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Environmental Education – OERs for Rural Citizens (EnvEdu - OERs)

Water Resources and Water Balance for Sustainable Community

TM 5

Water Balance, Climate Change Effects and Water Pollution: The case study of Rangárvellir in Iceland

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Introduction

Water balance is a crucial concept in hydrology and environmental science, representing the equilibrium between water inflows and outflows within a specific system. This balance is essential for sustaining natural ecosystems, supporting human activities, and ensuring water availability for various purposes. The complex interplay of precipitation, evaporation, runoff, infiltration and other hydrological processes determines the state of the water balance in a given region. Human interventions, such as irrigation and dam construction, can significantly alter the natural water balance, leading to potential environmental consequences. Understanding and managing water balance are vital for effective water resource management, flood control and sustainable development. This presentation explores the fundamental principles and factors influencing water balance, highlighting its importance in addressing water-related challenges and fostering a harmonious relationship between human needs and the environment.

Fresh water resources

The world's fresh water resources are distributed across various sources, including rivers, lakes, groundwater and glaciers. These sources play a crucial role in supporting ecosystems, human communities and economic activities. However, water scarcity and mismanagement are increasingly becoming global challenges, impacting billions of people.

- Rivers and Lakes: Rivers and lakes are significant sources of fresh water, providing essential supplies for drinking, irrigation, industry and various other purposes. Major river systems, such as the Amazon, Nile, Yangtze, and Mississippi, contribute significantly to the availability of fresh water in their respective regions.
- Groundwater: Groundwater is the water stored underground in porous rock formations called aquifers. It serves as a critical reserve of fresh water, especially in arid and semi-arid regions where surface water may be scarce or seasonal. Groundwater supports agriculture, provides drinking water and sustains many ecosystems.
- Glaciers and Ice Caps: Glaciers and ice caps hold a substantial portion of the world's fresh water. These frozen reservoirs slowly release water, contributing to river flows and providing a critical source of freshwater in various regions. However, due to climate change, many glaciers are melting at an accelerated rate, affecting downstream water availability and potentially leading to water stress.
- Wetlands: Wetlands, including marshes, swamps, and bogs, are valuable ecosystems that store and purify water. They serve as natural buffers against floods, provide habitats for diverse species and contribute to the overall health of the environment.

Despite the abundance of fresh water resources on a global scale, several regions face water scarcity due to uneven distribution, increasing demand and unsustainable water management practices. Factors such as population growth, industrialization, climate change and pollution further exacerbate water stress in many parts of the world.

Sustainable water management, conservation and responsible usage are essential to ensure the availability and accessibility of fresh water resources for current and future generations. Addressing water challenges on a global scale requires cooperation, innovative solutions and a holistic approach that considers both human needs and the health of the planet's ecosystems.

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The water cycle, also known as the hydrological cycle, is a continuous and natural process that describes the circulation and transformation of water on Earth. It is a fundamental process that sustains life and regulates the planet's climate. The water cycle involves several interconnected stages, where water transitions between different physical states (solid, liquid and gas) as it moves through the atmosphere, land and oceans. The key stages of the water cycle are as follows:

- Evaporation: The cycle begins with the process of evaporation, where the Sun's heat causes water from oceans, lakes, rivers and other bodies of water to transform from liquid to water vapor (a gas) and rise into the atmosphere.
- Condensation: As the water vapor rises higher into the atmosphere, it cools down and condenses back into tiny water droplets, forming clouds. Condensation occurs around microscopic particles in the air known as cloud condensation nuclei.
- Precipitation: When the water droplets in the clouds grow larger and become too heavy to remain suspended in the atmosphere, they fall back to Earth's surface as precipitation. Precipitation can take various forms, such as rain, snow, sleet or hail, depending on atmospheric conditions.
- Infiltration: Once the precipitation reaches the Earth's surface, it can follow different paths. Some of it may be absorbed into the soil, a process known as infiltration, where it becomes groundwater. Groundwater is stored in aquifers, and it can feed into rivers or be drawn up by plants through their roots.
- Runoff: Another portion of the precipitation that falls on the land does not infiltrate the soil and instead flows over the surface as runoff. Runoff occurs in rivers, streams, and eventually makes its way back to the oceans, completing the cycle.
- Evapotranspiration: In addition to evaporation from water bodies, water also evaporates from the surfaces of plants through small openings called stomata. This process is known as transpiration. Transpiration is an essential part of the water cycle as it contributes to the overall moisture in the atmosphere.

