required to have the same resolution as input into WaSiM model. A land cover raster as a zone is defined from all areas in the input that have the same raster value (i.e. land category). The ArcGIS zonal statistics tool was used to determine the soil class raster data with majority values and used the result as a link between one land cover type and one soil class. In other words, majority is the most count of raster cells of a certain soil class value which belongs to the particular land cover type in each zone which is appointed to all cells in that zone. The resultant reclassification of the land cover raster included the particular name necessary for the particular land cover type as an output format type. Therefore, the same name as the reserved field for the particular output raster as the name of the zone field should be changed in the attribute table. Detailed description of the creation of land use scenarios will also be considered in the next section (3.7) below.

Table 1. Determination of the original vector data for land cover classes and their values in WaSiM grids. The WaSiM numbers are used in the model runs. (Source: Guðjónsson & Gíslason 1998).

Flokkur (e.class)	WaSIM model	Definition
500	1	Vegetated areas, grasslands etc.
503	2	Wetlands
600	3	Barren area, sands etc.
509	4	Semi vegetated areas such as moss or heathland
743	5	Lakes
504	6	Forest or shrub
701	7	River
621	8	Glacier

3.7 Determination of land use scenarios

One of the objectives of this project was to explore the sensitivity of the WaSiM model to different land cover scenarios. Existing land cover within the watershed boundaries was based on the land cover as mapped in the Vegetation Map of Iceland (Guðjónsson & Gíslason 1998) (Table 1). The different scenarios of land cover and soil class used as an input into the WaSiM model were based on the numerical values of the data on soil classes (Table 2). The features of watershed polygons had identical values and these were connected to several attributes. From these databases land covers and soil classes were extracted. The watershed polygon clipped from the original land cover and soil feature classes needed to be converted into an appropriate data format and grid size to input the WaSiM model. Table 3 shows land cover types and original soil classes in the River Fnjóská watershed.

Table 2. Determination of the original vector data for soil classes and their values in WaSiM grids. The original soil classes which define according the number of WaSiM model for input data. Source: Icelandic Soils, Rala (2004).

Flokkur (e.class)	WaSIM model	Definition
H	1	Histosol
HA	2	Histic Andosol
WA	3	Gleyic Andosol
BA-WA	4	(Mixed)
BA	5	Brown Andosol
MV	6	Cambic Vitrisols
MV-SV	7	(Mixed)
SV	8	Arenic Vitrisols
SV-L	9	(Mixed)
L	10	Leptosol
C-WA	11	Cryosols – WA
GL	30	Glacier
WAT	20	Water

This project considered the hypothesis that changes in land cover will affect runoff and thus the simulated discharges. The changes of original land cover raster values from original values were executed by using a reclassify as table tool in ArcGIS. To reclassify original land cover values, two items in remap in reclassify table were used. The reclassification land cover value needs to select as an input land cover raster to change land cover type. The first identifies the land cover value which belongs to change. The second has the land cover value according to the requirement of WaSiM model values as an output value. The denomination of scenarios selected according to the output values of land cover types as a land use category. Obtained 5 types of scenarios of Fnjóská River watershed indicated in Table 4.

Table 3. Land cover types and original soil classes in River Fnjóská watershed. Land cover types and their area were extracted from the Vegetation Map of Iceland (Guðjónsson & Gíslason 1998). Calculation of land cover type areas on values of a raster is executed with zonal statistics spatial analyst tool Arc GIS. Then as a basic land cover type selected for the majority of the tied values.

Land cover types	Area, km^2	Original soil classes
Grassland	273	1 (H)
Wetland	1	2 (HA)
Barren land	797	3 (WA)
Moss or heath land	8	4 (BA-WA)
Forest or shrub land	15	6 (MV)
	Total area 1094 km^2	

Table 4. Hypothetical scenarios of land use for River Fnjóská watershed.

Scenarios	Land cover changed	Land cover changed into	Area of change, km^2	Soil class change
Degradation	Grassland	Barren land	273	3 (WA)
Dramatic degradation	All land cover types	Barren land	303	3 (WA)
Restoration 1	Barren land	Moss and heath land	797	4 (BA-WA)
Restoration 2	Barren land	Grass land	797	1 (H)
Restoration 3	Moss and heath land	Forest or shrub land	23	6 (MV)

Initiation of land use scenarios has assumptions that land use change over time influences on the soil under a range of land use types. Dataset for calculation of zonal statistics applied as an input data values were received from land cover (Table 1) and soil class (Table 2). Definition of zonal statistics in ArcGIS spatial analysis is the land cover values are considered as integer output data. Therefore, as an input raster the majority value of cells of watershed locations pertains to similar zone as the output cell. Within the locations of the zones have values raster datasets and used as the zone dataset in majority values. The maximum of the value input for each zone was executed by using the reclassify tool in ArcGIS to define a link between a certain soil class and each land cover type in the watershed area (Table 3 and Fig. 7).

Establishment of soil class scenarios was based on the spatial link between land covers and soil classes. The soil class scenarios were defined by using reclassify tool in ArcGIS spatial analyst toolset. The reclassified land cover types in the Fnjóská River watershed with soil class will create map as the result, which was used. The grids of land cover and soil class scenarios converted in ArcGIS according to ASCII grid format as input data in the in the WaSiM model.

Convert the grid formats each scenario and soil class scenario executed with tool in ArcToolbox. The procedure of determination of land use scenarios is presented in Figure 8.

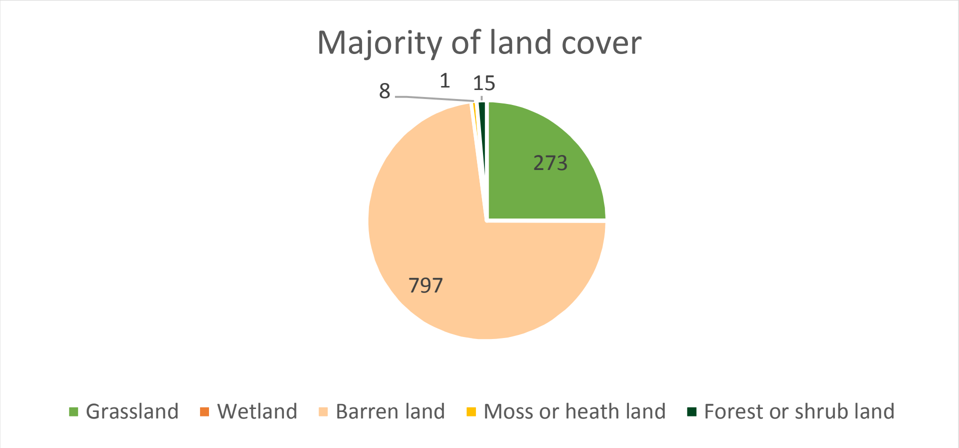


Figure 7. The original land cover types in the River Fnjóská watershed. Numbers show the area (km^2) of each land cover type in the watershed (see also Table 3).

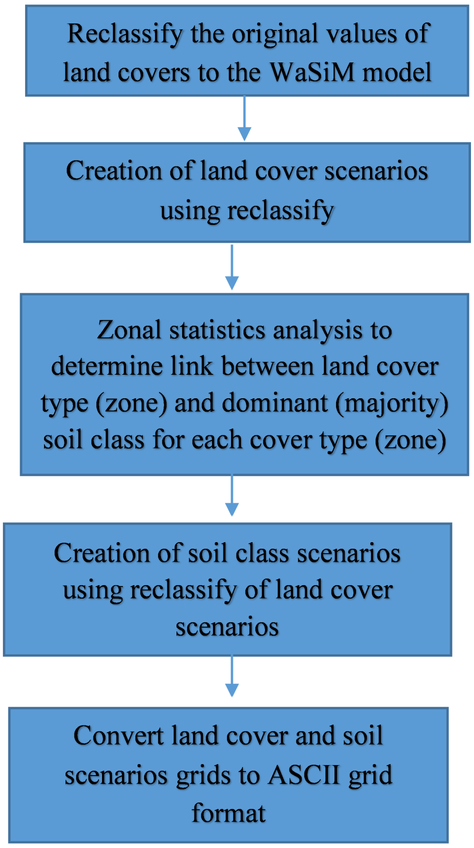


Figure 8. The procedure of the creation of land cover and soil class scenarios.

3.8 The WaSIM model

The hydrologic model WaSiM is a physically based distributed model working on a regular grid. Therefore, the input data such as DEM, land use, sub-catchments, soil types, and river networks are presented on grids. The format required for the WaSiM model was prepared in Arc GIS for land use and soil data. The meteorological data used were temperature (Crochet et al. 2011), precipitation (Crochet et al. 2007), humidity (Rögnvaldsson et al. 2007), wind and radiation (Grell et al. 1994). The model was used to simulate discharge with daily time steps and calibrated by comparing simulated and observed discharge. The best simulation was obtained at the IMO and was used as the base run for this project. The quality of the best simulation can be seen in section 4.4. Figure 9 shows the model structure of WaSiM-ETH.

