Master's thesis

Applying a Coastal Vulnerability Index (CVI) to the Westfjords, Iceland: a preliminary assessment

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Declaration

I hereby confirm that I am the sole author of this thesis and it is a product of my own academic research.

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Abstract

Coastal environments are of significant economic, ecological and social importance to the global population. However, they are under increasing pressure from both rapid anthropogenic development and predicted consequences of climate change, such as sea-level rise, coastal erosion and extreme weather events. In light of this, effective coastal management is necessary to ensure the conservation and prosperity of these important environments. Coastal vulnerability assessments are a useful means of identifying areas of coastline that are vulnerable to impacts of climate change and coastal processes, highlighting potential problem areas. These assessments often take the form of an 'index' that quantifies the relative vulnerability along a coastline. This preliminary assessment adapted a coastal vulnerability index (CVI) methodology applied in the KwaZulu-Natal province, South Africa to the fjordic environment of the Westfjords, Iceland. By measuring prescribed physical parameters, the study evaluatedthe relative coastal vulnerability of the Westfjords coastline to impacts of sea-level rise, erosion and extreme weather events and subsequently assessedsocio-economic features located in particularly vulnerable areas. Furthermore, the methodology was adapted to incorporate Westfjords specific hazards e.g. avalanche risk. The majority of coastal sections scored similarly: in a possible range of 6-28, 66% of coastal sections scored between 15-18.Areas that were ranked as higher vulnerability were scattered across the study area with no real geographical association, although two of the three highest scoring coastal sections were located in Dýrafjörður. Seven of the eight highest scoring coastal sectionswere situated in an estuary environment. Other common higher score determinants were short beach width, high avalanche risk and minimal vegetation behind the back-beach. Transport infrastructure was present in all but one of the coastal sections scoring 22 and above, ranging from major to minor roads. Other socio-economic features located in these areas were residential and agricultural.Data and methodological limitations mean findings from this study cannot provide anything more than a generalisation of coastal vulnerability to coastal process such as erosion and inundation.However, this studycan provide a possible foundation for future work, especially if relevant wind and wave data are incorporated.

Key words: Coastal Vulnerability Index (CVI), Sea-level rise, Westfjords, Coastal zone management

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List of Acronyms

CVI	Coastal Vulnerability Index
DEM	Digital elevation model
IPCC	Intergovernmental Panel on Climate Change
RSLR	Relative sea-level rise
SLR	Sea-level rise
SRTM	Shuttle Radar Topographic Mission
UNEP	United Nations Environment Program

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1. Introduction

'Planet Earth is a coastal planet' (Martinez et al., 2007, p255)

'We are a predominantly a coastal species' (Mee, 2010, p2)

Whilst estimates may vary, approximately 40-60% of the global population lives within the coastal zone (UNEP, 2002, Lakshmi &Rajagopalan, 2000, Martinez et al., 2007), an area (depending on how the coastal zone is defined) that accounts for approximately 10-29% of the world's land mass ((Lakshmi &Rajagopalan, 2000, Martinez et al., 2007). The coast clearly possesses a particular allure to populations worldwide, with this appeal predicted to persist into the 21st century; the Intergovernmental Panel on Climate Change (IPCC) estimating that by 2080, the global coastal population will have risen from its 1990 level of 1.2 billion to anything in the range of 1.8-5.2 billion (Parry, 2007, p40).

It is the coast's unique characteristics, the meeting point between land and sea and where marine and terrestrial environments interact, that ensure its popularity (Kay and Adler, 2005). Prominent reasons for such considerable human settlement and activityare ascribed to the 'diverse and productive ecosystem' provided for human use, coupled with its convenience in acting as a trading base between countries due to its proximity to oceans and rivers (ibid, p8). Economically, the resources and services provided by the coastline environment are of significant global worth (Remoundou et al., 2009), both directly (e.g. fisheries, aquaculture, tidal barrages) and indirectly (e.g. recreational tourism) (Zhai and Suzuki, 2009). The European Environment Agency outlines the extent of the services directly provided by the coastal environment,

> On a global scale, these include regulation and support services, such as shoreline stabilisation, nutrient regulation, marine life nursery functions, carbon sequestration, buffering from natural hazards, detoxification of polluted waters and waste disposal. They also include provisioning services, such as the supply of food, fuel wood, energy resources and natural products, and cultural (amenity) services, such as tourism and recreation. These services are of high value not only to local

communities living on the coasts, but also to national economies and global trade. (EEA, 2006, p48)

The coastal environment is dynamic, this dynamism the result of ‘constantly changing types of interactions among the ocean, atmosphere, land and people’ (Kusky, 2008, p15). Coastlines are not static entities but fluctuate at a short-term seasonal level as well as a longer-term climatic-change level (ibid). However, much development in the littoral zone occurs with the intention of ‘stabilising the shoreline’ (ibid, p15), creating a conflict between human use and the coastline’s natural processes. The dynamic systems found on the coast areunder increasing pressure by anthropogenic development (Nicholls et al., 2007). Developmental pressures within the coastal zone are clearly set to increase as its population rises; Sale et al. estimating that by 2050, 91% of the world’s coast will be impacted by development (Sale et al., 2008). Pressure is not only exerted from within the coastal zone but increasingly at a broader, more global scale (Swaney et al., 2011). Ultimately, with population and development growing at a rapid rate, the world’s coastal environments are under increasing stress. This pressure is exuberated by the growing threat of climate change and the significant impact the consequences of such a climatic shift will have on the world’s coastal regions. Relative sea-levels are predicted to rise increasing the risk of erosion and inundation, coupled with an increased likelihood of extreme weather events and storm surges (Nicholls et al., 2008). In this context, the need for effective coastal management is paramount and therefore it is not surprising that ideas such as Integrated Coastal Zone Management have risen in prominence over the last few decades (Hilderbrand, 2002).

One tool used to help facilitate coastal management has been coastal vulnerability assessments. Such assessments involvemapping certain areas of coastline that are particularly vulnerable to the impacts of erosion, sea-level rise, flooding and extreme weather events (Palmer et al., 2011). Using a selection of parameters that indicate vulnerability (such as beach width and coastal slope), such assessments are useful in offering a quick and cost-effective means for those involved with coastal zone management, providinga general overview of where current or future areas of risk might lie. The exact methodology of these coastal vulnerability assessments varies greatly worldwide. Some make use of dozens of parameters and others only a handful, with some parameters being conceived as more important in one study, less so in another

(McLaughlin and Cooper, 2011). In light of this, this study undertakes a preliminary assessment of coastal vulnerability for the Westfjords, Iceland. The need for some form of coastal vulnerability mapping in the Westfjords is clear: nearly all of the human settlement and infrastructure takes place in close proximity to the coastline, due to the region's steep fjordic topography. Furthermore, it is a remote region with limited transport infrastructure hugging close to the coastline, the consequence being that if only a small stretch of coastline is impacted due to coastal processes it can have a significant effect on the region. Furthermore, little to no coastal vulnerability mapping has been undertaken in Iceland since 1992 and 1995, despite the fact that 'need for such work is recognised' (Jónsdóttir, 2011, p15).

This study is a preliminary assessment that uses a modified coastal vulnerability index (CVI) initially devised by Palmer et al (2011) for assessing coastal vulnerability in South Africa and applies this methodology in a very different context: the fjordic environment of the Westfjords, Iceland. This method is a desktop study involving the measurement of certain physical parameters using a combination of orthophotographs, digital elevation models and bathymetric maps. Once measured, and following some field visits to ground truth results, sections of the coast are ranked and their relative vulnerability assessed. Subsequently, a closer inspection is undertakento observewhich socio-economic featuresare present in higher vulnerability areas, along with an analysis of coastal defence options currently in use. Therefore the overall aims of this study are:

- *To assess the relative coastal vulnerability of thenorthern Westfjords coastline to impacts of changing coastal processes, such as sea-level rise, erosion and extreme weather events*
- *To assess the socio-economic features located in areas determined as 'higher vulnerability'*
- *To assess coastal defence options being utilised in areas determined as 'higher vulnerability'*

This study is structured as follows.Chapter 2 reviews literature that focuses on coastal zone threats such as climate change and sea-level rise, coastal management options and coastal vulnerability assessments. Chapter 3 presents the Icelandic context along with the physical background of the Westfjords. Chapter 4 outlines the methodology used,including rationale for modifying parameters. Chapters 5 and 6 present and discuss results, firstly looking at physical parameter measurements before detailing CVI rankings. Chapter 7 presents study conclusions and recommendations. Consequently, this work helps address Icelandicknowledge gaps identified by Jónsdóttir(2011).

2. The Coastal Zone and Coastal Vulnerability

2.1 Threats to the coastal zone

The coast's unique and dynamic characteristics offer human populations a diverse array of value and services. Nonetheless, this uniqueness and dynamism contributes to the multifarious stressors impacting the coastal ecosystem (Duxbury and Dickenson, 2007). The most significant threat to the world's coastlines occur within the coastal zone, where intensive development on the land adjacent to the sea dramatically shape biophysical characteristics (Duxbury and Dickenson, 2007, Palmer et al., 2011, EEA, 2006). Nevertheless, global changes are becoming increasingly more influential in impacting the coastal zone. Utilizing the novel 'syndrome' approach (created by Schellnhuber et al (2007) to conceptualize 'global change') Newton et al (2011) outline many of the 'synergetic multi-stressors' impacting the world's coasts.

- ❖ **Sediment syndrome:** from sediment trapping by damming of rivers and the physical disruption of the coastal dynamics by coastal engineering, as well as subsidence
- ❖ **Water syndrome:** such as the over-extraction of water from coastal aquifers, decreased river-flow and ageing of water at the river-mouth from damming
- ❖ **Eutrophication syndrome:** from agriculture, animal rearing, processing of organic matter and sewage
- ❖ **Coastal land-use syndrome:** such as the destruction of coastal forest, mangroves, salt marshes and wetlands
- ❖ **Coastal urbanization syndrome:** in a flood prone, low-lying coastal zone, on marginal land, as well as coastal megacities
- ❖ **Biodiversity syndrome:** from stressing or over exploitation of biotic resources, introduction of invasive species, changes in the food web and regime change

- **Pollution and contamination syndrome:** from industrial sources, agriculture and oil spills as well as underwater noise and marine litter
- **Exploitation of non-renewable resources syndrome**: such as oil and gas;
- **Global change syndrome**: including increasing temperature, sea-level rise, storminess and ocean acidification.

Figure 2.1 Synergetic multi-stressors found in the coastal zone (Newton et al., 2011, p2-3)

In the 'State of the Environment and Policy Retrospective: 1972–2002', the United Nations Environment Program (UNEP) lists five key threats affecting coastal and marine areas;

- Marine pollution
- Fisheries
- The introduction of exotic species
- Physical alteration
- Global climate and atmospheric change (UNEP, 2002)

All of the above factors profoundly impact the coastal ecosystem. Marine pollution (e.g. contamination from sewage, elevated nitrogen inputs leading to eutrophication of coastal waters, non-biodegradable waste entering the ecosystem) has increased in the last few decades (ibid). The world's fishing stocks have suffered intensive over-harvesting and the subsequent depletion of these stocks has impacted the coastal ecosystem (Jentoft and Chuenpagdee, 2008, UNEP, 2002). Furthermore, as the world economy continues to globalise, the frequency in which invasive species enter foreign coastal ecosystems (predominantly travelling within ship ballast water) has risen dramatically (Carlton, 1996, UNEP, 2002). However, the report outlines that 'arguably the most important single threat to the coastal environment' is the direct physical alteration of the coastline and the concurrent destruction of habitats caused by such activity (UNEP, 2002, p184). Ultimately this alteration can dramatically affect the 'natural coastal functioning', exposing the coastline to 'impacts of sea-level rise, coastal erosion, extreme weather and other coastal hazards' (Palmer et al., 2011, p1). The last remaining threat in the above list, 'Global climate and atmospheric change' has been described as a threat unprecedented in human history and one that will especially impact the world's coastal environments (Rayner et al., 1998).Withclimate change predicted to greatly impact the coastal processes this vulnerability assessment focuses on (sea-level rise, erosion and extreme weather events), it is felt necessary to briefly discuss this subject. The following section explores the issue.

2.2 Climate change, storminess and sea-level rise

The Earth's climate has varied throughout history, influenced by the complicated interrelationship between terrestrial, oceanic, solar, atmospheric and living components. This variation can come abruptly (e.g. as a consequence of a severe volcanic eruption) or over a long period of time (e.g. through shifts in oceanic circulation). Human civilisation, existing for the geologically short period of approximately 10,000 years, has experienced relatively stable climatic conditions, albeit with regional variations that have forced some populations to adapt to the new conditions or collapse (Burroughs, 2009). This notion of 'climate influencing human civilisation' has been reversed in the last century, as it has become increasingly clear that anthropogenic activity is resulting in a changing climate (Solomon et al., 2007). The continued (and rising) release of significant quantities of three greenhouse gases (carbon dioxide, methane and nitrous oxide), the result of rapid industrialisation, the burning of fossil fuels and the destruction of 'carbon sinks' such as rainforest habitats, has accentuated the 'greenhouse effect' (Hardy, 2003, Burroughs, 2007). As a consequence more solar radiation reaching Earth is captured within the atmosphere and has contributed to a sharp rise in the global mean-temperature in the last few decades, as outlined by the graph in Figure 2.2, taken from the Intergovernmental Panel on Climate Change Fourth Assessment Report: Technical Summary.