The water cycle is a dynamic process, with water continuously moving through these stages at different rates depending on local climate, geography and land use. It is a finely balanced system that helps regulate Earth's temperature, influences weather patterns and supports various ecosystems and life forms. Human activities, such as deforestation, urbanization and the release of greenhouse gases, can impact the water cycle and lead to imbalances and water-related challenges like floods, droughts and water pollution. Understanding and managing the water cycle are critical for sustainable water resource management and the well-being of both natural environments and human populations.

Climate change effects

Introduction

Climate change refers to long-term alterations in Earth's climate patterns, specifically changes in temperature, precipitation, and weather events that have been occurring over the past century and are expected to continue in the future. The primary driver of modern climate change is the rapid increase in greenhouse gas emissions, primarily carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), resulting from human activities.

The main human activities contributing to climate change include:

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- Burning Fossil Fuels: The combustion of fossil fuels such as coal, oil and natural gas for electricity, transportation and industrial processes releases large amounts of CO2 into the atmosphere.
- Deforestation: Clearing of forests for agriculture, logging and urban development reduces the Earth's ability to absorb CO2 through photosynthesis, leading to increased atmospheric CO2 levels.
- Industrial Processes: Certain industrial activities, such as cement production and chemical manufacturing, release greenhouse gases and other pollutants into the atmosphere.

The consequences of climate change are far-reaching and impact various aspects of the Earth's environment and ecosystems, as well as human societies. Some of the observed and projected impacts of climate change include:

- Rising Global Temperatures: The Earth's average surface temperature has been increasing, leading to more frequent and intense heat waves.
- Melting Glaciers and Ice Caps: Glaciers and ice caps in polar regions and high mountains are melting at an accelerated rate, contributing to rising sea levels.
- Changes in Precipitation Patterns: Climate change can lead to altered rainfall patterns, causing more intense rainfall in some regions and prolonged droughts in others.
- Sea Level Rise: As glaciers melt and seawater expands due to higher temperatures, sea levels are rising, threatening coastal communities and low-lying areas.
- Ocean Acidification: Increased CO2 levels in the atmosphere also lead to higher CO2 absorption by the oceans, resulting in ocean acidification, which can harm marine life, particularly organisms with calcium carbonate shells.
- Extreme Weather Events: Climate change is associated with more frequent and severe weather events, such as hurricanes, droughts, wildfires and floods.
- Ecosystem Disruption: Many plant and animal species are facing challenges in adapting to the rapid changes in their habitats, leading to disruptions in ecosystems and potential loss of biodiversity.

Addressing climate change requires collective global efforts to reduce greenhouse gas emissions, transition to renewable and sustainable energy sources, conserve forests and natural habitats and implement adaptation measures to cope with the unavoidable impacts. International agreements, such as the Paris Agreement aim to promote cooperation between nations in combating climate change and working towards a more sustainable and resilient future.

Effect on the water balance

Climate change has significant impacts on the water balance of various regions around the world. Changes in temperature, precipitation patterns and evaporation rates alter the availability, distribution and quality of water resources, affecting both natural ecosystems and human societies. Some of the key effects of climate change on water balance include:

- Changes in Precipitation Patterns: Climate change can lead to shifts in precipitation patterns, causing some regions to experience more intense and frequent rainfall, while others face prolonged droughts. This alteration in precipitation affects the inflow of water into rivers, lakes and groundwater, disrupting the natural water balance.
- Altered Snowmelt Timing: In regions where snowfall is a significant source of water, rising temperatures lead to earlier snowmelt. This can result in reduced water availability during critical periods, affecting water supply for agriculture, drinking water and hydropower generation.
- Increased Evaporation: Higher temperatures lead to increased evaporation from water bodies and soil surfaces. This can reduce water levels in lakes and rivers and exacerbate water scarcity in already dry regions.