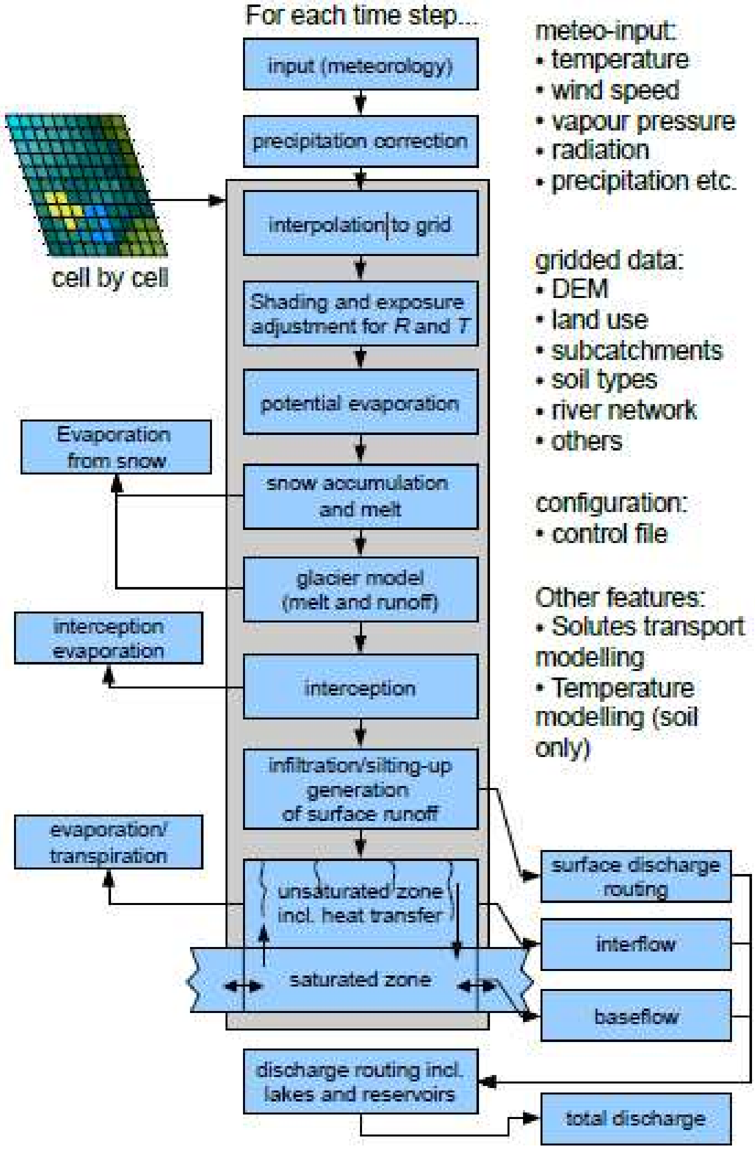


Figure 9. Model structure of WaSiM-ETH. (Source: http://www.wasim.ch/en/).

The model was then used to simulate discharge series using different land cover scenarios with changed percentages of land cover types such as grassland, wetland, barren land, moss and heath land, and forest and shrub land. This project included the following values of land use parameters:

- Albedo – list of values for every sample day and variate in within (0…1)
- IntercepCap – interception capacity defines water storage capacity on leaves, expressed in mm
- rs_evaporation - soil surface resistance only for evaporation, s/m
- Rsc - leaf surface resistance in s/m
- LAI - leaf area index in m^2/m^2
- z0 - aerodynamic roughness length, m
- VCF - vegetation covered fraction which variate within (0…1)
- RootDepth - root depth, m.

The values of these parameters are presented in Table 5.

The potential transpiration from plant leaves, evaporation from bare soil and the evaporation from interception surfaces was then calculated in WaSiM, using the approach after Penman-Monteith. The leaf surface resistance (Rsc) indicates the resistance of vapour flow through stomata openings from the total leaf area and the soil surface. The evapotranspiration modules of WaSiM contain this parameter and most other necessary parameters like the leaf area index (LAI) and the vegetation coverage factor (VCF) (Model description WaSiM, 2015) (Table 5).

Table 5. Parameters that change within different land use types, defined in the land cover module in WaSiM.

Land use types	**Albedo**	**IntercepCap (mm)**	**rs_evaporation (s/m)**	**Rsc***	**LAI***	**VCF***	**z0* (m)**	**Root depth (m)**
Grassland	0.2	0.4	400	90	4	0.95	0.15	0.4
Wetland	0.14	0.2	200	90	4	0.95	0.15	0.4
Barren land	0.15	0.1	100	250	1	0.8	0.05	0.1
Moss and heath	0.2	0.2	200	90	4	0.9	0.1	0.2
Forest and shrub	0.2	0.6	1000	80	5	0.9	1.5	0.5

*values change with Julian days

Interflow may be generated from porosities or between soil layers of different hydraulic conductivities. Surface runoff, interflow, and base flow formatted drainage runoff. These summed components give the total runoff, which is then the input to the routing model which then simulates routed discharge (Model description WaSiM 2015). In order to compare observed and simulated discharge and evaluate the quality of the simulation, the equation of Nash – Sutcliffe coefficient of efficiency (E) (Richard et al. 2006) was used:

$$E = 1 - \left[\frac{\sum_i^n (\mathrm{Qm,i} - \mathrm{Qs,i})^2}{\sum_i^n (Qm,i - Q)^2}\right] \qquad \text{Equation (1)}$$

where, $\mathrm{Qm,i}$ – Observed discharge (m^3/s)
$\mathrm{Qs,i}$ – Simulated discharge (m^3/s)
Q – Average simulated discharge (m^3/s)

In this study the model was used to simulate discharge series from 1976 to 2003. The model's simulated discharge series were used to analyse the effects of five land cover scenarios on the discharge of Fnjóská watershed.

4. RESULTS

4.1 Flowchart for flow direction and accumulation

The watershed delineation of the basin required to check the zonal continuous stream by using the Fill tool to check in the data enables flow direction to pass through all the cells towards the outlet point. Flow direction was created as a grid of flow from each cell in the elevation grid to downward neighbour cells, as described in section 3.4. Then flow accumulation process was run and indicated a grid which accumulated flow to cell from other surrounding cells. The flowchart for flow direction and flow accumulation of the study area is shown in Figure 10.

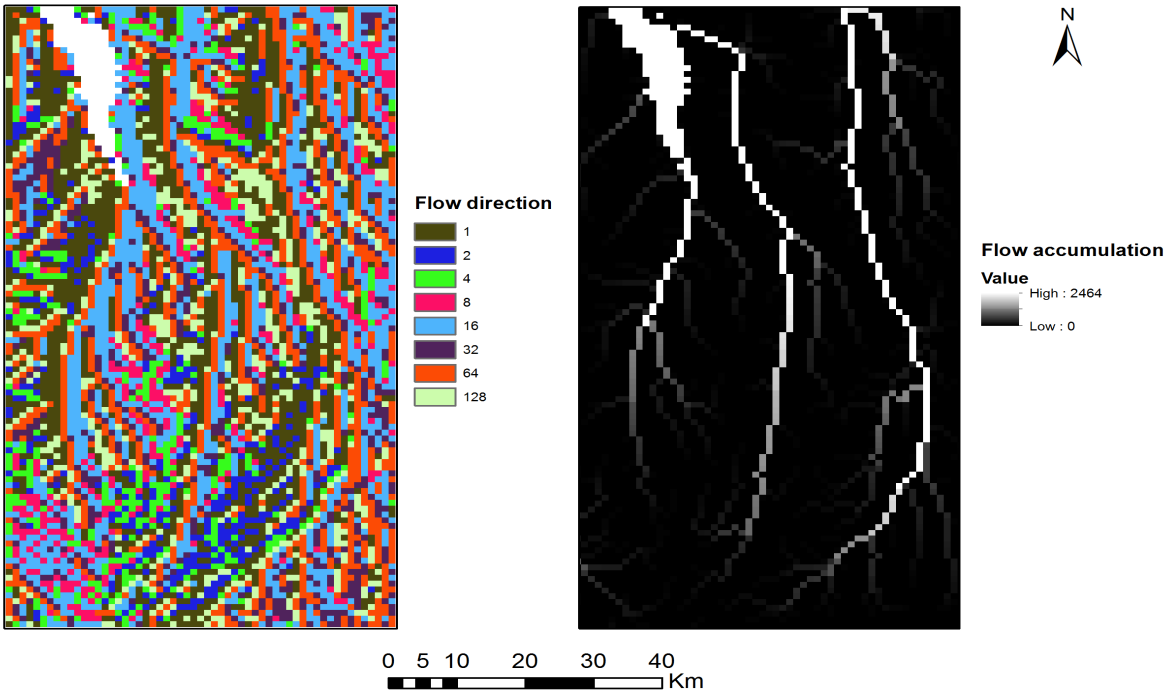


Figure 10. Original and resampled DEM, flow direction and accumulation grids.