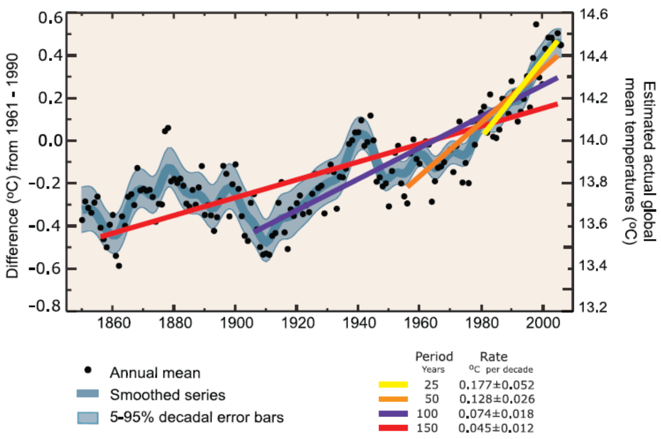

Figure 2.2Global mean temperature (^{o}C) 1890-2005 (IPCC, 2007, p37)

That greenhouse gas emissions from anthropogenic activity are responsible for this recent climate change is ascribed a 90% (very likely) certainty by the IPCC (Solomon et al., 2007). Global mean temperature is predicted to rise by 2-5^{o}C by 2030-2060 (if, as expected, the level of greenhouse gases reaches double pre-industrial levels) (Stern, 2006). Whilst the exact consequences of climate change are not fully known, it is widely agreed that its impact on the biosphere (and subsequently the world's economies and societies) is likely to be immense: major shifts in plant and animal ranges or extinctions, increased risk of extreme weather events, longer, more intensive heat waves, droughts, increased storminess, large-scale sea-ice reduction and rise in global sea-levels (Nicholls et al., 2008, Solomon et al., 2007, Burroughs, 2007, Stern, 2006).

Coastal environmentsare likely to be severely affected by this climatic shift. Nicholls et al (2008) outline the main climate change-influenced impacts in Table 2.1.

Table 2.1 Main climate drivers for coastal systems, their trends due to climate change, and their main physical and ecosystem effects (Nicholls et al., 2008, p92)

Climate driver (trend) [a]	**Main physical and ecosystem effects on coastal systems**
CO^2 concentration (↑)	Increased CO2 fertilisation; decreased seawater pH (or ''ocean acidification'') negatively impacting coral reefs and other pH sensitive organisms
Sea surface temperature (SST) (↑, *R*)	Increased stratification/changed circulation; reduced incidence of sea ice at higher latitudes; increased coral bleaching and mortality; poleward species migration; increased algal blooms
Sea level (↑, *R*)	Inundation, flood and storm damage; erosion; saltwater intrusion; rising water tables/impeded drainage; Wetland loss (and change)
Storm Intensity (↑, *R*)	Increased extreme water levels and wave heights; increased episodic erosion, storm damage, risk of flooding and defence failure
Frequency (?, *R*)	Altered surges and storm waves and hence risk of storm damage and flooding
Track (?, *R*)	
Wave climate (?, *R*)	Altered wave conditions, including swell; altered patterns of erosion and accretion; re-orientation of beach platform
Run-off (*R*)	Altered flood risk in coastal lowlands; altered water quality/salinity; altered fluvial sediment supply; altered circulation and nutrient supply

a ↑ increase; ? uncertain; R Regional Variation

Of the climate drivers outlined above, two are of particular relevance for this study: sea-level rise (SLR) and increased storm intensity. Change in sea-level is 'one of the principal determinants of shoreline position' (Phillips and Crisp, 2010, p211). The effects of accelerated SLR are, as Ashton et al (2011) describe, 'one of the cornerstone challenges facing coastal geomorphologists and engineers' (Ashton et al., 2011, p217). Figure 2.3shows how global SLR has risen since 1870, with the IPCC predicting that global SLR will accelerate throughout the 21st century, with estimates of an 18-59cm rise by the year 2100 (Solomon et al., 2007).

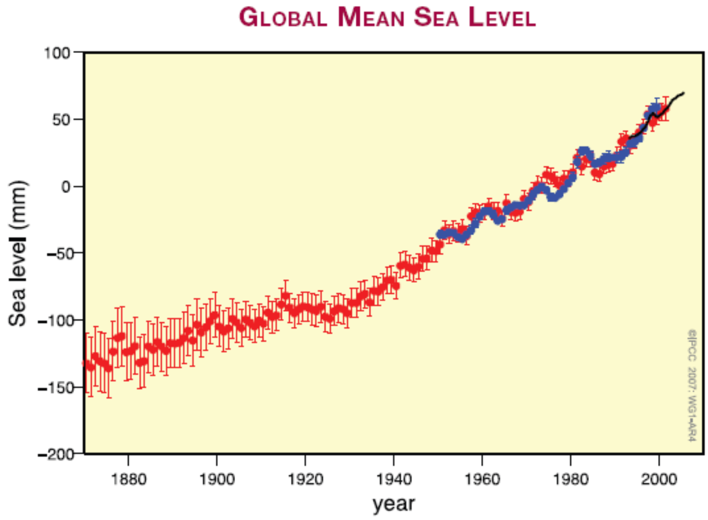

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Figure 2.3Annual averages of the global mean sea level (Units are in mm relative to the average for 1961 to 1990) (Solomon et al., 2007, p49)

Furthermore, due to uncertainties in knowing how large ice sheets will react to changing climate conditions, the IPCC have put no upper bound on global SLR predictions for the 21st century (Nicholls, 2010). The three main processes contributing to climate change-induced SLR are the thermal expansion of world's oceans, the melting of glaciers/ice-caps and the reduction of the Greenland and West Antarctic ice sheets (Griggs, 2001). Regarding the extent of coastal impacts from global SLR, it is Relative Sea-Level Rise (RSLR) that is the determining factor of a coastline's susceptibility to sea-level changes. RSLR accounts for all the multi-scale components of SLR: incorporating the melting ice, thermal expansion and alterations in oceanic dynamics with non-climate related processes like glacial isostatic adjustment along with both natural and anthropogenic-induced subsidence (Nicholls, 2010, p19). Regional variation is significant, as in some cases there is a decrease in RSLR, (e.g. in the Northern Baltic as a result of GIA rebound effect), whereas in other regions, RSLR is significantly greater than the global average (ibid).

The main physical effects attributed to RSLR are commonly agreed to be: increased erosion on beaches and bluffs, increased inundation of low-lying area, increased flooding and storm damage, higher water tables and saltwater intrusion into aquifers (Douglas et al., 2000, Nicholls, 2010, Oyzurt et al., 2009). Phillips and Crisp (2010) explain how a rise in RSLR can lead to increased coastal erosion.

1. Higher water levels enable waves to break closer to shore.
2. Deeper water decreases wave refraction and this increases the capacity for longshore transport.
3. With higher water levels, wave and current erosion processes act further up the beach profile causing readjustment of that profile.

(Phillips and Crisp, 2010, p11)

The Bruun rule is a particularly famous (and controversial) rule that has been applied to help explain the erosional effects of RSLR (Douglas et al., 2000). Bruun postulated that beaches will erode 50-200 times the rate of increased RSLR (ibid). Whilst proponents of Bruun's modelling exist (see Zhang et al., 2004), criticism has been levelled at the rule for its simplicity:namely that it assumes a constant equilibrium profile and instantaneous profile response to RSLR (Walkden and Hall, 2005) and is only applicable if no cross-shore or long-shore sediment transportation exists (Stive, 2004). Many attempts have been made to better model the effect RSLR plays in coastal erosion, with some arguing that the beach shorelines are given more academic attention than 'rocky shore' coastlines with regards to this research (Naylor et al., 2010).

Inundation of low-lying coastal areas will increasingly become an issue for settlements and infrastructure found within 100m of the shoreline (the broad area that is most likely to be impacted by SLR) (Purvis et al., 2008). Not only will inundation occur as the high water mark rises, its effects will become accentuated by the increased storminess predicted throughout the 21st century (Purvis et al., 2008, Solomon et al., 2007). Storm surges, defined as the difference between tide and total water level and essentially driven by meteorological factors (Gaslikova et al., 2011), are generally accepted to become increasingly intense as the climate continues to warm (Nicholls et al., 2007). The consequence of which is the increased risk of severe flooding to coastal zones prone to extreme storm events (e.g. see Frazier et al's(2010) work in Florida, USA, Karim and Mimura's (2008) study on the incredibly vulnerable region of Bangladesh and von Storchet al's (2008) discussion on the increased frequency and intensity of storm surges off the North Sea of Germany).

With increased risk of erosion, inundation, flooding, saltwater intrusion and extreme weather events, it is clear that the combination of climate change and RSLR raises important and challenging questions over traditional coastal management practices. The following section will briefly explore methods commonly used to manage the shoreline.

2.3 Coastal management options

Coastal management options can be broadly split into the more traditional 'hard-engineering' approaches and the more recently-utilised approaches of 'soft-engineering' (Phillips and Jones, 2006). Traditional hard-engineering approaches include seawalls, revetments, groynes, breakwaters, jetties, piers and trestles (French, 2002). Despite the known problems of these traditional approaches(such as often promoting erosion (Phillips and Jones, 2006), dramatically impacting the coast's sediment budget and having a considerable impact on the natural environment (French, 2002))these defences are still the most commonly applied worldwide. French (2002) outlines the reasons for this:

- Tradition
- Perceived Security
- High-Value of the Hinterland
- Politics
- Inability to adopt a proactive-based defence policy

(French, 2002, p47)

This is not to say that hard-engineering options do not have a role to play in coastal management. Nevertheless, they are becoming less and less the *de facto* choice to protect coastlines (Phillips and Jones, 2006).

Soft-engineering options are being increasingly fashionable, partly due to the ecological impacts of the 'harder' options but also their ability to significantly reduce expenditure if done correctly (French, 2002). One option is beach nourishment, where sediment is artificially brought into the beach system from a remote area. An example can be seen in Vale do Lobo beach in South Portugal, where 700,000m^3 of sand was dredged 4km seaward from the beach at 20m depth to create a beach platform. Though successful at slowing beach erosion rates, the beach still required periodical replenishing of sand nourishment if it was to be anything but a short-term solution (Veloso Gomes et al., 2006). Other soft options include beach drainage (where water is removed either via extraction or evaporation) and dune protection and rehabilitation(whereby dunes, an important natural coastal defence, are strengthened) (French, 2002).

As aforementioned, coastal environments are complex, where the interplay between land and sea creates an ever-changing shoreline impacted by processes working at various temporal scales. Despite this, the historical approach to coastal erosion has been to make the shoreline as permanent as possible (French, 2002). Critics of this approach argue such an approach is based on a ‘fundamental lack of understanding of natural coastal processes and a view of the boundary between land and sea as fixed rather than dynamic’ (Brennan, 2007, p587). This attitude to coastal defence is shifting, as coastal processesbecome better understoodand the imminent threat of climate change and RSLR raise questions over the viability of placing settlements and infrastructure in such vulnerable areas (French, 2002). It is becoming clear that the traditional methods of building structures at increasing expenditure to ‘hold the line’ are no longer optimum approaches. Instead it may be wiser to account for the shoreline’s dynamism and plan for managed retreat (Abel et al., 2011, O’Riordan et al., 2006). As Pethick(2001) writes,

> ‘If we persist in applying our static coastal management systems as sea levels rise, then an increasing disparity will arise between our needs and the coastal resource. Instead, we must begin to manage change at the coast in a more positive manner.’
>
> (Pethick, 2001, p321)

However, the social, economic and political ramifications of the ‘retreating-the-coastline’ approach are significant. Many who dwell in such regions have been weaned on a discourse where coastlines remain ‘fixed’ by provision of coastal defence and stand to lose greatly from a management shift increasingly favouring ‘adaption’ to natural coastal processes (Cooper and McKenna, 2008). The key question is therefore:if coastal communities’ settlementsbecome threatened from erosion/inundation caused by natural coastal processes, do they have a right to demand government action to ensure stability of the coastline?

2.4 Coastal vulnerability

The term 'vulnerability' possesses a plethora of definitions, the result of its use among a wide range of scientific disciplines and policymakers from differing backgrounds (Zou and Thomalla, 2008). One definition used to describe vulnerability is offered by the Stockholm Environment Institute:

'Vulnerability is the degree to which an exposure unit (e.g. social group or ecosystem)is susceptible to harm due to exposure to a perturbation or stress, and the ability (or lack thereof) of the exposure unit to cope, recover, or adapt'

(Zou and Thomalla, 2008)

Two perspectives can be taken on the concept of vulnerability. One perspective is to view vulnerability as the 'variation in level/chance of impact', where the ability to cope with an event/hazard of a particular intensity defines vulnerability. The second perspective is 'sensitivity to impacts', where vulnerability is definedby sensitivity to changes, ability to adapt to these changes and exposure to such changes (IoWCCE, 2007, p6). Itshould be noted that vulnerability is closely related to other concepts used such as hazard (the event/occurrences that threaten property/life), risk (the quantitative/qualitative estimation of the probability of event/occurrence) and resilience (amount of impact a property/system can endure whilst maintaining function) (Ramieri et al., 2011).

Regarding vulnerability to climate change, the IPCC define this as 'a function of the character, magnitude, and rate of climate change to which a system is exposed, its sensitivity, and its adaptive capacity' (Ramieri et al., 2011, p13). The key elements of this definition are explained below:

- Exposure – the nature and level of which the system is exposed to the consequences of climate change
- Sensitivity – the system ability to be affected by climate change, either positively or negatively
- Adaptive Capacity – ability of system to maintain function in light of climate change-related impacts (Ramieri et al., 2011)

Coastal vulnerability incorporates ideas developed by the IPCC's definition of vulnerability and applies them to the coastal environment. Klein and Nicholls (1999) present a framework outlining coastal vulnerability, which incorporates both natural and socio-economic systemsfound in coastal environments (see Figure 2.4). Key elements of this framework include the differentiation between 'autonomous adaptation' and 'planned adaptation' and the significant influence the socio-economic system has on the natural system.