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- Glacier Melting: Climate change causes glaciers and ice caps to melt at an accelerated rate. These frozen reservoirs of water are critical contributors to river flows in some areas. As glaciers shrink, they can initially increase river flow but in the long term, this trend leads to reduced water availability, particularly during the dry season.
- Sea Level Rise: Rising sea levels due to the melting of polar ice caps and glaciers can lead to the intrusion of saltwater into coastal aquifers, threatening freshwater supplies in coastal regions.
- Groundwater Depletion: Changes in precipitation patterns and increased evaporation can lead to changes in groundwater recharge rates. In many areas, groundwater is being withdrawn faster than it can be naturally replenished, leading to groundwater depletion.
- Water Quality Issues: Climate change can impact water quality by influencing the concentration of pollutants and nutrients in water bodies. Altered precipitation patterns can lead to more intense runoff, carrying pollutants from the land into rivers and lakes, affecting water quality and ecosystem health.
- Increased Water Stress: Climate change exacerbates water stress in already water-scarce regions, making it challenging for communities to meet their water needs for agriculture, industry and daily living.
- Shifts in Ecosystems: Changes in water availability and temperature can lead to shifts in ecosystems and species distributions. Some species may struggle to adapt or find suitable habitats, leading to potential biodiversity loss.

The complex interplay of these factors impacts the delicate balance of water availability and distribution. Sustainable water management practices, including water conservation, efficient irrigation techniques and proper monitoring of water resources, become increasingly crucial in the face of climate change. Adaptation and resilience strategies are essential to mitigate the effects of climate change on water balance and ensure a sustainable water supply for future generations.

Water pollution

Water pollution refers to the contamination of water bodies, such as rivers, lakes, oceans, groundwater and even drinking water sources, by harmful substances or pollutants. These pollutants can be natural or human-made, and they disrupt the normal functioning of aquatic ecosystems, endanger human health and adversely affect various forms of life that depend on clean water. Water pollution is a global environmental concern with significant consequences for both the environment and human society.

Sources of Water Pollution

- Industrial Discharges: Factories and industrial facilities release various chemicals, heavy metals and toxins into water bodies, often without proper treatment, leading to water contamination.
- Agricultural Runoff: Pesticides, herbicides and fertilizers used in agriculture can wash into nearby waterways through runoff, contaminating water sources and causing ecological imbalances.
- Municipal Wastewater: Wastewater from households, commercial establishments and urban areas, if not adequately treated, can introduce pathogens, nutrients and pollutants into water bodies.
- Oil Spills: Accidental releases of oil from ships, pipelines or offshore drilling platforms can cause severe pollution in marine environments, harming marine life and coastal ecosystems.
- Improper Waste Disposal: Dumping of solid waste, including plastics and other non-biodegradable materials, directly into water bodies contributes to water pollution.

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- Mining Activities: Mining operations can release toxic chemicals, heavy metals and sediments into waterways, contaminating surface and groundwater sources.

Effects of Water Pollution

- Ecological Impacts: Water pollution disrupts aquatic ecosystems by harming aquatic plants, fish and other organisms. It can lead to the loss of biodiversity and the destruction of habitats.
- Drinking Water Contamination: Water pollution can render drinking water unsafe, leading to waterborne diseases and health issues in human populations.
- Harm to Marine Life: Polluted water negatively impacts marine species, such as fish, mammals and birds, through ingestion of pollutants and habitat degradation.
- Eutrophication: Excessive nutrients from fertilizers and untreated wastewater can cause eutrophication, leading to the growth of harmful algal blooms and oxygen-depleted "dead zones" in water bodies.
- Economic Costs: Water pollution affects tourism, fishing industries and other water-dependent economic activities, leading to financial losses and reduced livelihood opportunities.
- Groundwater Contamination: Polluted surface water can seep into groundwater sources, contaminating underground aquifers that serve as essential sources of drinking water.

Addressing Water Pollution

Efforts to combat water pollution involve a combination of regulations, pollution control measures and public awareness:

- Water Quality Standards: Governments set water quality standards and regulations to limit the release of pollutants into water bodies from various sources.
- Wastewater Treatment: Proper treatment of municipal and industrial wastewater before discharge helps reduce the impact of pollution.
- Best Management Practices: Implementing best practices in agriculture and industry to minimize runoff and pollutant discharges.
- Sustainable Waste Management: Encouraging proper waste disposal and recycling to prevent litter and pollutants from entering water bodies.
- Environmental Education: Increasing public awareness about water pollution and its consequences to encourage responsible water use and pollution prevention.
- International Cooperation: Addressing water pollution often requires collaboration between nations, especially for transboundary water bodies.