4.2 Watershed outlet point and delineation

The pour point of the study area is at the location of the current gauging stations in the River Fnjóská, station VHM200 having the co-ordinates 17°53'51" W longitude and 65°51'04" N latitude. The pour point feature class which defined the watershed was created. Then this location in the feature format was converted into decimal degrees and finally projected into the ISN 93 coordinate system. The processed watershed delineation required an outlet point and as an input raster of flow direction and flow accumulation. Watershed delineation was executed after determining location of the rainfall runoff contributing area through a common confluence point on the study river.

4.3 Land cover and its scenarios

Determination types of land cover scenarios was conducted, assuming that the changes in soil class and land cover were impacted by the dynamics of land use influence on the discharge of the River Fnjóská. As the main data source of land cover and soil class, vegetation and soil maps from the Agricultural University of Iceland and Icelandic Institute of Natural History were used. Thus, the simulation of land cover consisted of two parameters: the type of land cover and the associated soil class types, as indicated in Table 2. Each land cover was adjusted to the land use grid as input to the calibrated WaSiM model. Table 3 shows values and definitions of land cover classes in the original vector data and in WaSiM grids.

When simulating effects of land use or soil types it is necessary to change this initial information. Arc GIS contains a spatial analysis tool to reclassify the land cover raster based on the value of the cells. The resampling operation GIS with 1x1 km grids extracted five land cover types. The following types of land cover were obtained after reclassification: grassland, wetland, moss and heath land, forest and barren land in raster format grids (Fig. 11).

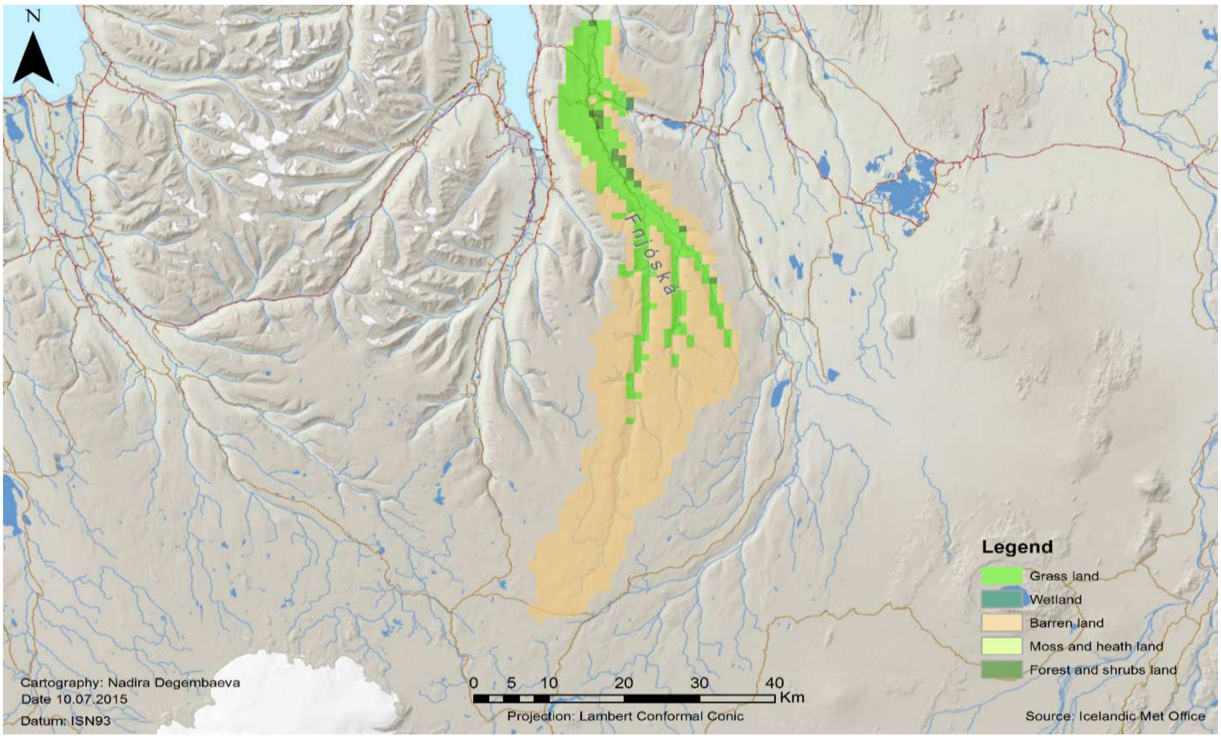


Figure 11. Delineated Fnjóská River watershed and land cover types. (Source: Guðjónsson & Gíslason 1998).

Creation of different hypothetical land cover scenarios from the original was done on the basis of studying the effect on the discharge. When replacing land cover types the soil class under the land cover was also changed. The linkage of land use and soil class for each scenario (section 3.7) was carried out based on the Flokkur soil classes in the WaSiM grid, as presented in Table 4. Figures 12 and 13 show all the hypothetical scenarios of land cover types and soil classes on the Fnjóská watershed.

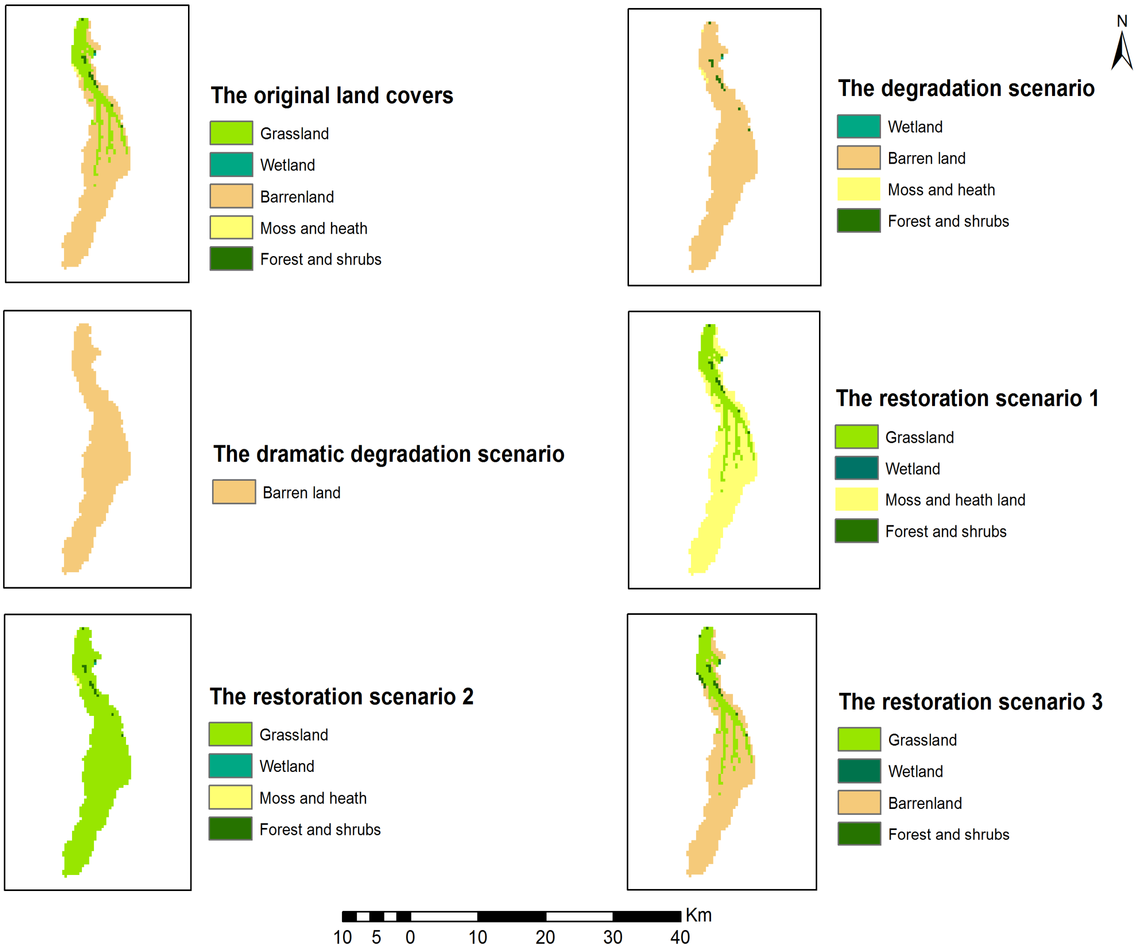


Figure 12. Delineated Fnjóská River watershed and land cover with different scenarios.