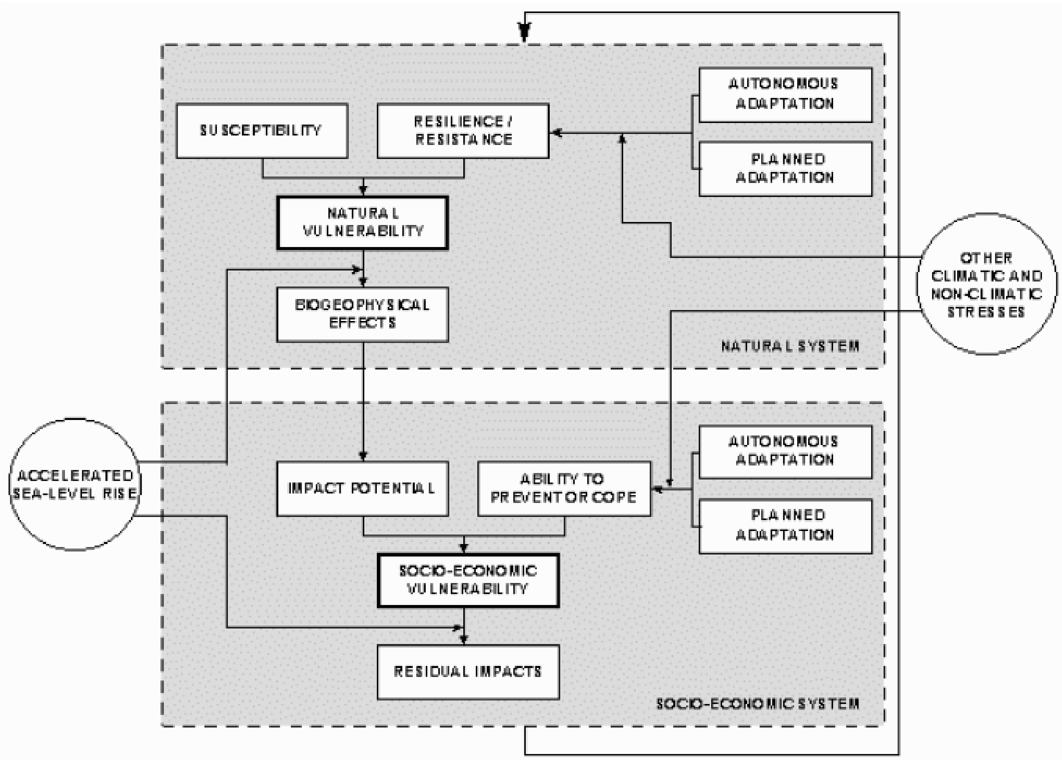


Figure 2.4 Coastal vulnerability framework(Klein and Nicholls, 1999, p182)

It has been noted the term 'coastal vulnerability' is too often associated with just the effects of RSLR, neglecting the other non-climate drivers coastal environments may be exposed to, sensitive towards or be unable to adapt to (Nicholls et al., 2008, Oyzurt et al., 2009). Some argue this is a consequence of being easy to 'assess' vulnerability to RSLR compared to other non-driver indicators (Ramieri et al., 2011). The assessment and quantification of coastal vulnerability is the subject of the following section.

2.5 Assessing coastal vulnerability: the Coastal Vulnerability Index (CVI)

The core purpose of coastal vulnerability assessments are to act as guidance for scientists, coastal managers and policymakers to improve their understanding on where along the coastline the impacts of RSLR, climate change and other non-climate drivers will be most keenly felt. This knowledge facilitates better management of the coastline, as management efforts can be prioritized for particularly vulnerable areas in advance of any problem they may face (Hinkel and Klein, 2009). A common form of coastal vulnerability assessment involves calculating an 'index', a method that can 'simplify a number of complex and interacting parameters, represented by diverse data types, to a form that is more readily understood and therefore has greater utility as a management tool' (McLaughlin and Cooper, 2011, p234). The first Coastal Vulnerability Index (CVI) focusing on the effects of SLR (particularly inundation and erosion) was devised by Gornitz(1990)(Ramieri et al., 2011). This CVI used six physical variables as indicators of a coastline's vulnerability to the impacts of SLR:geomorphology, coastal slope, rate of relative sea-level rise, rate of shoreline erosion/accretion, mean tide range and mean significant wave height. With the variables chosen, each parameter is assigned a score ranging from 1-5 (1 being the lowest contribution to coastal vulnerability, 5 being the highest). Once ranking is complete, a formula is used to calculate a single numerical value that defines the vulnerability of each coastal section. The formula used in Gornitz's study took the form of the square root of the six variables, as shown in Figure 2.5

$$\mathrm{CVI} = \sqrt[2]{\frac{a.b.c.d.e.f}{6}}$$

a = geomorphology;

b = shoreline change rates;

c = coastal slope

d = relative sea level rate;

e = mean significant wave height;

f = mean tidal range

Figure 2.5CVI formula devised by Gornitz (Ramieri et al., 2011, p21)

The ranking component is semi-qualitative, as it is for the researcher to decide for each variable where the boundaries for ranking lie (e.g. what ‘mean tidal range’ constitutes a score of 4?). Rationale describing the ranking of parameters is a crucial component to the validity of any CVI study. Variations on parameter ranking do exist, as exemplified in Abuodha and Woodroffe’s (2006) CVI study of the Australian coast, where they altered the original ranking to better suit the geology of their study area. Attempts have been made to synthesise the CVI process globally: the EU-funded project named SURVAS (Synthesis and Upscaling of Sea-Level Rise Vulnerability Assessment Studies) the most notable effort. However, SURVAS was only partially successful, as the variation in methodologies, scenarios and assumptions proved too much of an impediment (Hinkel and Klein, 2009). One problem often cited with CVI methods is the issueof data quality and availability (Hinkel and Klein, 2009, Nicholls et al., 2008, Oyzurt et al., 2009). As Palmer et al explain, datasets are ‘characterised by having low spatial resolution, relying on averagedglobal data and simplistic assumptions’ (Palmer et al., 2011, p1).

Variants of the Gornitz’s original CVI are plentiful, with some studies considerably modifying the method (see Oyzurt et al., 2009) and others only slightly (see Gaki-Papanastassiou, 2010, Pendleton et al., 2004, NageswaraRao et al., 2008). Whilst variation is evident, all CVI methods maintain the essence of the original: to rank and quantify vulnerability along the coastline. In recent years, CVI have begun to incorporate a socio-economic component, a facet of coastal vulnerability that some argue is often overlooked (Palmer et al., 2011, Abuodha and Woodroffe, 2006). Indeed, some suggest CVIs that incorporate only physical variables are not really analysing coastal vulnerability *per se,* but more ‘coastal sensitivity’ (Abuodha and Woodroffe, 2010) Socio-economic components (such as population, infrastructure and property value) can be assessed by either associating ‘other indicators and indicator indices’ to a CVI that focuses on just physical variables or by incorporating socio-economic variables intothe formula alongside physical variables (Ramieri et al., 2011, p19). Anexemplar of the lattercan be witnessed in McLaughlin and Cooper’s (2011) CVI index for Northern Ireland. This method is novel in two respects. Firstly, their study attempts a multi-scale approach, creating an index at three different spatial levels: national, regional and local. Secondly, a framework is usedthat involves three sub-indices: an index for ‘Coastal characteristics’, an index for ‘Coastal forcing' and an index for 'Socio-economic'. This framework is presented visually in Figure 2.6.

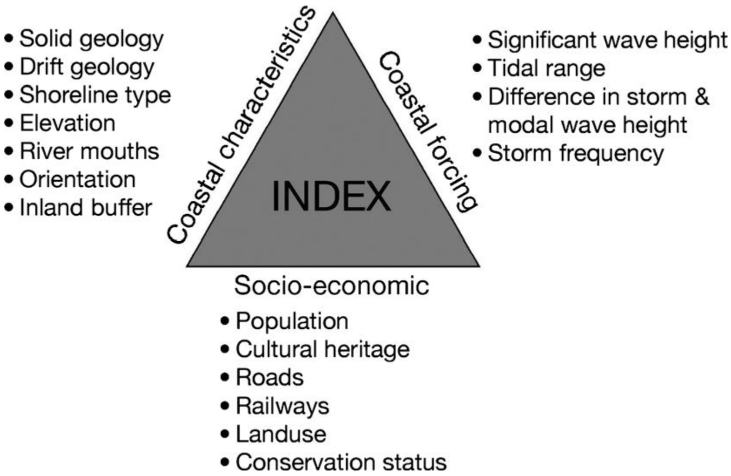


Figure 2.6Variable classifications for sub-indices in McLaughlin and Cooper's CVI for Northern Ireland(McLaughlin and Cooper, 2010)

One CVI method recently undertaken in South Africa assesses physical parameters and then seeks to find the socio-economic features found in areas of high vulnerability. This study utilises this CVI method (in a slightly modified form). For this reason, the next section provides a summary of the method.

2.6 CVI: Case Study (Palmer et al., 2011)

The CVI method used in this study was originally devised by Palmer et al. for their coastal vulnerability assessment of the KwaZulu-Natal province in South Africa. The group observed a need for local scale assessment after an extreme storm event occurred in the province during 2007 causing extensive damage. The CVI was the first step in a five-step procedure to map and manage areas of particularly high vulnerability. This procedure is described as the following:

1. Assessing physical coastal vulnerability
2. Listing resources andservices
3. Assigning values to these goods and services
4. Identifying the vulnerabilities of each resource/service

5. Mitigating or removing the risks for the most important resources.

The key physical variables chosen were selected by a panel of relevant experts as the most important with regards to vulnerability: beach width, dune width, distance from 20m isobath, percentage rocky outcrop and distance of vegetation behind the back beach. These variables were ranked under the criteria show in Table 2.2.

Table 2.2CVI parameter ranking for Palmer et al.'s study

Physical Parameter	**ExtremelyLow (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
Beach width	> 150m	100 –150m	50 – 100m	< 50m
Dune width	> 150m	50 –150m	25 – 50m	< 25m
Distance to 20m isobath	> 4km	2 – 4km	1 – 2km	< 1km
Distance of vegetation behind the back beach	> 600m	200 –600m	100 – 200m	< 100m
Percentage Rocky Outcrop	> 50%	20 –50%	10 – 20%	< 10%

These variables were measured using a combination of orthophotographs and bathymetry maps at 30m intervals along the coast before being placed into a 'relative CVI' formula as shown below.

Parameter rating	Beach width Dune Width Distance to 20m isobath Distance vegetation behind back beach % rocky outcrop	+	Parameter weighting	+	Estuary weighting	=	CVI Score
	20 (Max)	**+**	**4**	**+**	**4**		**28 (Max)**

Figure 2.7 Palmer et al.'s study CVI formula

A parameter weighting was placed on the three most critical of these variables: if the first three variables listed above were ranked 'high' than an extra '4' was added. This highlighted the importance of these variables. Lastly, an estuary weighting was used to signify their 'sensitive and dynamic' effect on coastal processes. Once parameters were measured, a CVI score ranging between 5 and 28 was calculated for each section. These numerical values were inputted into GIS software to map out the range of vulnerabilities. A key aspectof this method was to first assess the physical vulnerability before assessing socio-economic components. This was done by first pinpointing areas of 'high vulnerability' and then looking at the relationship between key socio-economic features and these areas. The key features chosen are shownin Table 2.3.

Table 2.3Key socio-economic features found in the KwaZulu-Natal coastal environment

Economic & commercial activities	**Strategic infrastructure**	**Recreational areas**	**Subsistence sites**	**Ecological important areas**	**Residential properties**
Dune mining	Piers	Boat launch sites	Subsistence fishing sites	Marine Protected Areas	Residential erven
Forest plantation	Forest plantation	Fishing hot spots	Subsistence harvesting sites	Bird sanctuary sites	
Sugar cane	Railway lines	Swimming beaches	Subsistence farming areas	Turtle nesting sites	
Commercial & industrial buildings	Lighthouses	Sports facilities		Estuary mouths	
Commercial farms		Coastal Public Property		Protected areas (terrestrial)	

Using only a few parameters and available data, this CVI method allowedfor coastal vulnerability to be assessed for a long stretches of coastline in relatively short space of time.

3. Context and Study Area

3.1 Iceland's coastal environment

Situated in North-West Europe, just south of the Arctic region and in the middle of the Atlantic Ocean (see Figure 3.1), Iceland can be described as a 'coastal country'. Not only do 100% of its 320,000 inhabitants reside within 100km of its coast (Martinez et al, 2007), its history is also strongly tied with its maritime activities, especially its fishing industry which today accounts for 40% of its export revenues (Statistics Iceland, 2011).A uniform definition of what constitutes the Icelandic coastal zone, both seaward and the landward, does not exist (Ólafsdóttir, Unknown).

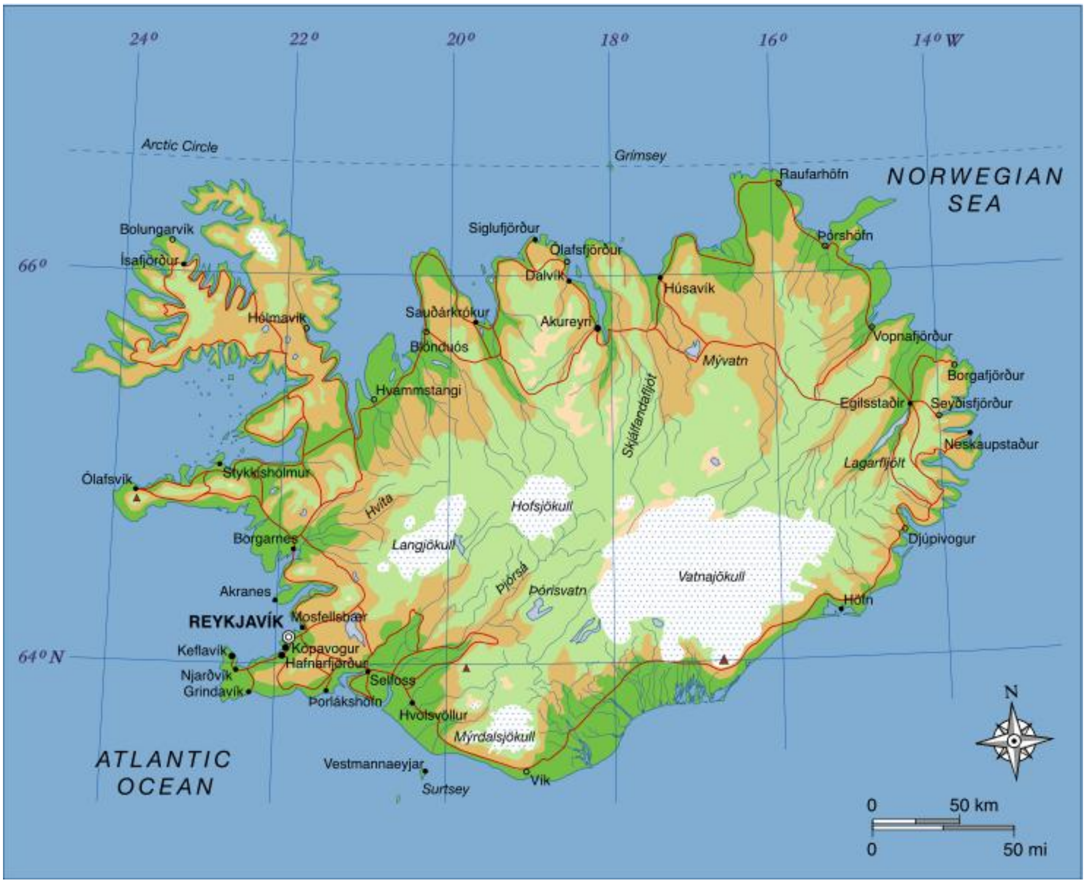


Figure 3.1 Map of Iceland (Source: Wikipedia.org)

Like most other countries in Europe, Iceland's coastal environment suffers from issues highlighted in earlier sections, although to varying degrees. The recent'Climate change in Iceland: Impacts and adaptive measures: CoastAdapt report'by the University of Iceland's Institute for Sustainability Studies outlines the issues facing Iceland's coast, especially in the context of climate change. Of these issues, the most concerning are the unknown consequences of ocean acidification on proximal fish stocks and RSLR (but only in certain regions, as due to glacial isostatic adjustment the effects of RSLR are unevenly distributed, with the eastern landmass currently rising) (Jónsdóttir, 2011). Whilst the authorities and the public are concerned about climate change, little of this concern is translated into policy or strategy. Furthermore, there are no climate adaptation plans at a local or municipal level (ibid).