Water pollution is a multifaceted problem that demands a collective effort from governments, industries, communities and individuals to safeguard our water resources and protect the health of the environment and future generations.

Case study from Iceland

Introduction

- Iceland, known as the "Land of Fire and Ice," is a country abundant in water resources due to its unique geological and climatic characteristics. The country's water resources are mainly derived from its glaciers, rivers and groundwater. These resources play a vital role in supporting Iceland's ecosystem, economy and energy production.
- Glaciers: Iceland is home to numerous glaciers, covering approximately 11% of its land area. These massive ice formations act as natural reservoirs, storing vast amounts of freshwater. During the summer months, as

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the glaciers melt, they release melt water into rivers and lakes, contributing to the country's water supply. The biggest glacier of Iceland is called Vatnajökull.

- Rivers: Iceland's glacier-fed rivers are an essential source of freshwater. These rivers flow through the country's diverse landscapes, providing water for various uses, including hydropower generation, agriculture and drinking water supply. Some of the prominent rivers in Iceland include the Þjórsá (the longest river of Iceland, 230 km), Ölfusá (the greatest flow of an Icelandic river) and Hvítá (includes the Gullfoss waterfall).
- Groundwater: Iceland's volcanic geology creates a unique hydrological system with substantial groundwater reserves. Aquifers and permeable volcanic rocks act as underground reservoirs, providing a stable supply of freshwater to wells and springs. Groundwater is particularly important for rural communities and agricultural activities.
- Lakes: Iceland has numerous glacial and volcanic lakes, which serve as additional water sources. These lakes are often fed by glacier melt water and groundwater inflows, providing valuable water resources for both human use and aquatic ecosystems.
- Geothermal Springs: Iceland's geothermal activity results in hot springs and geysers that provide a unique source of freshwater. While these sources may not contribute significantly to the overall water supply, they are essential for local communities and offer opportunities for geothermal energy utilization.

Due to its abundant water resources, Iceland has harnessed its hydroelectric and geothermal potential for electricity generation and district heating. Hydropower and geothermal energy together account for almost all of Iceland's electricity production, making it one of the greenest energy systems in the world.

Despite its water wealth, Iceland faces challenges related to water management, including the need for sustainable use, protection of sensitive ecosystems and potential impacts of climate change on glacier melt water and precipitation patterns. Responsible water resource management remains essential to ensure the continued availability and quality of water resources in this unique and geologically active country.

The case study of Rangárvellir

A sustainable water balance requires a resilient ecosystem that can withstand extreme weather patterns, volcanic eruptions, earthquakes and sufficient agricultural production for local needs. Resilience is the capacity of an ecosystem to respond to a perturbation or disturbance by resisting perturbations and recovering quickly. In this presentation we will present the Hydro Resilience project, which will assess the effects of ecosystem restoration on the resilience of water resources by increasing the field capacity (FC) in the Rangárvellir restoration area (Figure 1a) in southern Iceland. An increased FC secures water availability during droughts, reduces the flood risk during heavy precipitation events and enhances the water quality in some cases. The Rangárvellir area presents ideal conditions for such investigations. Dramatic deforestation during the last millennium and year round livestock grazing along with devastating ash emissions during volcanic eruptions and a harsh sub-polar oceanic climate have led to severe degradation in Rangárvellir (Figure 1c). Since the beginning of the 20th century diverse restoration measures have been implemented, restoring large parts of the Rangárvellir area (Figure 1b). This makes Rangárvellir an ideal case study to investigate the effects of restoration on the resilience of water resources. Furthermore, in a joint effort to provide an overview of terminated and ongoing research project, the Soil Conservation Service of Iceland (SCSI) and Reykjavik University have established a metadata

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base (Figure 2) summarizing all relevant restoration projects in the Rangárvellir area, a representative study site in southern Iceland.