Thus the Fnjóská watershed land use changes investigated five hypothetical land use scenarios for runoff generation (Table 4). The hypothetical land use scenarios included two Degradation and three Restoration conditions. The first scenario was generated by shifting the grassland into barren land. The second scenario was used to explore the effects of Dramatic Degradation by changing all the vegetation covers on the Fnjóská watershed to barren land. The Restoration scenarios represented a future land use scenario at different scales. The Restoration 1 and 2 scenarios showed an alteration of barren land into moss and heath, and also grassland on a large scale. Restoration 3 scenario indicated the small scale change of moss and heath land into forest and shrub land (Table 4).

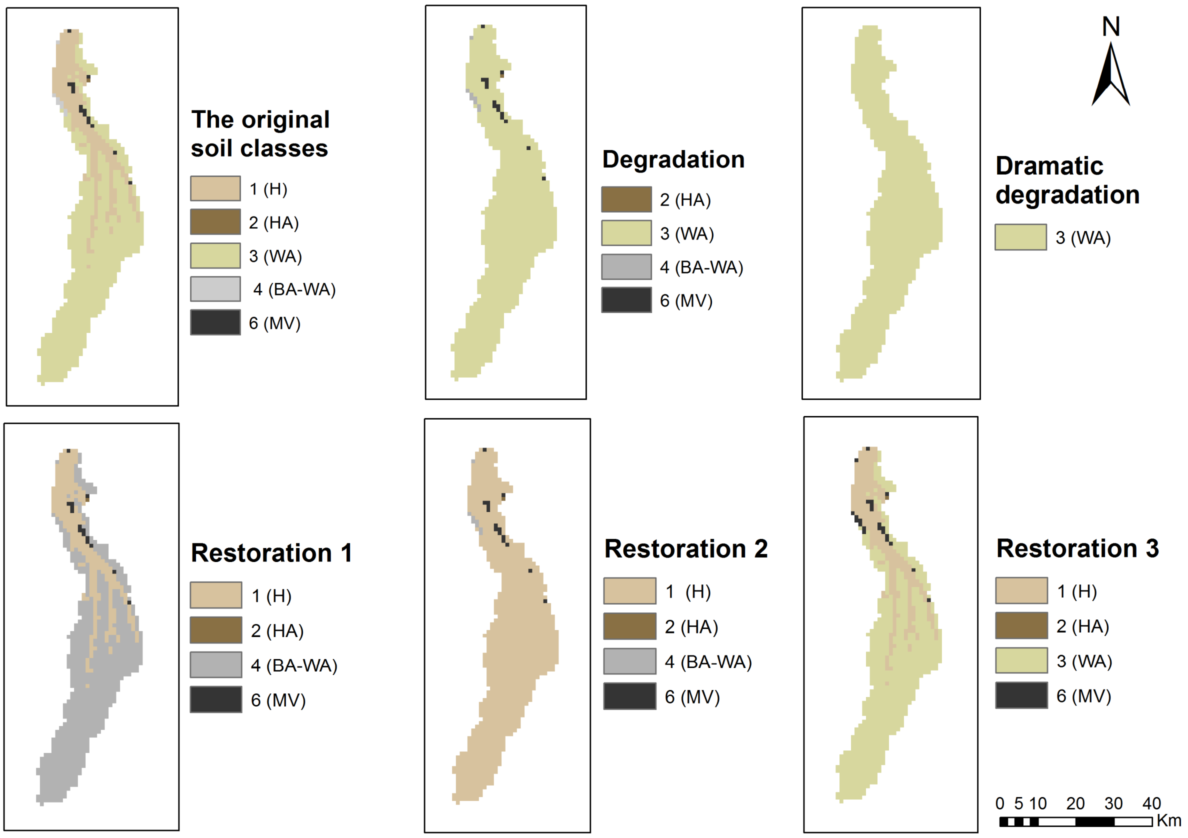


Figure 13. Fnjóská River watershed soil class change scenarios.

4.4 Discharge sensitivity analyses

Figure 14 shows a comparison of observed and simulated discharge over the time period 1976 to 2003. It can be seen in Figure 14 that the calibrated discharge did not manage to represent the highest peaks of the observed discharge, and also that the low flow was a bit higher in the simulated discharge compared to the observed discharge. The scatter plot of calibrated discharge against observed discharges of Fnjóská is shown in Figure 15. The regression lines reveal that the simulated discharge results can fit the data analysis and the R^2 value was around 0.68.

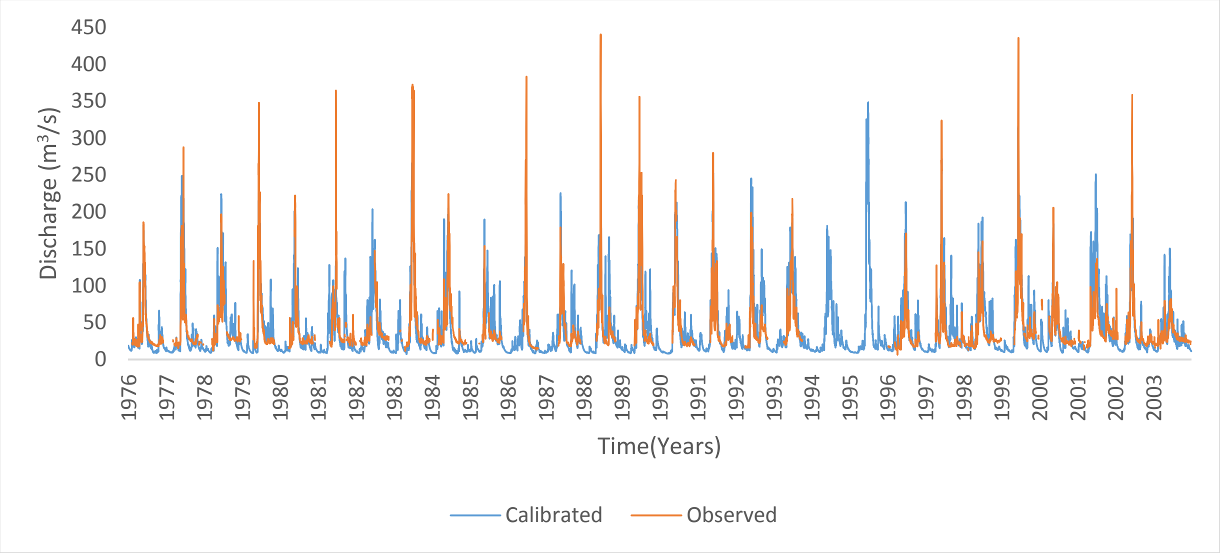


Figure 14. Comparison of observed and calibrated discharge of River Fnjóská from 1976 to 2003.

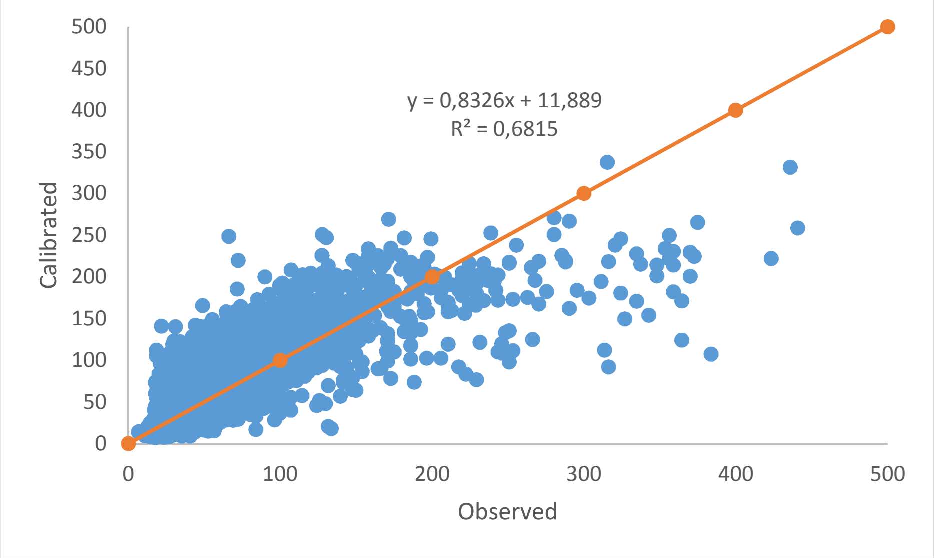


Figure 15. Scatter plot of calibrated and observed discharges at gauge VHM200 of River Fnjóská.