Much of Iceland's coastline is made of solid rock outcrop, reducing, to some extent, the impact of coastal erosion. However, low-pressure storms and wave height are both relatively frequent and high, contributing to stress and weathering of the coast (Jónsdóttir, 2011). It is estimated that severe coastal floods occur approximately every 11 years, the last flood occurring in Raufarhöfn in the North in 1995 (ibid). However, shoreline protection investment pales in comparison to expenditure spent on protection schemes for other 'natural disasters' such as avalanches and volcanic eruptions (Isaksson and Helgasson, 2005). Historically, lack of state-funding meant seawalls (the predominant form of coastal protection in Iceland) were 'weak constructions that neither lasted very long nor ensured much protection', although this gradually changed throughout the latter half of the 20th century (ibid, p2). The core material used for these seawalls is quarried rock, examples of which can be seen in Figure3.2.

Figure 3.2Photos of seawall defences constructed in Iceland. The left shows a larger quarried rock defence protecting a fish-processing factory in Eyrarbakki, the right a smaller quarried rock defence found in Drangsnes(Isaksson and Helgasson, 2005, p5)

Iceland passed the Sea Defence Law in 1997 setting in law the process in which coastline protection would be built: local authorities submit their protection ‘requests’ to the Icelandic Maritime Administration. This organisation assesses the merits of each case by observing wave impact, flood risk, distance of properties from the proposed protection, value of the properties and erosion risk. Once this is completed, they categorise the proposals in the following grading system:

A: Life at stake and/or precious properties, f. ex. many dwelling houses or one great factory (e.g. a fish processing firm) at stake.

B. Properties at stake, like a number of dwelling houses or a medium fish processing firm.

C. Considerable land erosion and perhaps 1-3 dwelling houses at stake.

(As a rule of thumb, the relation between the proposed shore protection costs and the value of the property to be protected is<1)

(Isaksson and Helgasson, 2005, p5)

With regards to coastal risk assessments, surprisingly little research has been undertaken since two reports in 1992 and 1995 explored the risks of coastal flooding in light of the IPCC's 1st Assessment Report (Jónsdóttir, 2011). The need for future research in this area is generally accepted, as highlighted in the CoastAdapt report: 'Organized development ofscenarios or mapping of future impacts of sea-level rise has not yet begun, but the need for such work is recognised'(ibid, p15).

3.2 Study area

The study area for this assessmentis situated in the Westfjords:a large peninsula 22,271 km^2 in size possessing many fjords and located in north-west Iceland (Statistics Iceland, 2011). The study area does not assess the whole of the Westfjords coastline, focusing instead on a 240km located in the north of the region. This area incorporates a stretch of coastline ranging from Kambsnes (the northern-most point of Álftafjörður) and Hafnarhyrna (the western-most point of Dýrafjörður). The study area is presented in Figure 3.3.

Figure 3.3 Study area: from Kambsnes (the northern-most point of Álftafjörður) and Hafnarhyrna (the western-most point of Dýrafjörður). The red line indicates the study area (Source: map.is)

This fjordic landscape consists of 'Miocene basaltic lava flows, intercalated with sedimentary rock layers, which were carved into troughs valleys and fjords during the Pleistocene glaciations' (Decaulne and Saemundsson, 2006, p81).Whilst Iceland's climate is described as subpolar-oceanic in accordance with Köppen climate classification, this region of theWestfjordsis strongly influenced by Arctic conditions found to its North and North-west (Decaulne et al., 2009). Weather patterns are notably very changeable: temperature, wind, rain and snowfall can fluctuate considerably (Decaulne and Saemundsson, 2006). The strongest winds are most often north-easterly (Jónsson et al., 2003).

Beach composition of the northern Westfjords predominantly consists of comprised of large, coarse clastic sediments (Decaulne and Saemundsson, 2006). One section of the coastline is notably different: Holtstangi beach in the upper reaches of Önundarfjörður.

The coastline here consists of white sandy beach, somewhat incongruous with the rest of the study area’s coastline.

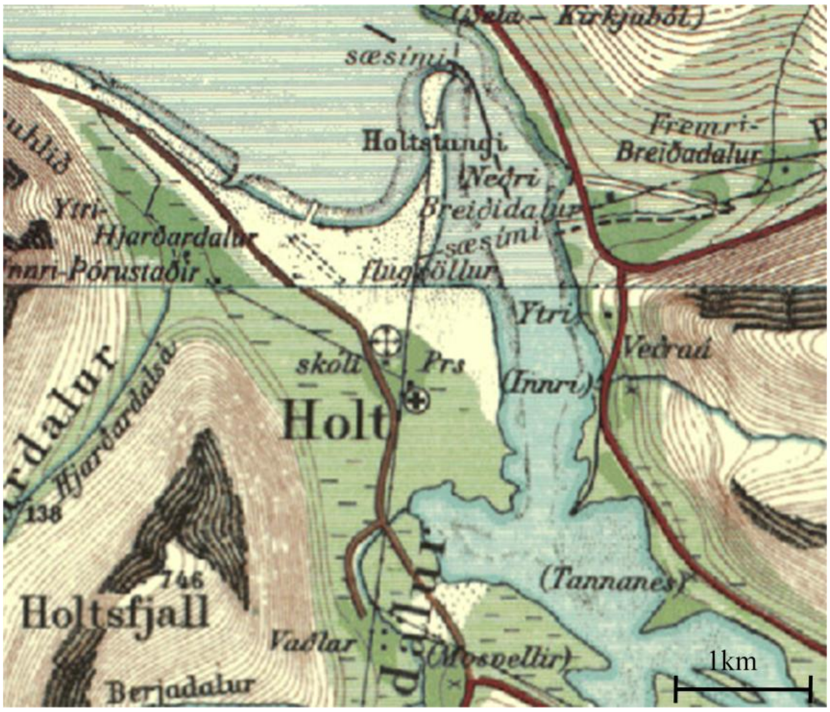


Figure 3.4 Map of Holtstangi. The white sandy beach located here notably differs from the rest of the study area’s beach composition (Source: lmi.is)

The towns of Ísafjörður, Bolungarvík, Súðavík, Suðureyri, Flateyri and Þingeyri are located within the study area. These towns account for the vast majority of the Westfjords’ ~7000 inhabitants(Statistics Iceland, 2011). For this reason,this area of the Westfjordswas chosen as the focus of this study.Ísafjörður, the municipality capital, possesses~4000 inhabitants and is home to nearly all of the Westfjords’ administrative and other services.The economy is based heavily around the fishing industry with the region possessing one of the largest fisheries in Iceland. A controversial quota system has seen the fishing industry decline in recent years. Nonetheless, fish-factories in towns such as Flateyri and Suðureyri are by far the main employer, with the town’s residents economically dependent on their presence (Matthiasson, 2000). Human settlement is predominantly situated on the relatively low coastal slope situated in-between the steep fjord walls and the ocean, or, in the case of Ísafjörður town centre and Flateyri, on the flatlands of spit formations (see Figure 3.5).

Figure 3.5Map showing Flateyri (left) and Ísafjörður (right). Both are predominantly located on the flat land of a spit formation(Source: lmi.is)

Figure 3.6Image of outer Ísafjörður. Human settlement takes place on the low and relatively narrow space between the steep fjord walls and the ocean (Author).

Between towns, there is little built environment. The only notable infrastructure present is the road that connects towns and predominantly hugs the coastline. All roads, to varying degrees, are susceptible to both avalanche risk and coastal flooding (Grímsdóttir, 2006). The major road in the region,Route 61,connects the towns of Súðavíkin the east to Ísafjörður. Up until September 2010, Route 61followed the coastline to Bolungarvík, the town found in the northwest of the study area. However, a tunnel was constructed to connect Bolungarvík, as this stretch of road between Hnifsdalur and Bolungarvikwas deemed too dangerous from frequent and considerable rock-fall (Visir, 2009). Towards the south of the study area, the minor road infrastructure that connects Flateyri and Þingeyri to the towns in the north does not follow the coastline around the fjord, instead travelling via a tunnel in the south of Skutulsfjörður to Önundarfjörður and a mountain path from Önundarfjörður to Dýrafjörður. Whilst no major roads travel far up Önundarfjörður and Dýrafjörður, less-maintained minor roads travel to small farms located towards the mouth of the fjord.

Figure 3.7Road located near Hnífsdalur. This road has since been closed due to frequency of dangerous rock-fall (Author)

4. Methodology

This is a preliminary study to assess methodological applicability whilst concurrently providing a preliminary evaluation of the northern Westfjords coastline.The study area was broken into 240 1km ‘cells’, with each cell being assigned a CVI score once parameters were measured.Since the introduction of the coastal cell concept by Carter (1988), cells have been adopted in UK shoreline management plans to represent a coastal stretch (SBCEG, 1999). Measurements were taken by placing a transect line perpendicular to the coastline. The transect measurements represented the physical parameter measurements for each 1km cell and to avoid bias, a central location was chosen. Although arguably coarse, it is common in UK shoreline management plans to monitor profiles greater than one kilometre apart (SBCEG, 1999). Thelandward boundary of the cellwas defined as 200m landward of the mean high water mark.

This study used a CVI methoddevised by Palmer et al (2011) to measure the coastal vulnerability of KwaZulu-Natal province in South Africa. This method was designed to offer a quick and efficient means of assessing coastal vulnerability over long stretches of coastline (ibid). Part of this process involved keeping the number of parameters to only the essential and easily measurable.For thisreasonthis method was chosen. Evaluated by a specialist consultation involving geomorphologists, oceanographers and coastal engineers, six physical parameters were chosen for their study:beach width, dune width, distance to 20m isobath, distance of vegetation behind back beach, percentage rocky outcrop and estuary presence. These parameters are well-documented as crucial components in assessing coastal vulnerability to the impacts of RSLR, inundation and extreme weather events (see the numerous example studies outlined in Chapter 2v). Each of these parameters were then ‘weighted according to its value and corresponding perceived level of risk’ (Palmer et al., 2011, p2), with a ranking system of 1-4: 1 being Extremely Low, 2 being Low, 3 being Moderate and 4 being High. The criteria used for this ranking system is discussed later in this chapter.

The original intention was to follow the CVI method used by Palmer et al. as closely as possible. However, whilst the core of the method was retained, some necessarymodifications were made to account for the different geography/geology of the Westfjords. Firstly, the parameter dune width was omitted from this study, as dunes are very rare in the Westfjords and therefore deemed an inappropriate parameter to measure. In its placecoastal slope was introduced, as this is a commonly-used parameter in coastal vulnerability studies (Gaki-Papanastassiou et al., 2010). Furthermore, a parameter unique to the region was incorporated:avalanche frequency. The rationale behind the choice of parameters and how they impact coastal vulnerability to the impacts of RSLR, inundation and extreme weather eventsis nowdiscussed, along with the methods used to measure them.

4.1 Physical Parameters

4.1.1 Beach width

Beach width affects coastal vulnerabilityby acting as a buffer, dissipatingwave energy:the wider the beach width, the greater its capacity to dissipate wave energy and reduce the impacts of extreme weather events and RSLR. Beach width will be determined using orthophotographs at 0.5m resolution provided by the company Loftmyndir (Aerial Photography)[1]. Orthophotographs are useful tools to measure such a parameter, coupling the spatial attributes of map with the visual attributes of a photograph. It should be noted that orthophotographs do not differentiate from high water mark and low water mark. After consulting with the Icelandic Marine Institute, it was agreed that given the region’s steep relief and relatively low tidal range of 2.1-3m, that the difference in beach width would be fairly insignificant. An example of beach width measurementbeing taken is shown in Figure 4.1.

[1]Ortho-photographs from Loftmyndir are referenced as (Loftmyndir) throughout. Further details of Loftmyndir available at www.map.is

Figure 4.1 Example of beach width measurement using an orthophotograph (LoftMyndir)

4.1.2 Distance of vegetation behindback beach

This parameter is an important indicator of the coast's susceptibility to the impact of extreme storm conditions and RSLR. If vegetation is present, it can help dissipate wave energy as well as helping reduce erosion by binding the soil in the littoral zone (Arnalds et al., 2001). This parameter was measured using the same orthophotograph tools as the beach width parameter. The presence of vegetation was determined by clear and evident signs of flora, this being indicated by the verdancy of the area behind the back beach. For this study, the back beach is defined as the area beyond the advance of the usual waves and tides (McGraw-Hill, 2003). The transect measurement was measured from the point where evidence of usual wave/tide impact ends (e.g. a coastal berm, presence of vegetation). Where this study's method varies from Palmer et al.'s study is the decision to measure this vegetation to the nearest infrastructure, which is often the coastal road that runs parallel to the coastline. This decision was made to take into account the fairly unique conditions of the Westfjords: the steep relief of the fjordic environment ensures most human settlement and activity occurs in close proximity to the coastline. Therefore for this assessment to better reflect the vulnerability of coastal settlements in the Westfjords, it was deemed inappropriate to measure vegetation beyond that of the nearest infrastructure (often the road). If no infrastructure was present, then the parameterwas measured to the point where visible signs of vegetation ended. An example of this parameter being measured can be seen in Figure 4.2.