In the Hydro Resilience project we will assess and quantify the evolution of water resources in Rangárvellir by assessing the runoff dynamics in the main rivers of Rangárvellir under four main scenarios: i) present conditions, ii) degraded conditions as was the case 100 years ago, iii) under hypothetical fully restored ecosystems (Figure 1d) and, finally, iv) under conditions of a scenario developed in collaboration with local stakeholder groups to optimize socio-ecological benefits. For this purpose existing data will be complement with additional field observations (Figure 3a) and the dynamics of the relevant hydrological processes in the area (incl. river runoff, ground water table, snow cover duration, soil moisture dynamics) will be reconstructed using hydrological models (Figure 3b) to run the above mentioned scenarios. Based on initial investigation, we hypothesis that restoration has significantly reduced flood peaks and increase ground water availability during dry periods (Figure 3c). The scientific findings and conclusion of this project will generate valuable insights on the effects of land restoration on water runoff and water quality. The presentations will outline the main methods used during the project and conclude by providing an outlook on the expected results.

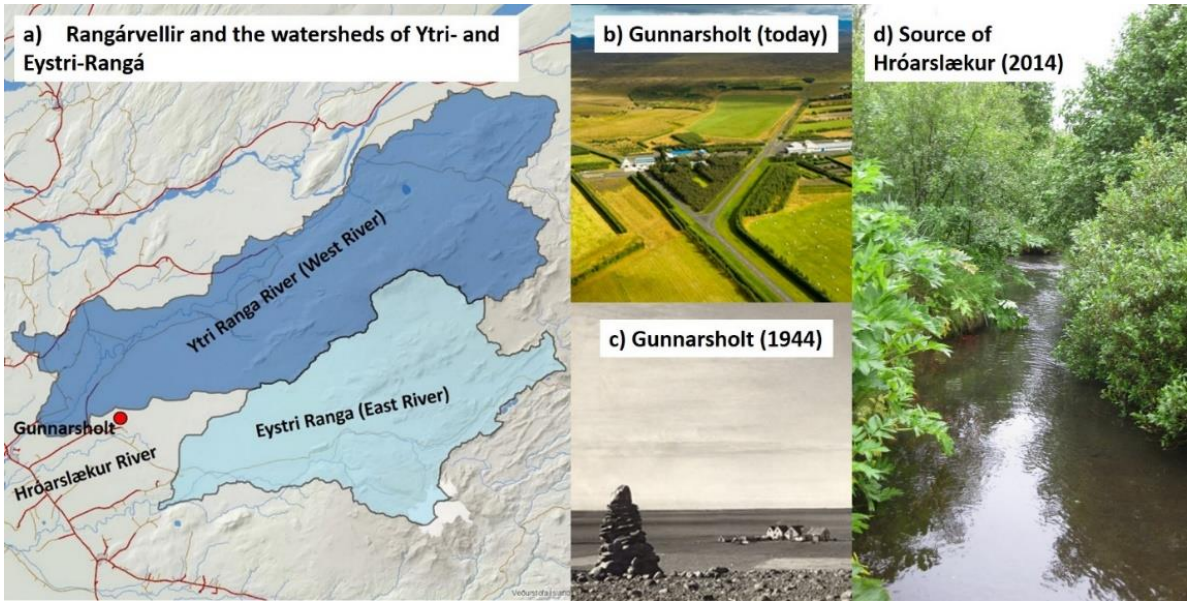

Figure 1. Overview of the two watershed of Ytri- and EystriRangá in Rangárvellir in southern Iceland (a). Picture of Gunnarsholt, the headquarters of the SCSI in 1944 (b) and 2012 (c) (photo from land.is). Picture (d) Visualizes natural succession of birch trees in a protected area around the source of Hróarslækur (photo taken in 2014 by Finger).