Figure 16 presents a comparison of simulated discharge with simulations from all scenarios for the year 1999. This year was chosen to analyse the comparisons between discharge series because it had one of the highest values of maximum simulated discharge in the Dramatic Degradation scenario. In the analysed time period from1976 to 2003 the highest discharge rates were observed in spring, summer and autumn with different frequencies of discharge peaks for all scenarios. The lowest discharge was registered in the winter and early spring months. The maximum values of discharge were found to be similar for the Degradation and Dramatic Degradation scenarios. A simulated discharge for Restoration scenario 3 was found to have a similar distribution compared to the Degradation scenarios.

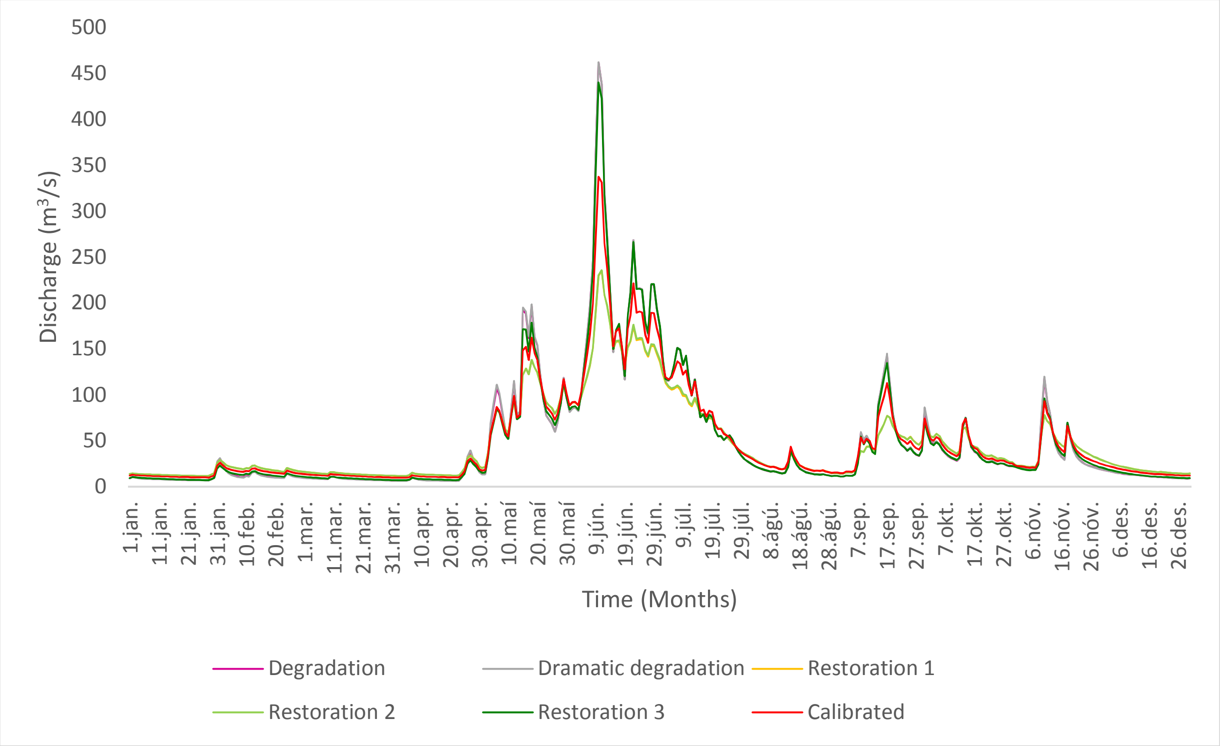


Figure 16. Simulated discharge for the year 1999, using different land cover scenarios of River Fnjóská.

The analysis of simulated discharge detected an increase in the volume of water within the flood peaks when comparing the Dramatic Degradation scenario with other scenarios. The results of the simulation discharge of each scenario showed the highest maximum runoff in the Dramatic Degradation scenarios. This suggests that land use change will have a strong influence on flow by increasing the maximum volume of discharge peaks in summer. Restoration scenario 3 also had a similar trend as the Degradation scenarios. The other two Restoration scenarios 1 and 2 had a low magnitude of discharge in flood. The maximum simulated discharges for all scenarios are shown in Table 6. Therefore, the discharge series of the Dramatic Degradation scenario was chosen for further analyses. Figure 17 shows the long-term discharge rates over 27 years' time for the Fnjóská, using the Dramatic Degradation scenario. The average discharge during the studied time from 1976 to 2003 was 144.24 m^3/s. It can be seen from Figure 17 that the highest discharge was simulated in the years 1995 and 1999.

The discharge series for the Dramatic Degradation scenario for the year 1995 in both the summer and winter seasons are shown in more detail in Figures 18 and 19. The summer seasonal discharge of the study area for the year 1995, which had one of the highest simulated discharges, is shown in Figure 18. The maximum simulated discharge in June was found to be 276.71 m^3/s and the minimum was about 36 m^3/s. The monthly average simulated discharge in June was 139.97 m^3/s. The highest discharge was simulated when grassland and also all vegetation cover was turned into barren land (Degradation and Dramatic Degradation scenarios). The lowest simulated discharge was observed for the Restoration 2 scenario with the lowest discharge from late June to the end of the summer season. All of the scenarios had a low simulated discharge from the middle of August on. Analysis of the results of the seasonal hydrographic year for all scenarios indicated that the Degradation scenarios and Restoration 3 during the flood peaks had the highest rates of discharge. It can also be seen that the trend of distribution of simulated discharges was almost similar to the discharge of the Restoration 1 and 2 scenarios. Comparison of the volume of peak discharge between Degradation and Restoration scenarios showed that the discharge from the Restoration 2 scenario was 37% lower than the discharge from the Dramatic Degradation scenario. Analyses of precipitation and temperature for the 27 year time period on the catchment in question showed the highest maximum value was found in the summer of 1999 (Table 6).

Table 6. Comparison of maximum simulated discharges for the time period 1976 – 2003 for River Fnjóská watershed for all scenarios; calculated in SAS.

	Simulated discharge scenarios, m^3/s				
Time period	**Degradation**	**Dramatic degradation**	**Restoration 1**	**Restoration 2**	**Restoration 3**
1976	233.05	233.02	129.87	130.58	225.35
1977	298.32	298.03	200.79	201.47	291.8
1978	297.01	297.08	159.88	160.63	288.41
1979	278.31	278.73	178.05	179.2	268.97
1980	258.79	258.72	148.61	152.8	252.94
1981	184.77	186.63	111.76	111.87	183.65
1982	263.41	263.88	154.06	154.89	251.45
1983	335.1	335.42	203.32	204.23	325.59
1984	280.78	282.1	154.02	158.26	261.92
1985	246.36	246.32	139.25	140.22	236.49
1986	224.24	224.55	117.56	120.81	221.87
1987	313.29	313.68	152.23	153.83	298.85
1988	345.53	345.86	170.44	173.74	341.07
1989	277.19	277.27	179.73	180.7	274.96
1990	263.61	265.13	166.87	167.73	250.1
1991	327.03	327.26	184.05	184.53	317.46
1992	328.3	328.55	181.47	183.86	316.33
1993	236.96	237.28	143.13	145.15	234
1994	227.35	227.67	134.86	135.32	213.88
1995	441.99	446.34	279.38	280.45	408.25
1996	276.27	276.71	156.71	159.73	274.35
1997	352.49	352.48	186.94	187.93	344.67
1998	249.27	249.41	137.44	138.09	247.47
1999	442.04	462.25	235.1	235.77	440.34
2000	227.23	227.33	134.61	136.21	225.31
2001	322.94	323.21	187.07	187.62	315.81
2002	273.99	280.27	144.45	146.76	257.11
2003	190.17	191.01	109.25	110.67	187.85