Figure 4.2Example of distance of vegetation behind back beach measurement using an orthophotograph (LoftMyndir)

4.1.3 Coastal slope

Coastal slope is often used as a parameter in determining coastal vulnerability. The lower the relief of the coastal slope, the higher the susceptibility of the coast to flooding and inundation, two major impacts predicted from increased frequency of extreme storm events and RSLR. The data used to measure coastal slope was Shuttle Radar Topographic Mission (SRTM) data collected in 2000 and compiled into the SRTM 90m digital elevation model (DEM). As Gorokhovich and Voustianiouk explain, the DEM ‘presents a great value for scientists dealing with terrain analysis, thanks to its easy download procedure and ready-to-use format’ (Gorokhovich and Voustianiouk, 2006, p409). Accuracy concerns do exist, with an accuracy value commonly specified at 16m (Gorokhovich and Voustianiouk, 2006, Rodríguez et al., 2006). Such an accuracy value is not ideal, however this particular DEM was the only accessible data available to measure coastal slope in the Westfjords (at time of writing). For this reason, coastal slope measurements in this study are to be viewed with caution and used as only avague and general indication of coastal slope.

The software used to access this DEM dataset was Google Earth: a free and easily-accessible tool that has integrated the SRTM 90m DEM data into its extensive cartographic database. Coastal slope was calculated in percentage form, dividing the rise by the distance from the shoreline and multiplying by 100. The distance from the shoreline was measured to the nearest infrastructure, for the same reasons explained for the vegetation parameter. The significantly steep fjord environment meant that using a set distance similar to studies like Abuodha and Woodroffe's study of South-East Australia (Abuodha and Woodroffe, 2006), where a 500m distance was used would not be feasible due to topography of the region: such is the sudden rise in elevation up the fjord wall, it would alter the 'average coastal slope' to such an extent that it measurements would be irrelevant. Where infrastructure was not present in close proximity to the shoreline, the distance was cappedat 200m. This was decided as some regions were considerably far from any infrastructure and would have involved distances in the kilometres, travelling up and down the topography, leading to confusion in the results. An example of how coastal slope was measured is shown in Figure 4.3

Figure 4.3 Example of coastal slope measurement using Google Earth

4.1.4 Percentage rocky outcrop

Rocky outcrop (the areas where rock formation protrudes the beach sediment) influences the coastline's susceptibility to erosion: the greater the percentage of rocky outcrop found on the coastline, the less susceptible the coastline is to erosion processes. As with beach width and vegetation from the back beach, this was measured using orthophotographs of the region. However, unlike Palmer et al.'s study where relatively exact % rocky outcrop could be quantified, here four ranges were used instead. This is due to the nature of beaches found along the Westfjords coastline. These beaches are mainly comprised of coarse clastic sediments and there was difficulty distinguishing mobile sediment from rock outcrop. Therefore, using the four 'ranges' outlined in Palmer et al's (2011) study: >50%, 20%-50%, 10-20% and <10%, the extent of visible rock in each transect was estimated. Where buildings or other structural elements were present, a rocky outcrop score of >50% was assigned.

4.1.5Distance from 20m isobath

This parameter is important as the greater the distance from the shoreline tothe 20m isobath(the contourbeyondwhich sea depth is >20m), the greater the dissipation of wave energy. Subsequently, a reduction in wave energy reaching the shoreline entails lower vulnerability to the effects of extreme weather conditions and RSLR. To measure this, a regional bathymetry map was acquired from the Icelandic Marine Institute, entitled Chart No46 (see Figure 4.4). In addition, a report from the Icelandic Maritime Administration contained some relevant bathymetry information (Jónsdóttir et al., 2007).For each section, the distance to the 20m isobath was measured from the transect line (at its starting-point on the shoreline) to the 20m isobath line.

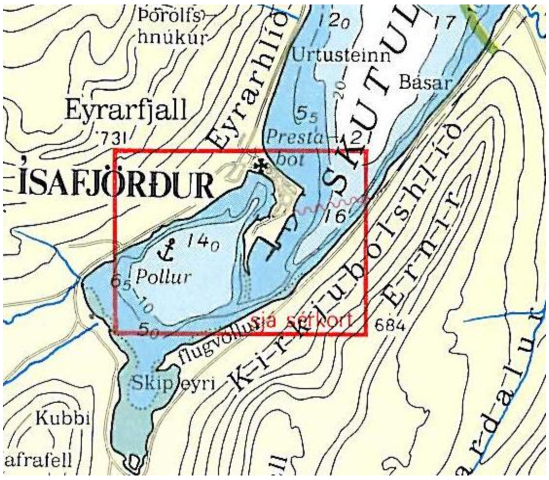


Figure 4.4Examples of bathymetry map used: Chart no46. This bathymetry map was obtainedfrom the Icelandic Maritime Administration

4.1.6 Avalanche Frequency

Avalanches are a very real threat to the coastal communities of the Westfjords (Decaulne and Saemundsson, 2003). As Decaulne and Saemundsson write, ‘catastrophic slope processes have claimed 193 lives, have caused severe damage and have hada considerable economic effect in many parts of Iceland, especially threatening a large number of fjord settlements’ (Decaulne and Saemundsson, 2006, p81). The geographical arrangement of

Westfjords settlements, situated as they are in the relatively small space between the coastline and steep fjord walls, ultimately means not only are these coastal settlements at risk from coastal processes but have the added threat from ‘behind’ in the form of avalanche risk. As a consequence, additional considerations are necessary when assessing the possibility of moving settlements and infrastructure inland. For this reason, it was deemed necessary to incorporate this parameter into the index, despite not being a conventional coastal vulnerability parameter.

To measure and map this avalanche frequency, records of avalanche incidences impacting the region’s roads in the time period between 1996 (a year after the Westfjords had experienced some of the most severe and fatal avalanches in modern times (Decaulne and Saemundsson, 2003)) and 2011 were used. These records were provided by both VeðurstofaÍslands (Icelandic Meteorological Office) and Vegagerðin (Icelandic Road Administration). From these records, it was possible to determine where the most avalanches hadimpacted major roads in the region. In consultation with the avalanche department at VeðurstofaÍslands, a ranking of 1-4 was applied depending on the number of recorded avalanches. This ranking can be seen later in this Chapter in Table 4.1. Along with these records, a report published by VeðurstofaÍslands in 2006 entitled, ‘Assessment of risk of avalanches and the road:Súðavík and Bolungarvík’ was used to support the insights gathered from these records (Grimsdottir, 2006). Furthermore, consultation with the VeðurstofaÍslandswas required for the sections of the study area possessing no major roads along its coastline. By outlining recorded incidents of extreme avalanches and assessing the topographical features of these areas (i.e. whether these features contribute to avalanche frequency) a ranking of 1-4 was applied using their expertise in this field.

4.1.7Estuary Presence

Where rivers meet the coast are areas that are particularly dynamic and sensitive to coastal processes (Palmer et al., 2011). For the CVI to incorporate this factor, a score of 4 was added if the coastal section possessed visible signs of an estuary. A visual examination of the orthophotographswas undertaken to determine estuary presence.

Figure 4.5 Example of estuary presence in Önundarfjörður

4.2 Calculation of CVI

With all the data collected, a ranking system was applied to parameters.The category measurement rangesare outlined in Table 4.1. Palmer et al (2011) use a scale of 'extremely low', 'low', 'moderate' and 'high' to qualitatively assess vulnerability. Criteria for ranking parameters used in Palmer et al's study was kept for this study, having been determined by a specialist consultation involving geomorphologists, oceanographers and coastal engineers. Furthermore, these ranges are supported by the work of Carter (1988), Davis and Fitzgerald (2009) and Trenhaile (1997).The ranking criteria for coastal slope was taken from Gaki-Papanastassiou et al.'s CVI study for Argolikos Gulf in Greece (Gaki-Papanastassiou et al., 2010). Avalanche frequency was determined in consultation with the avalanche department at VeðurstofaÍslands.

Table 4.1 Criteria for physical parameter rankings

Physical Parameter	**ExtremelyLow (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
Beach width	> 150m	100 –150m	50 – 100m	< 50m
Coastal Slope	>12	12-8	8-4	<4

Distance to 20m isobaths	> 4km	2 – 4km	1 – 2km	< 1km
Distance of vegetation behind the back beach	> 600m	200 –600m	100 – 200m	< 100m
Percentage Rocky Outcrop	> 50%	20 –50%	10 – 20%	< 10%
Avalanche Frequency	0	1-10	11-50	>50

With rankings applied, these values were then put into a simple equation to calculate for each coastal section a 'relative' CVI score: a score that indicates coastal vulnerability comparative to other sections of the coastline. The minimum score possible was 6 and the maximum was 28.

Relative CVI = **a** + **b** +**c** +**d** +**e** + **f** + **g**

a = Beach width **4 (max)**

b = Coastal slope **4 (max)**

c = Distance of vegetation behind back beach **4 (max)**

d = Distance from 20m isobaths **4 (max)**

e = % rocky outcrop **4 (max)**

f = Avalanche risk **4 (max)**

g = Estuary presence

4 **= 28 (max)**

Figure 4.6CVI equation

In Palmer et al.'s study, they organised the CVI scores into five categories: 'very low', 'low', 'moderate', 'high' and 'very high' vulnerability. Coastal sections scoring within the mid-range (between the 25%percentile and 75% percentile) were ranked as 'moderate' vulnerability. Coastal sections scoring below or above this moderate ranking were categorised as lower and higher vulnerability respectively. This ranking is presented below.

Very low = 6-12

Low = 13-15

Moderate = 16-18

High = 19-22

Very High = 23-28

With each coastal section attributed a score, vulnerability was mapped using a colour-code system (see Chapter 6).

4.3 Socio-economic assessment

Once physical parameterswere measured, socio-economic features located in each coastal section's 'cell'were assessed. As the northern Westfjords is a substantially different environment to South Africa, a different set of categories/features to those selected byPalmer et al (2011) was required (see Table 2.2for Palmer et al.'s categorisation). Categorisation for this study involved using what Ketchum describes as 'the main spheres of activity in the coastal zone' (Ketchum, 1972, Phillips and Jones, 2006, p518). An assessment was made for coastal sections with the highest vulnerability, detailing the features that were present, their prevalence and to what extent they are within the cell and their distance from the shoreline.

Table 4.2 Categories and features of socio-economic features using Ketchum's (1972) 'main spheres of activity in the coastal zone'

Residency and Recreational	Strategic / Transport Infrastructure	Industrial and Commercial	Waste disposal	Agricultural	Aquaculture and Fishing	Conservation
Housing areas/ built urban areas Isolated housing/buildings Boat launch sites	Major roads Minor roads Harbours Airstrip Lighthouses	Supermarkets Factories, e.g. fish-processing plants Power stations	Waste-water treatment plants Sewage-treatment plants	Farm houses Arable land	Fishing hot-spots Aquaculture sites	Designated nature reserves

In the context of this study, major roads are defined as roads which offer the only connection between towns located in the study area. Minor roads are defined as smaller roads not used to travel between towns and exist to connect remote housing and farms. Distances of socio-economic components from the shoreline were measured in ranges of 10m (e.g. ~10m, ~50m, ~100m).

4.4 Coastal defence assessment

A brief assessment was undertaken to assess both the extent and type of coastal defence found in areas determined to be higher vulnerability. This assessment was based loosely upon a methodology devised by Davies et al (2010) whereby structural fronting, elevation and average stone size of coastal defences are measured. As previously mentioned in Chapter 3, seawalls are the predominant coastal protection structurein Iceland. Due to the practical limitations of this study, exact elevations and average stone sizes were not calculated as was done by Davies et al (2010). Instead, consultation with the Icelandic Road Administration (the organisation responsible for coastal defence in the Westfjords) was undertaken to identify what coastal defence options (and to what extent) had been used in the areas of higher vulnerability.

5. Physical parameter measurements

This chapter outlines the physical parameter measurements from each coastal section.

5.1 Beach Width

Table 5.1 and 5.1present beach width measurements in both table and chart format.