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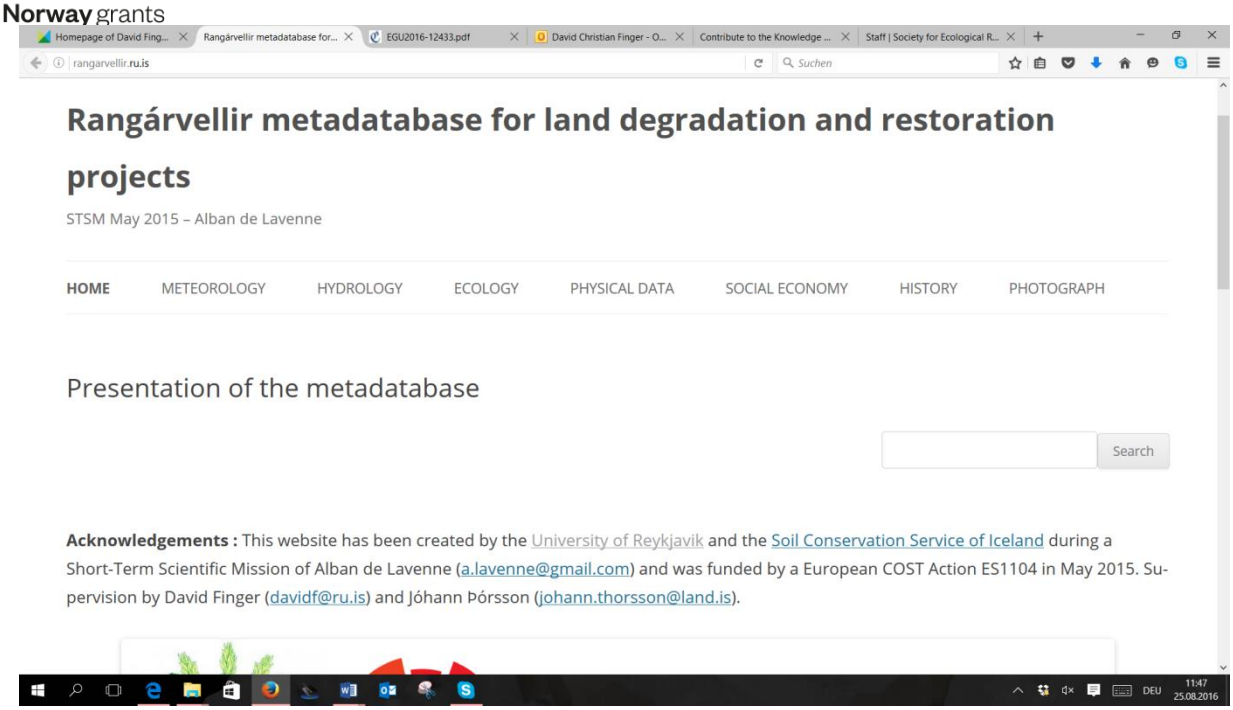

Figure 2. Screenshot of the web-based metadata base for land degradation and restoration in southern Iceland: *http://rangarvellir.ru.is/*

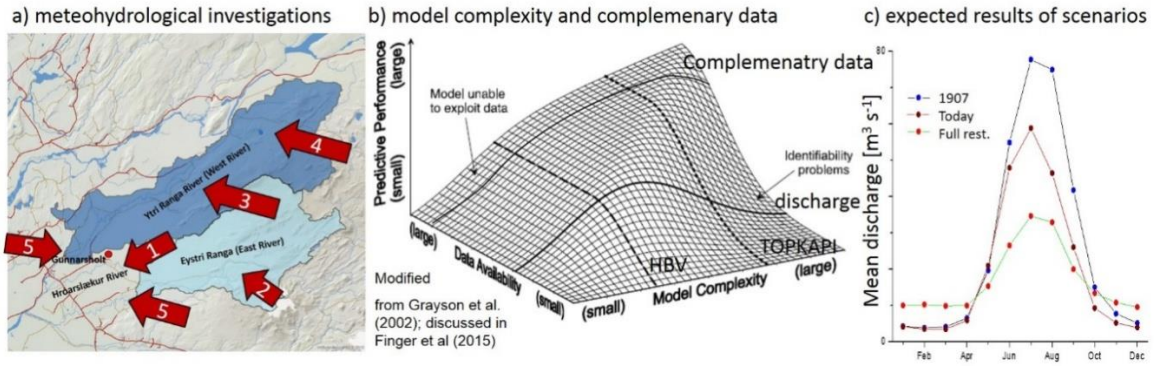

Figure 3. Fesearch steps of the project: a) complementary field observations, b) application and calibration of appropriate modeling tools and c) expected results from hypothetical scenario runs.

Conclusion

In summary, this presentation explores the significance of water resources, climate change, water balance and water pollution, focusing on Iceland's Rangárvellir as a case study. It emphasizes the need for responsible water management, conservation and pollution control, especially in the context of climate change. The Rangárvellir case study demonstrates how ecosystem restoration can enhance water resource resilience. As we tackle water-related challenges, cooperation and a holistic approach are crucial to protect water resources for the future.

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