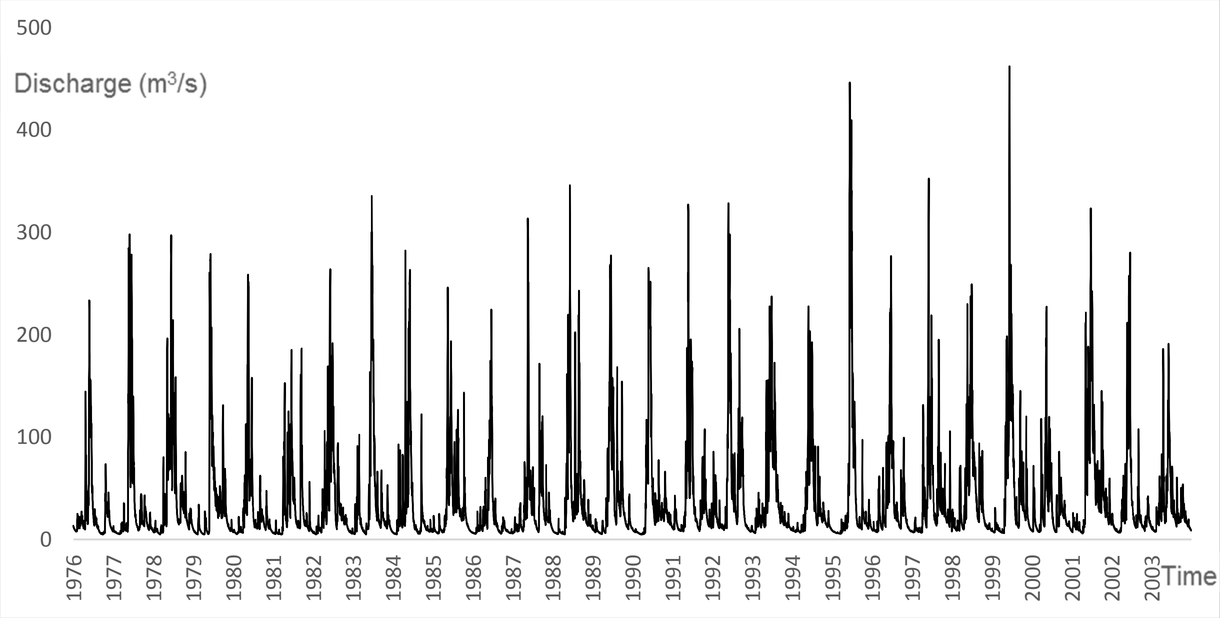


Figure 17. Long-term discharge of River Fnjóská watershed for Dramatic Degradation scenario for time period 1976 to 2003.

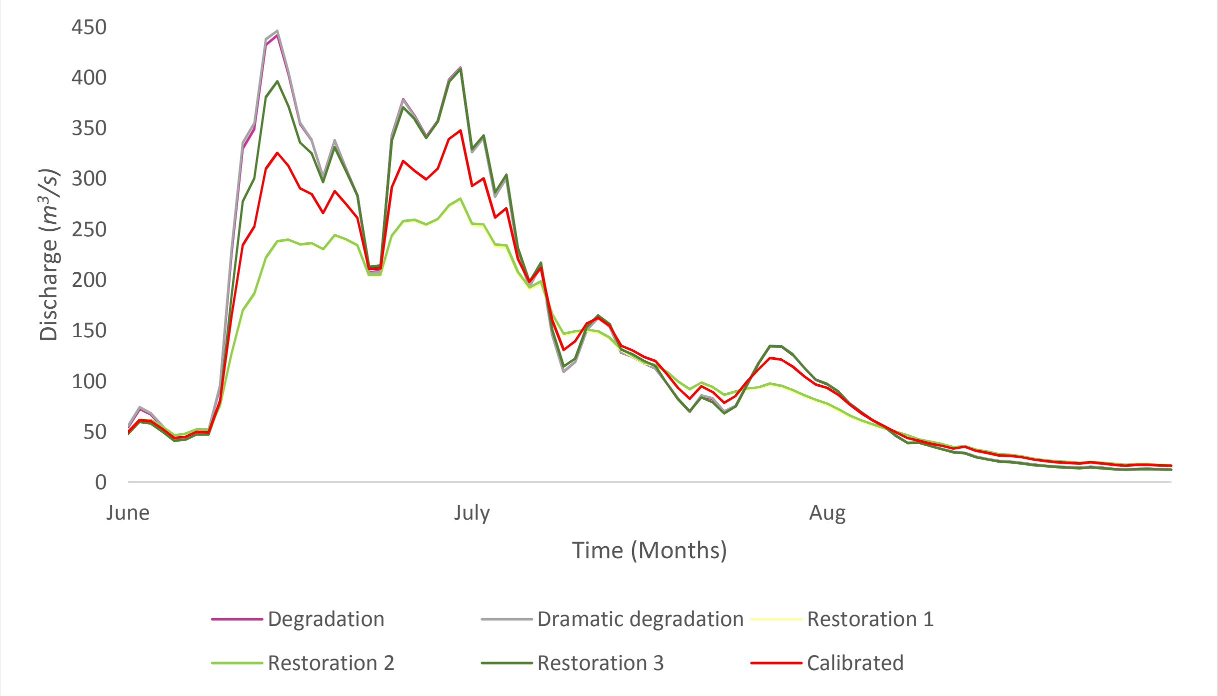


Figure 18. Summer seasonal discharge of River Fnjóská watershed for all scenarios in the year 1995.

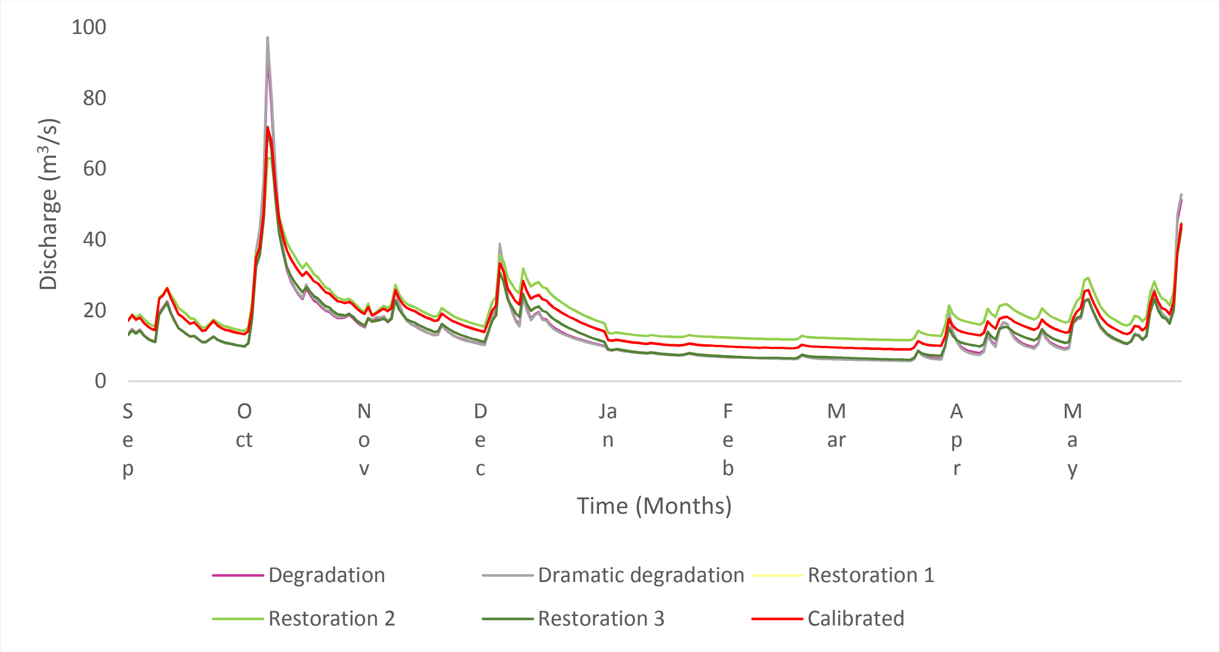


Figure 19. Low winter seasonal discharge of River Fnjóská watershed in the year 1995.

Figure 19 shows simulated spring and winter discharges for 1995 when all the scenarios had similar trends with high discharge in the spring and a similar recession of water level in winter. The increase in discharge for all scenarios started from April with a similar trend of distribution of the discharge rates. The lowest discharge rates were in November and February, when the temperature was lower.

The volume during the recession in the simulated discharge of the River Fnjóská was analysed for October 1995, as shown in Figure 20. Comparison between the calibrated and simulated discharges of the Dramatic Degradation scenario in the hydrographs for one hydrological month shows that the reduction in discharge started from the first decade of the month (Fig. 20). Comparison of the recession during the peak discharge for each scenario for 7 days is shown in Figure 21. Analysis of the reduction in the discharges for all scenarios is presented in a residual plot from calibrated discharge. The increase in simulated discharges for the Degradation and Dramatic Degradation scenarios started in the beginning, and in the middle they intersected with the calibrated one and then decreased. Recession in the discharge volume in the Degradation and Dramatic Degradation scenarios had a similar trend (Fig. 21). Restoration scenarios 1 and 2 had less discharge volume in comparison with the Degradation scenarios. But in the middle of the studied time the volume of discharge in these scenarios intersected with the calibrated volumes and then started increasing. The Restoration 3 scenario had a lower discharge rate than the calibrated one.