Table 5.1 Beach width measurements

Coastal section	Beach Width (m)	Coastal section	Beach Width (m)	Coastal section	Beach Width (m)	Coastal section	Beach Width (m)	Coastal section	Beach Width (m)
1	42.1	**49**	22.9	**97**	72.5	**145**	102.9	**193**	31.3
2	20.1	**50**	21.3	**98**	71.1	**146**	112.7	**194**	68.7
3	32.2	**51**	36.5	**99**	56.6	**147**	26.4	**195**	60.3
4	24	**52**	13.4	**100**	45.8	**148**	35.4	**196**	36.8
5	37.2	**53**	17.9	**101**	31.4	**149**	52.2	**197**	40.6
6	36.9	**54**	29.9	**102**	30.4	**150**	50.9	**198**	122.9
7	38.9	**55**	52.5	**103**	50.5	**151**	72.8	**199**	141.1
8	51.4	**56**	23.2	**104**	13	**152**	65.9	**200**	248.6
9	36.3	**57**	43	**105**	14.9	**153**	55	**201**	31.1
10	449.8	**58**	65	**106**	3.8	**154**	55	**202**	172.9
11	34.6	**59**	34.7	**107**	10.6	**155**	50.8	**203**	59.8
12	11.5	**60**	31.5	**108**	39.6	**156**	182.7	**204**	62
13	91.4	**61**	63	**109**	24.2	**157**	31.3	**205**	35.3
14	37.4	**62**	24.2	**110**	38.5	**158**	36.5	**206**	247.7
15	43.4	**63**	15	**111**	36.2	**159**	42.1	**207**	101.7
16	88.5	**64**	29.9	**112**	29.6	**160**	36.2	**208**	49.4
17	62.4	**65**	43.2	**113**	25.8	**161**	24.6	**209**	45.9
18	15.7	**66**	37.9	**114**	33.5	**162**	49.1	**210**	26.1
19	30.2	**67**	55.6	**115**	34.4	**163**	25.1	**211**	38.4
20	20.1	**68**	49.6	**116**	29.3	**164**	43.7	**212**	30.6
21	42.7	**69**	59.2	**117**	53.1	**165**	29.2	**213**	41.4
22	16.6	**70**	48.3	**118**	32.1	**166**	46	**214**	32.2
23	35	**71**	66	**119**	13.7	**167**	36.4	**215**	50.7
24	18.7	**72**	46.7	**120**	30.4	**168**	33.4	**216**	45.2
25	20.6	**73**	49.4	**121**	42.1	**169**	20.7	**217**	37.4
26	19.7	**74**	47.7	**122**	20.1	**170**	52.5	**218**	117.5
27	21.5	**75**	74.6	**123**	32.2	**171**	54.9	**219**	94
28	24.4	**76**	72.1	**124**	24	**172**	29.5	**220**	98.4
29	10.3	**77**	61.8	**125**	0	**173**	41.5	**221**	85.5
30	68.5	**78**	143.6	**126**	4.6	**174**	37.2	**222**	63.2
31	70	**79**	38.3	**127**	53.6	**175**	59.8	**223**	10
32	52.5	**80**	81.6	**128**	32.8	**176**	26.3	**224**	19.7
33	32.2	**81**	51.7	**129**	522.5	**177**	27	**225**	22.5
34	32.2	**82**	50.7	**130**	206.7	**178**	58.9	**226**	127

35	29.9	**83**	48.5	**131**	197.8	**179**	30.7	**227**	61.6
36	20	**84**	17.4	**132**	132.3	**180**	62.2	**228**	32.5
37	0	**85**	34.6	**133**	191.2	**181**	59.6	**229**	42.5
38	0	**86**	46.8	**134**	183.3	**182**	65.4	**230**	51.9
39	22.7	**87**	54	**135**	471.1	**183**	44.3	**231**	131.7
40	6.9	**88**	52.9	**136**	350.7	**184**	35.9	**232**	55
41	23.2	**89**	27.6	**137**	145.6	**185**	35.7	**233**	34.1
42	20.1	**90**	30.1	**138**	302.9	**186**	35.4	**234**	52.8
43	7.9	**91**	49.4	**139**	256.8	**187**	45.3	**235**	30
44	21.2	**92**	40.7	**140**	150.2	**188**	290	**236**	52.7
45	0	**93**	51.7	**141**	451	**189**	301.5	**237**	64.9
46	6.2	**94**	37.3	**142**	525.7	**190**	34.9	**238**	64.9
47	0	**95**	99.3	**143**	121	**191**	80.7	**239**	72.9
48	11.5	**96**	40.9	**144**	122.7	**192**	70.6	**240**	40.6

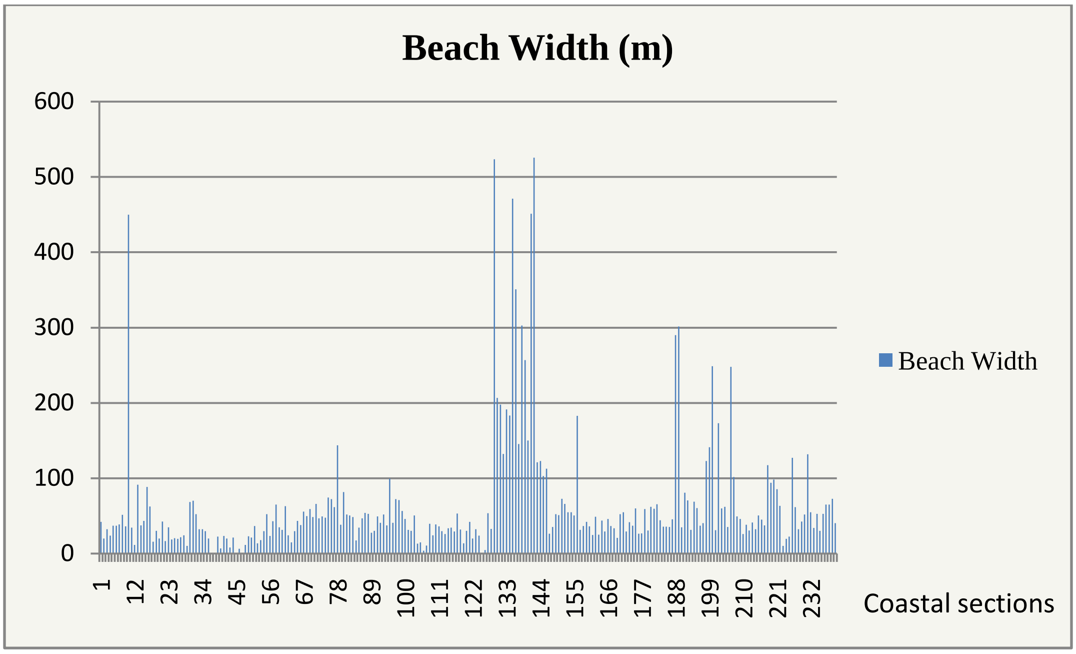


Figure 5.1Beach width measurements graph

As Figure 5.1shows, a large disparity exists between the widest and shortest beach widths recorded. The average beach width recordedwas 65.7m. However, this value will have been skewed by some of the coastal sections which recorded higher beach widths: only 13 of the 240 transects recorded a beach width greater than 200m. The mid-range (in between the 25% percentile and 75% percentile) better encapsulates the beach width generally recorded: this ranged from 29.2 - 62m. An interesting observation to make when looking at the data is how many of the measurements recorded lay close to the 50m mark. This is significant, as50m was the distinguishing line between scoring a score of 3 or 4. Thirty-five of the beach widths recorded were within ±5m of 50m.

Coastal section 142 recorded the highest width: 525.7m. This coastal section occurred well within Önundarfjörður, where Holtstangi beachis located. Indeed, there is a notable cluster of higher beach width measurements for coastal sections 129 to 146. The presence of Holstangi beach dissipates the wave energy entering into the upper reaches of the fjord, allowing for more sedimentation to settle behind it. Figure 5.2 present orthophotograph images of these areas.

Figure 5.2Beach width measurement for coastal section 142 and upper reaches of Önundarfjörður. Top: the beach width recorded for the coastal section represented by cell 142. Left; further in-fjord, a cluster of the largest beach widths were recorded, as Holtstangi beach acts as a buffer, allowing sedimentation to gather (Loftmyndir)

One notable outlier can be observed in the measurement for coastal section 10, where a considerably higher width was recorded than the measurements in close proximity to it. This is due to the transect being located near an estuary mouth where sedimentation had built up (see Figure 5.3).

Figure 5.3Beach width measurement for coastal section 10 (Loftmyndir)

The lowest beach width measurements recorded were 0m for coastal sections 37, 38, 45 and 47. This was due to transects being located at notable points of artificial infrastructure, namely the Ísafjörður harbour and the runway at Ísafjörður airport (See Figure 5.4).

Figure 5.4Ísafjörður harbour and Ísafjörður airport runway (LoftMyndir)

Generally, the beach along the study area coastline was primarily made up of large rock towards the back beach and smaller pebbles found towards the high water mark. Figure 5.5presents an example for coastal section 109.

Figure 5.5Beach width measurement for coastal section 109 (Loftmyndir)

5.2 Coastal slope

Table 5.2 and 5.6present coastal slope measurements in both table and chart format.

Table 5.2 Coastal slope measurements

Coastal section	Coastal slope	Coastal section	Coastal slope	Coastal section	Coastal slope	Coastal section	Coastal slope	Coastal section	Coastal slope
1	6.57	**49**	4.22	**97**	55.74	**145**	3.41	**193**	0.50
2	11	**50**	35.56	**98**	5.50	**146**	4.41	**194**	4.69
3	19.53	**51**	36.17	**99**	19.85	**147**	1.05	**195**	9.63
4	22.52	**52**	22.28	**100**	15.21	**148**	22.77	**196**	12.28
5	9.41	**53**	5.83	**101**	19.53	**149**	0.90	**197**	22.73
6	2.62	**54**	15.59	**102**	11.95	**150**	32.50	**198**	15.47
7	1.16	**55**	46.64	**103**	27.47	**151**	5.50	**199**	2.08
8	9.36	**56**	49.79	**104**	13.51	**152**	13.00	**200**	0.50
9	11.40	**57**	51.28	**105**	15.72	**153**	9.00	**201**	6.50
10	0.5	**58**	18.56	**106**	4.10	**154**	15.50	**202**	24.80
11	9.5	**59**	14.34	**107**	5.15	**155**	9.50	**203**	4.03
12	2.70	**60**	2.44	**108**	16.70	**156**	1.00	**204**	19.93
13	6.21	**61**	2.50	**109**	4.61	**157**	13.00	**205**	19.43
14	12.00	**62**	3.67	**110**	27.50	**158**	16.50	**206**	8.33
15	12.50	**63**	56.50	**111**	21.50	**159**	47.50	**207**	10.20
16	22.02	**64**	36.07	**112**	36.50	**160**	14.00	**208**	11.17
17	16.90	**65**	34.55	**113**	15.50	**161**	56.50	**209**	10.00
18	15.65	**66**	46.50	**114**	20.50	**162**	18.50	**210**	10.00
19	9.91	**67**	49.00	**115**	52.00	**163**	62.00	**211**	12.60
20	4.95	**68**	52.00	**116**	48.50	**164**	10.50	**212**	5.50
21	10.42	**69**	31.50	**117**	50.00	**165**	56.50	**213**	12.00
22	20.27	**70**	35.00	**118**	44.50	**166**	38.50	**214**	5.41
23	9.01	**71**	33.50	**119**	53.00	**167**	23.00	**215**	2.00
24	34.33	**72**	12.00	**120**	18.50	**168**	3.00	**216**	18.06
25	38.40	**73**	20.50	**121**	34.00	**169**	46.00	**217**	13.33
26	35.40	**74**	61.50	**122**	20.69	**170**	44.50	**218**	4.83
27	49.52	**75**	30.00	**123**	34.32	**171**	50.00	**219**	5.19
28	30.10	**76**	10.70	**124**	3.64	**172**	35.50	**220**	12.40
29	32.35	**77**	15	**125**	7.09	**173**	37.50	**221**	7.64
30	40.00	**78**	27.50	**126**	3.14	**174**	33.00	**222**	12.90
31	4.85	**79**	54.50	**127**	11.67	**175**	39.00	**223**	12.90
32	10.78	**80**	65.50	**128**	5.55	**176**	21.00	**224**	3.08
33	20.57	**81**	13.00	**129**	10.32	**177**	7.14	**225**	10.78
34	15.79	**82**	23.00	**130**	7.50	**178**	26.09	**226**	3.06
35	3.28	**83**	41.00	**131**	6.52	**179**	17.00	**227**	1.03
36	6.16	**84**	57.50	**132**	1.83	**180**	23.00	**228**	12.88
37	-	**85**	35.50	**133**	6.08	**181**	17.00	**229**	11.50
38	-	**86**	41.50	**134**	5.00	**182**	2.50	**230**	6.84
39	1.70	**87**	45.00	**135**	12.84	**183**	17.50	**231**	12.64
40	16.39	**88**	3.76	**136**	7.50	**184**	51.00	**232**	1.50
41	4.55	**89**	22.00	**137**	0.52	**185**	32.00	**233**	6.05
42	9.43	**90**	49.50	**138**	3.00	**186**	7.50	**234**	25.19
43	9.17	**91**	38.00	**139**	0.50	**187**	2.00	**235**	26.44
44	5.15	**92**	15.85	**140**	0.50	**188**	2.50	**236**	40.94
45	-	**93**	36.50	**141**	0.50	**189**	2.50	**237**	12.00

46	0.86	**94**	43.00	**142**	0.50	**190**	7.41	**238**	1.41
47	2.70	**95**	39.00	**143**	0.50	**191**	2.06	**239**	0.83
48	4.98	**96**	44.40	**144**	2.00	**192**	2.76	**240**	0.96

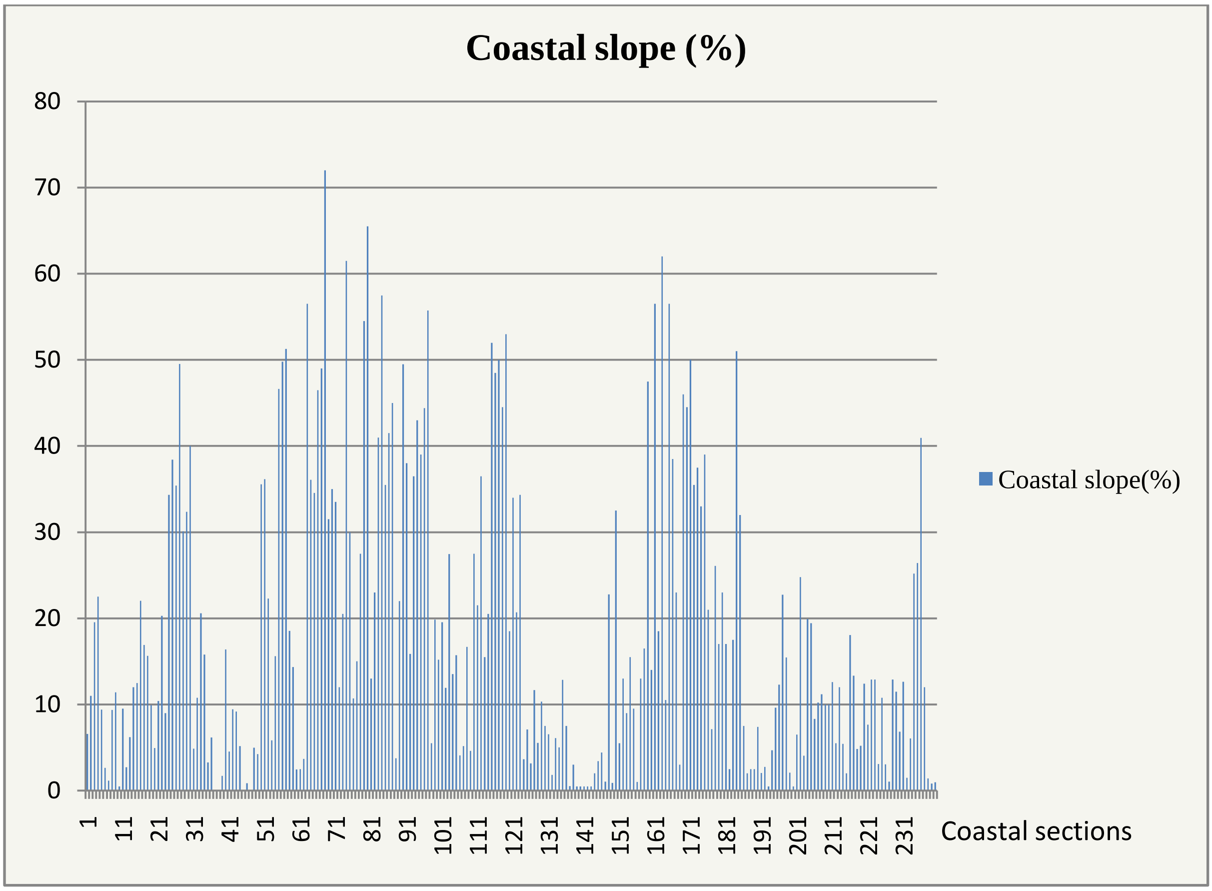


Figure 5.6Coastal slope measurementsgraph

There is a considerable disparity between the highest % coastal slope measured and the lowest. The average coastal slope was calculated as 18.77%, however because of the large disparity between highest and lowest, it is not indicative of the coastal slope for the whole region. The mid-range spreads across a large number of measurements, ranging from 5.15-32%. As Figure 5.6 shows, clusters of high coastal slopes can be observed, often being found in uninhabited stretches of coastline where the fjord walls are particularly steep:Stigahlíð, (coastal sections 63-75), Sauðanes (coastal sectons 110-121) and Skagafjall (coastal sections 169-175). An example of one of the steeper slope measurements is presented in Figure 5.7.

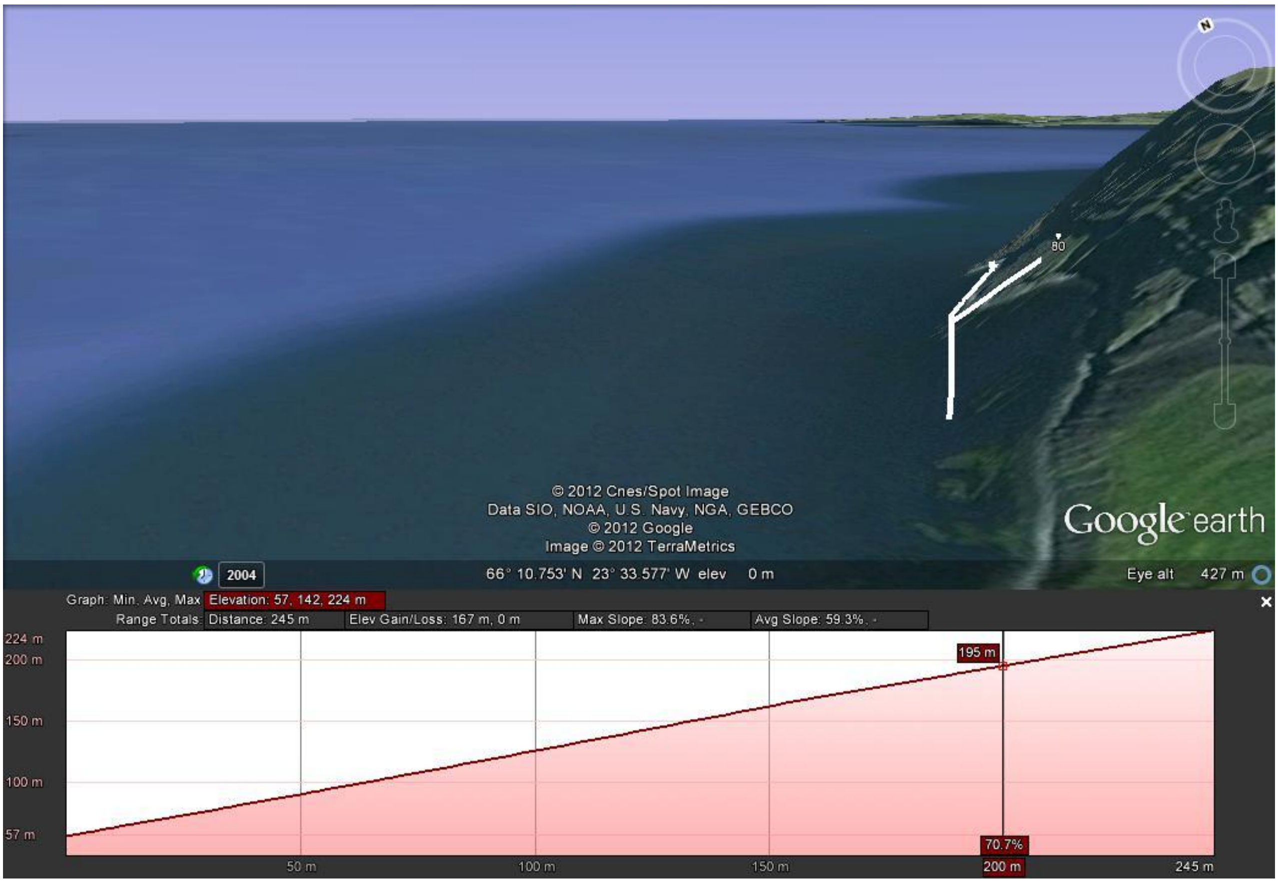


Figure 5.7Coastal slope measurement for coastal section 80. Note: due to the precision of the STRM data, the bottom elevation value is not necessarily 0m at the shoreline. This elevation value is subtracted to provide a better indication of coastal slope(Google Earth)

The area with the lowest coastal slope measurements was located in the Holtstangi region of Önundarfjörður (coastal sections 136-147), where a low-lying sandy beach environment is located (See Figure 5.8 as an example). For some coastal sections, a coastal slope was not calculated (37, 38, and 45) as these transects were located at areas such as Ísafjörður harbour and Ísafjörður airport runway where there was no real slope to measure.

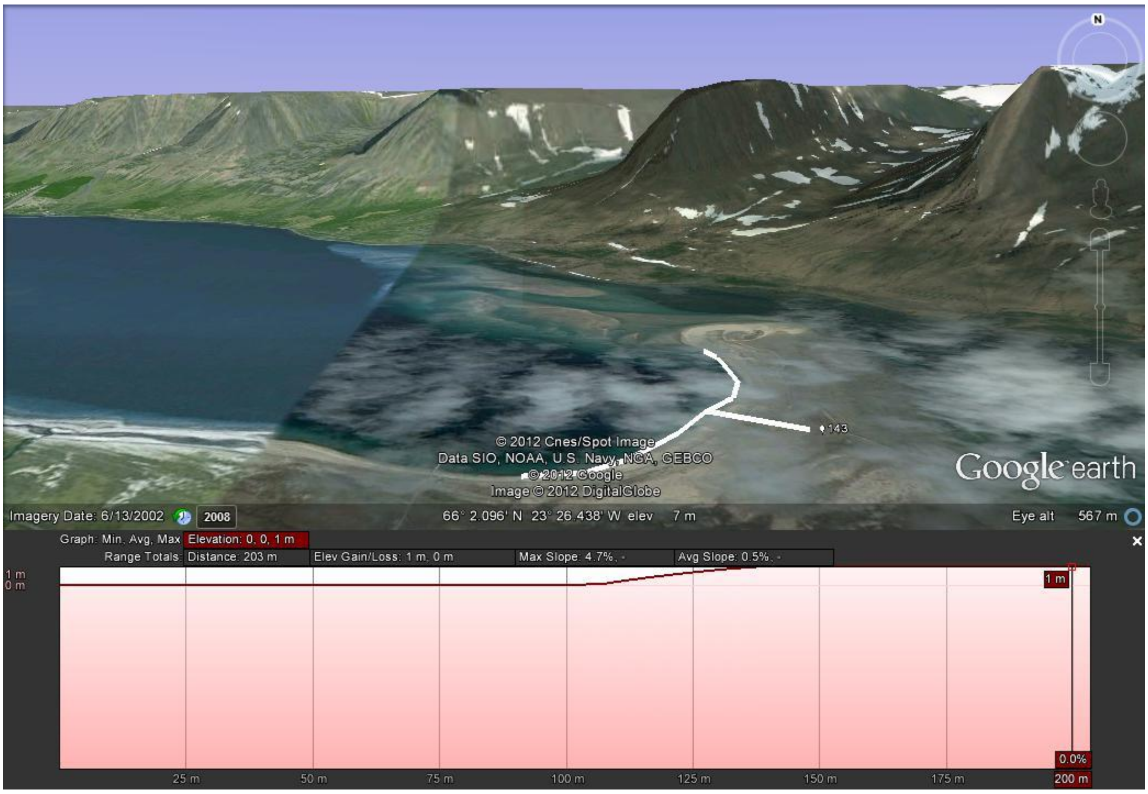


Figure 5.8Coastal slope measurement for coastal section143(Google Earth)

5.3 Distance from the 20m isobath

Table 5.3 and 5.9present distance from the 20m isobathmeasurements in both table and chart format.

Table 5.3 Distance from 20m-isobath measurements

Coastal section	Distance to 20m Isobath (km)	Coastal section	Distance to 20m Isobath (km)	Coastal section	Distance to 20m Isobath (km)	Coastal section	Distance to 20m Isobath (km)	Coastal section	Distance to 20m Isobath (km)
1	<1	**49**	<1	**97**	<1	**145**	<1	**193**	<1
2	<1	**50**	<1	**98**	<1	**146**	<1	**194**	<1
3	<1	**51**	<1	**99**	<1	**147**	<1	**195**	<1
4	<1	**52**	1-2	**100**	<1	**148**	<1	**196**	<1
5	<1	**53**	1-2	**101**	<1	**149**	<1	**197**	<1
6	<1	**54**	<1	**102**	<1	**150**	<1	**198**	<1
7	<1	**55**	<1	**103**	<1	**151**	<1	**199**	<1
8	<1	**56**	<1	**104**	<1	**152**	<1	**200**	<1
9	<1	**57**	<1	**105**	<1	**153**	<1	**201**	<1
10	<1	**58**	<1	**106**	<1	**154**	<1	**202**	<1
11	<1	**59**	<1	**107**	2-4	**155**	<1	**203**	<1
12	<1	**60**	<1	**108**	2-4	**156**	<1	**204**	<1

13	<1	**61**	1-2	**109**	2-4	**157**	<1	**205**	<1
14	<1	**62**	1-2	**110**	1-2	**158**	<1	**206**	<1
15	<1	**63**	<1	**111**	<1	**159**	<1	**207**	<1
16	<1	**64**	<1	**112**	<1	**160**	<1	**208**	<1
17	<1	**65**	<1	**113**	1-2	**161**	<1	**209**	<1
18	<1	**66**	<1	**114**	1-2	**162**	<1	**210**	<1
19	<1	**67**	<1	**115**	<1	**163**	<1	**211**	<1
20	<1	**68**	<1	**116**	<1	**164**	<1	**212**	<1
21	<1	**69**	<1	**117**	<1	**165**	<1	**213**	<1
22	<1	**70**	<1	**118**	<1	**166**	<1	**214**	<1
23	<1	**71**	<1	**119**	<1	**167**	<1	**215**	<1
24	<1	**72**	<1	**120**	<1	**168**	<1	**216**	<1
25	<1	**73**	<1	**121**	<1	**169**	<1	**217**	<1
26	<1	**74**	<1	**122**	<1	**170**	<1	**218**	<1
27	<1	**75**	1-2	**123**	<1	**171**	<1	**219**	<1
28	<1	**76**	1-2	**124**	<1	**172**	<1	**220**	<1
29	<1	**77**	<1	**125**	<1	**173**	<1	**221**	<1
30	1-2	**78**	<1	**126**	<1	**174**	<1	**222**	<1
31	1-2	**79**	<1	**127**	<1	**175**	<1	**223**	<1
32	1-2	**80**	<1	**128**	<1	**176**	<1	**224**	<1
33	<1	**81**	<1	**129**	<1	**177**	<1	**225**	<1
34	<1	**82**	<1	**130**	2-4	**178**	<1	**226**	<1
35	1-2	**83**	<1	**131**	2-4	**179**	<1	**227**	<1
36	2-4	**84**	<1	**132**	>4	**180**	<1	**228**	<1
37	2-4	**85**	<1	**133**	>4	**181**	<1	**229**	<1
38	2-4	**86**	2-4	**134**	>4	**182**	<1	**230**	<1
39	>4	**87**	2-4	**135**	>4	**183**	<1	**231**	<1
40	>4	**88**	>4	**136**	>4	**184**	<1	**232**	<1
41	2-4	**89**	1-2	**137**	>4	**185**	<1	**233**	<1
42	2-4	**90**	<1	**138**	>4	**186**	<1	**234**	<1
43	2-4	**91**	<1	**139**	>4	**187**	<1	**235**	<1
44	1-2	**92**	<1	**140**	>4	**188**	<1	**236**	<1
45	1-2	**93**	<1	**141**	2-4	**189**	<1	**237**	<1
46	2-4	**94**	<1	**142**	1-2	**190**	<1	**238**	<1
47	1-2	**95**	<1	**143**	1-2	**191**	<1	**239**	<1
48	1-2	**96**	<1	**144**	1-2	**192**	<1	**240**	<1