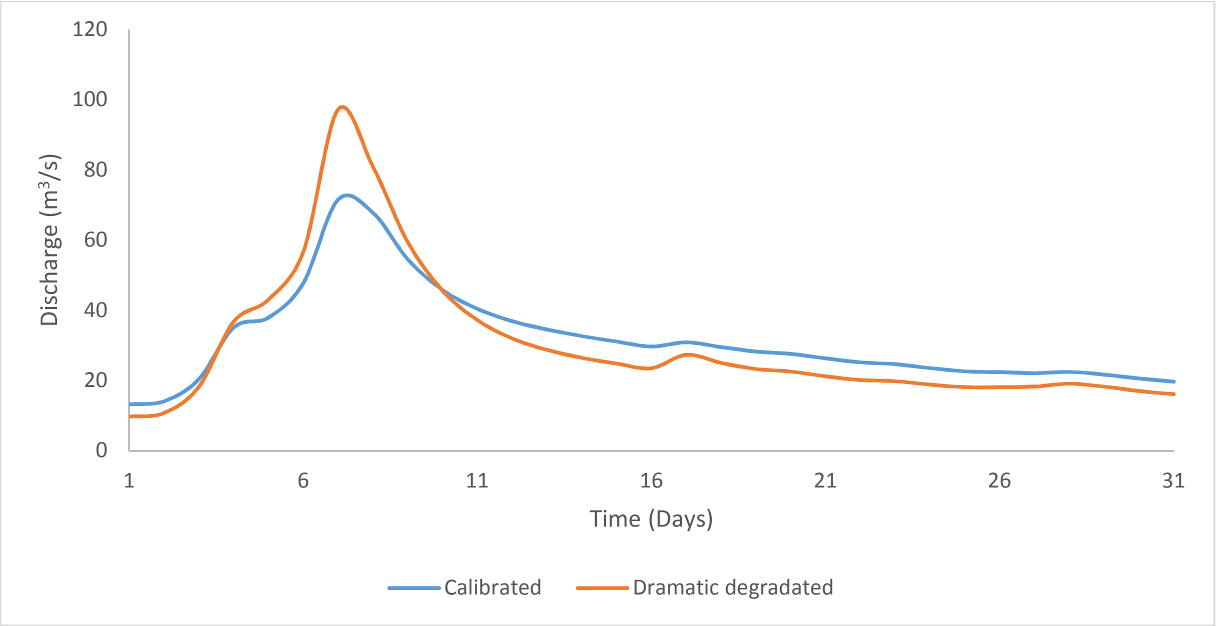


Figure 20. Recession of calibrated and simulated discharge for dramatic degradation scenario of River Fnjóská for October 1995.

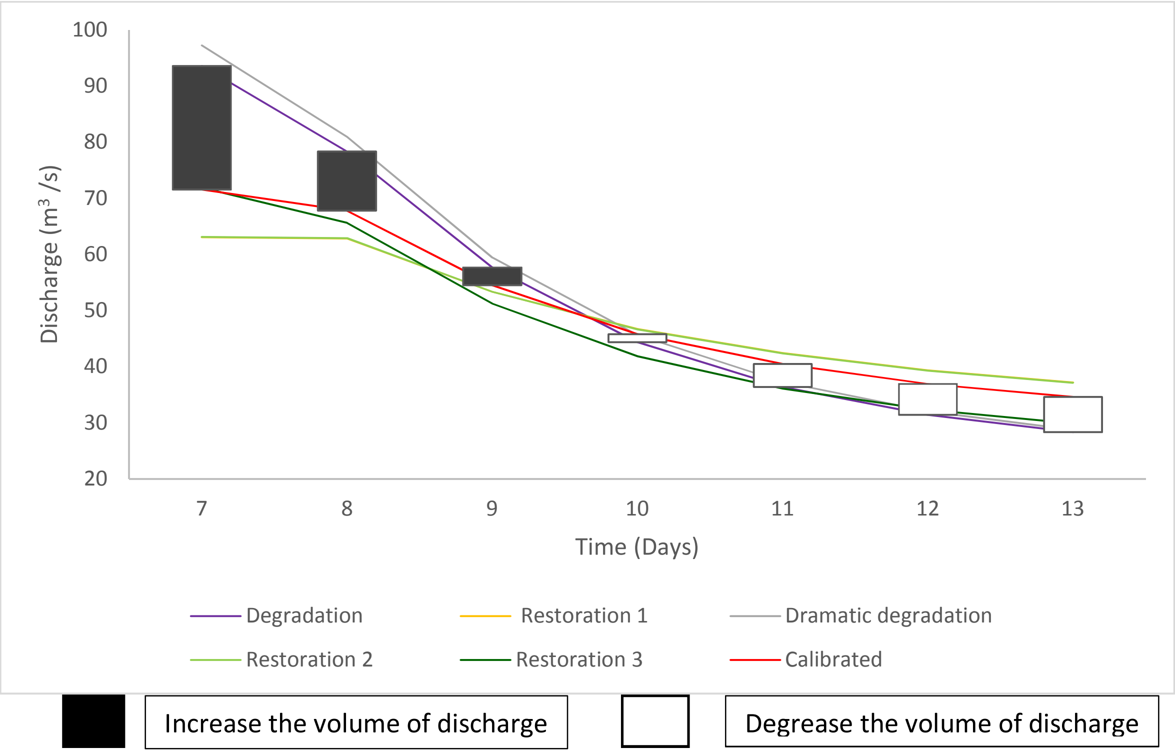


Figure 21. Comparison of recession of simulated discharges for all scenarios of River Fnjóská for October 1995.

Figure 22 shows the effect of each scenario when compared with the base run. If there had been little or no effect in the change of the land use the scatter plot would be close to the 1:1 line. The data points for Degradation and Dramatic Degradation lie over the 1:1 line, indicating that one would expect a higher peak discharge than the existing vegetated land with consequently a higher erosion power. It should be noted that the Restoration 3 scenario is also above the 1:1 line. The Restoration 3 had a small scale change from moss and heath into forest and shrub land and the area with altered land cover was indeed very small (Table 4). In this scenario barren land consisted of about 72.85% of the total area of the watershed. The small change in land cover together with the large area of barren land seems to explain why Restoration 3 was so close to the Degradation scenarios. The Restoration scenarios reflected in Figure 22 show significant lowering in peak discharge, reflecting the beneficial effects of the changed land cover.

5. DISCUSSION

Using the WaSiM model opened up the possibility of exploring in a non-invasive way the effect of discharge for different scenarios at various scales. Consequently it was suitable for analysing the impacts of different land use. The Fnjóská watershed was investigated using WaSiM to analyse the effect of a land use change based on five hypothetical land use scenarios, as reflected in Table 4. The long-term discharge for the Dramatic Degradation scenario was also analysed for the time period under study (Fig. 17). Figure 16 shows that, if all vegetated land cover becomes barren land, the result is a significant increase in the runoff of the River Fnjóská during the flood peaks. The magnitude and frequency of the simulated discharges of Degradation, Dramatic Degradation and Restoration 3 scenarios are very similar, having reiterated peaks of flooding during June and July, as seen on Figure 18. This is caused by snowmelt in spring and early summer and higher infiltration in spring and summer. Usually high flow appeared from spring snowmelt and in summer high discharge was caused by intense rainfall. High intensity of runoff water in the extreme flooding condition in these scenarios will increase inundated areas and sediment transportation. Hence, it is likely that Degradation and Restoration 3 have a tendency to be transformed into Dramatic Degradation, if nothing is done. Figure 18 showing the seasonal changes illustrates the same effect as Figure 16 on an annual basis.

Furthermore, the rather large scale change from barren land in the grassland caused reduction of discharge of a high magnitude. Within the Restoration scenarios, Restoration 3 had the smallest land cover change resulting in a much higher discharge than the other two Restoration scenarios. Therefore, the Restoration 3 scenario of moss and heath turned to forest and shrubs and took into account the small scale change. This was caused on a small change of land cover and did not have much influence on the discharge pattern in the simulation. The small scale change of about 2% of the total area under forest and shrubs was too small to express much of a change in the hydrological process such as in the infiltration rate of the soil profile. The rate of change of the simulated discharges was also different between the Restoration 1 and 2 scenarios compared to the others. During the winter season from the end of autumn the discharge volume declined (Fig. 19). Figure 19 shows the winter seasonal simulated discharges for all scenarios. The highest discharge for the winter season was found for the Restoration 1 and 2 scenarios while Dramatic Degradation came out at the bottom.

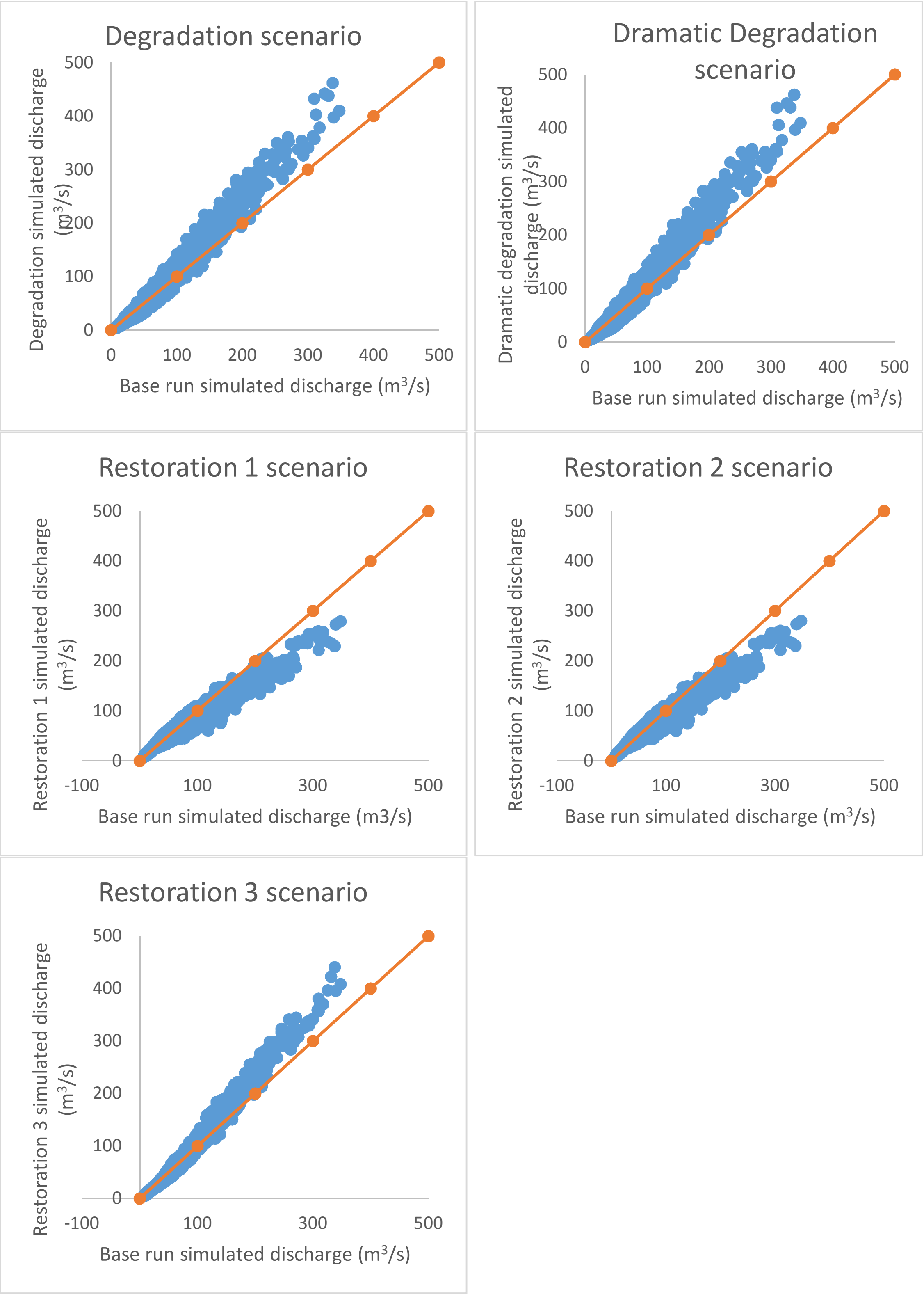


Figure 22. Scatter plot of calibrated and different simulated discharges scenarios of River Fnjóská.

When barren land shifted to the grassland in the catchment area (Restoration 2 scenario; Fig. 22) the change in the discharge could be significant as grassland increases the roughness and grass has a capacity to withhold water, thus increasing water storage and decreasing the erosion rates (Zhao & Xu 2013). Greipsson (2012) reported that the eroded soil results from wind and water erosion activities. In his research it was noted that the intensity and frequency of the highest peaks of flood increased sediment transportation and the possibility of developing gully erosion. The cause of increased runoff in the Dramatic Degradation scenario (Fig. 22) was the lack of vegetation cover and higher runoff volumes which influenced the soil moisture content, land use and soil types.

Former research has shown that land use changes have an effect on the hydrological regime of river drainage systems (Jasper et al. 2004; Krause et al. 2007*b*; Fan & Shibata 2015; Elfert & Bormann 2010). The finding in this present work was in full agreement with previous research, as can be seen in Figure 22. The scenarios containing grassland and forest illustrated a lowering in peak discharge, reflecting the beneficial effects of the changed land cover. Forest land had the highest capacity to absorb water as it impacted the parameters intercepCap, soil surface resistance, aerodynamic roughness length and root depth more than the other land use types (Table 5). It follows from Table 5 that barren land has the least values, which leads to that changes from one scenario to the other have profound consequences on the river drainage system. Soil parameter input data for the WaSiM model for the Fnjóská watershed consisted of 13 types (Table 2). The results in the simulation showed that the different soil and land use parameters influenced the water holding capacity and runoff. Soil moisture content, rainfall and its intensity, and temperature affected the infiltration process, which included soil profile, root depth and soil surface cover.

Vegetation cover slows the surface runoff, and increases the rate of infiltration. In addition, vegetation increases soil porosity and organic matter content, which have a positive effect on infiltration. The result in the simulation showed that the different soil and land use parameters influenced the water holding capacity and runoff. Krause et al. (2007*b*) reported the changes in land cover were connected with soil profile hydrological processes such as evapotranspiration, infiltration, percolation and root water absorption. In addition, the herbaceous plants increases the stability of the soil aggregate (Ekwue 1990), enhance surface roughness, and increase resistance to surface runoff via its leaves and stems (Sack & Holbrook 2006; Degembaeva 2006). According to the results increased grassland created good condition for infiltration and all barren land changes to grass as an outcome of implementations which included soil conservation and protection.

Restoration can be achieved by management activities, as reported by Brooks et al. (2003) and Galatowitsch (2012). The scenario where barren land shifted to moss and heath land was called Restoration 1. In this scenario alteration was allowed to take its course in a natural way, enabling long-term recovery. The Restoration 2 scenario indicated changes in the soil texture and vegetation density (Krause et al. 2007*b*) by increasing resilience to the erosive power of water runoff and reduced the peak of discharge. Improved land cover increases soil organic matter and stabilizes the soil (Arnalds et al. 1997; Francos et al. 2003), and also considerably diminishes the amount of suspended sediment (Brooks et al. 2003; Fan & Shibata 2015). There is increasing surface roughness in grassland and the root depths of the vegetation improves water movement. When comparing Restoration with Dramatic Degradation scenarios, barren land did not have enough organic matter in the soil profile. Additionally, the condition of the soil under barren land can change over time caused by raindrops on the surface.

The results obtained in this study are consistent with those of Elfert and Bormann (2010) on the impact of land use showing how the discharge was affected when agricultural land changed into urban. This condition led to the increase in runoff, which land use effects revealed through changing vegetation cover and soil characteristics. Thus the hydrologic regime changed from the result of the impact of land use. The hydrologic regime changed as a result of the land use changes when the hydrological properties of the land were changed by altering the vegetation cover and water holding capacities of soil layers. The impact of land use changes was significant when compared to barren land and grassland. These results point out the sensitivity of simulated discharge to land use changes, especially when influenced over the longest time period used in the study.

6. CONCLUSION

The study is about the impact of land use on the discharge of the River Fnjóská watershed and includes sensitivity analysis of the effects of different land covers. In the analysis five simulated land cover scenarios on the watershed area were compared. The analysis covered different types of land use such as grassland, wetland, barren and forest land, moss and heath. Different types of land use data, as well as likely changes in soil characteristics of the watershed, were used as input by the ArcGIS tool into the WaSiM model. The model was calibrated to historic/observed data to find a best fit. The best fit model was then used as a basis for comparison of the effect of having different land cover types within the modelled area. Consideration of the calibrated discharge with different land use scenarios included annual, long-term and seasonal analyses. The simulated discharges for Restoration 1 containing mainly moss and heath and Restoration 2 consisting mainly of grassland were close to the Calibrated/Natural scenario, and had a similar type of distribution. The Dramatic Degradation scenario, representing barren land cover differed substantively from the Calibrated/Natural scenario and had a higher discharge during the flood peaks. Based on the model runs, it is quite obvious that the condition of the land use affected the water runoff characteristics, and as a consequence of changed land cover and the soil class of the watershed. According to the results of this project the WaSiM model simulated discharge of River Fnjóská watershed well. It would be beneficial for further research in this field to extend the work to the impact of climate and land use change, together with sediment transportation. This would allow gaining better knowledge of the water balance required for sustainable watershed management.

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