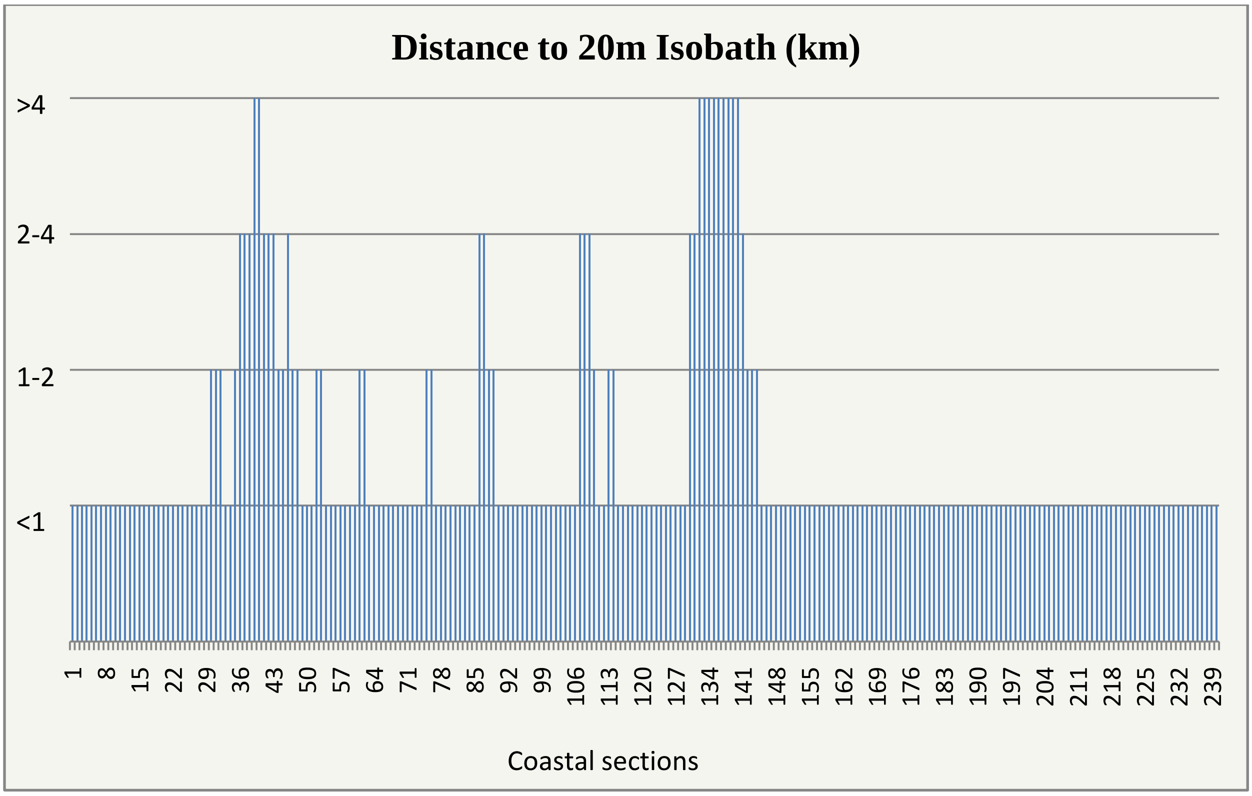


Figure 5.9 Distance to 20m-isobaths measurements graph

The bathymetry data available for the study area lacked the precision to measure accurately the exact distance from the coastline to the 20m isobaths line. For this reason an estimation was used following Palmer et al.'s ranking system (<1, 1-2km, 2-4km and >4km). Despite the lack of precise data, it did not prove too problematic for this study. In Palmer et al's CVI, the criteria to score 4 (high vulnerability) was set at <1km from the coastline. The fjordic environment of the Westfjords entailed that for the vast majority of coastal sections the 20m isobath line was comfortably within the <1km mark (196 of the 240). This can easily be seen in Chart no46 and in the extract of the Icelandic Maritime Administration's report on Wave research in the Westfjords (see Figure 5.10and 5.11). Fjords (or glacial troughs) are commonly very deep, narrow inlets, where glacial processes have eroded deep valleys that are eventually submerged by the sea (Bennett and Glasser, 2009). Hencethe 20m isobath line exists close to the coast.

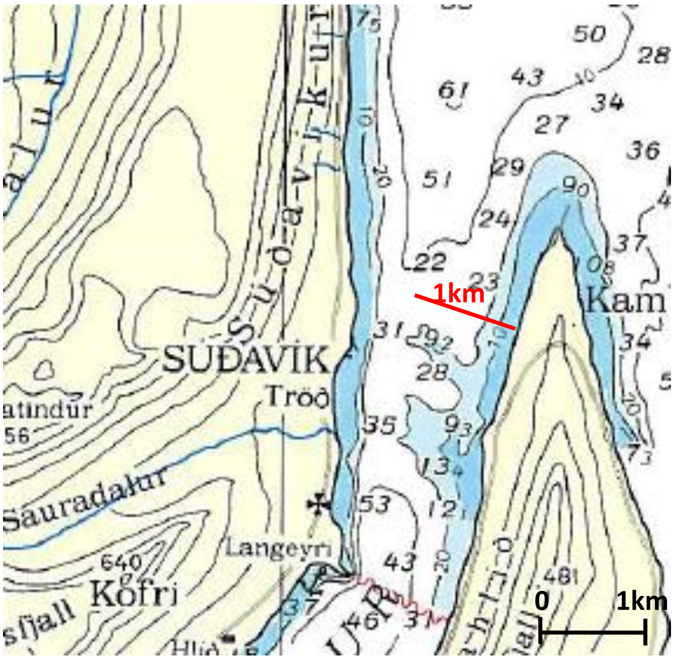


Figure 5.10Extract from Icelandic Bathymetry map Chart no46

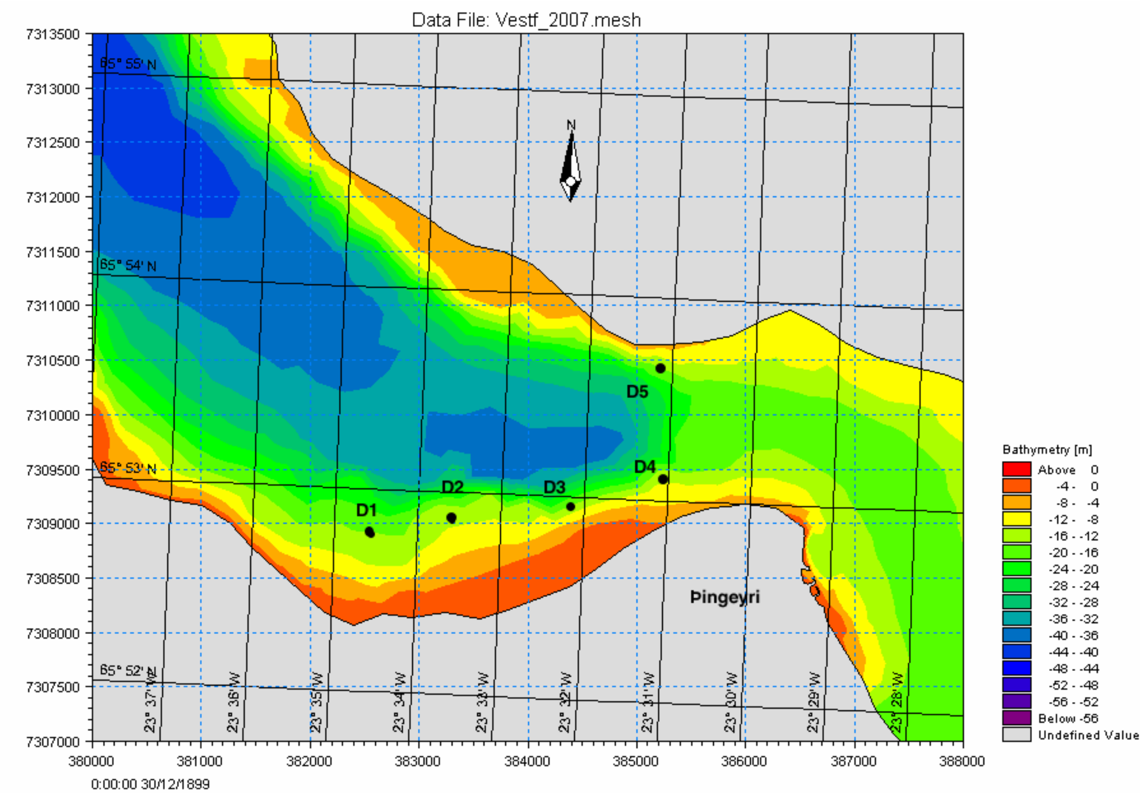


Figure 5.11Bathymetry data for Dýrafjörður(Jónsdóttir et al., 2007)

Some exceptions did exist. Deep within the fjord inlets towards the upper reaches of Skutulsfjörður and Önundarfjörður shallower waters were located (see Figure 5.12). Furthermore, areas of shallower water were found at the mouth of some fjords, as was the case in Súgandafjörður. This could be explained by terminal moraine deposits that often occur at the mouth of the fjord, although other explanations idiosyncratic of the region might exist (Bennett and Glasser, 2009). Indeed, Súgandafjörður is the shallowest of the fjords found within the study area. Unfortunately, as boats rarely travel down this fjord (largely in part to the shallow waters at its entrance), no accurate bathymetry data is available. However, on advice from the Icelandic Marine Institute, it is a near certainty that the water will be deeper than 20m at its trough and therefore within 1km.

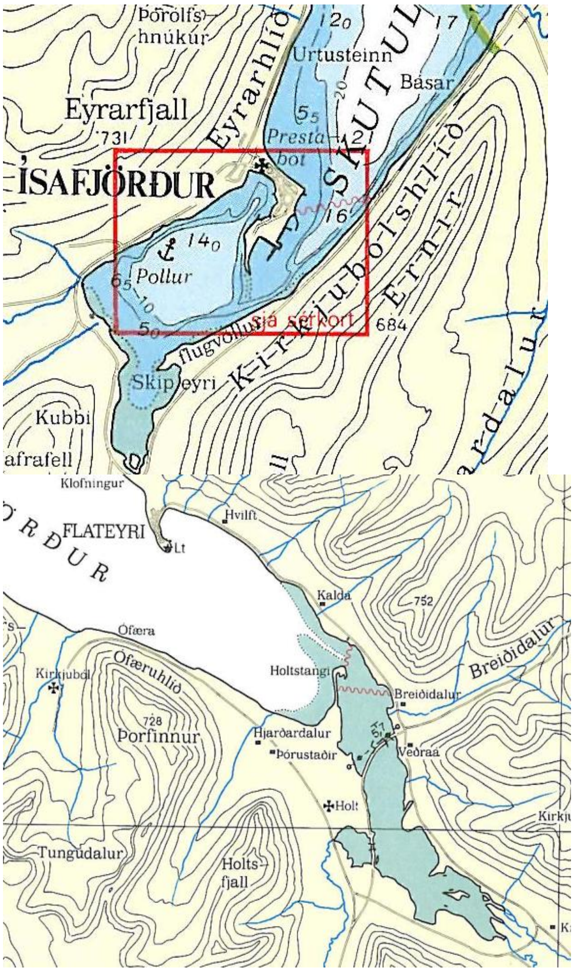


Figure 5.12Theupper reaches of Súgandafjörður (left) and Önundarfjörður (right), where the shallowest water of the study area were located.

5.4 Distance of vegetation behind back-beach

Table 5.4 and Figure 5.13present distance of vegetation behind back-beach in both table and chart format.

Table 5.4 Distance of vegetation behind back beach measurements

Coastal section	Distance of vegetation behind back beach (m)	Coastal section	Distance of vegetation behind back beach (m)	Coastal section	Distance of vegetation behind back beach (m)	Coastal section	Distance of vegetation behind back beach (m)	Coastal section	Distance of vegetation behind back beach (m)
1	289.6	**49**	16.1	**97**	49.7	**145**	45.4	**193**	210
2	102.1	**50**	0	**98**	224	**146**	53.3	**194**	17.2
3	71.2	**51**	0	**99**	116.2	**147**	0	**195**	41.5
4	88.6	**52**	41.3	**100**	40.4	**148**	26.6	**196**	68.5
5	32	**53**	0	**101**	43.4	**149**	342	**197**	56.4
6	31	**54**	19	**102**	19.1	**150**	0	**198**	55.7
7	34	**55**	0	**103**	11.7	**151**	64.1	**199**	64.2
8	100.4	**56**	0	**104**	22	**152**	141	**200**	150.2
9	43	**57**	0	**105**	4.9	**153**	0	**201**	203.8
10	48	**58**	0	**106**	0	**154**	0	**202**	133.7
11	328	**59**	0	**107**	10.7	**155**	163.2	**203**	74.9
12	0	**60**	38.5	**108**	0	**156**	121.4	**204**	18
13	100.8	**61**	83.3	**109**	16.2	**157**	281.3	**205**	58.6
14	183.1	**62**	9.3	**110**	92.6	**158**	0	**206**	54.5
15	90.5	**63**	0	**111**	0	**159**	0	**207**	59.5
16	10	**64**	0	**112**	0	**160**	0	**208**	152.6
17	74.1	**65**	0	**113**	0	**161**	106.2	**209**	210.7
18	45.4	**66**	0	**114**	306.6	**162**	76.5	**210**	91.2
19	59.7	**67**	0	**115**	194.2	**163**	14.3	**211**	164.4
20	0	**68**	0	**116**	104.2	**164**	36.9	**212**	170.4
21	22.3	**69**	0	**117**	283.9	**165**	192.9	**213**	127
22	4.4	**70**	0	**118**	133	**166**	134	**214**	17.3
23	0	**71**	0	**119**	19.8	**167**	106.6	**215**	281.5
24	12	**72**	0	**120**	160.9	**168**	654	**216**	69.2
25	18.7	**73**	0	**121**	289.6	**169**	52.5	**217**	99.1
26	0	**74**	0	**122**	102.1	**170**	77.1	**218**	141.9
27	0	**75**	0	**123**	71.2	**171**	295.9	**219**	127
28	0	**76**	23.1	**124**	88.6	**172**	0	**220**	43.1
29	14	**77**	343	**125**	0	**173**	83.5	**221**	30.5
30	0	**78**	0	**126**	0	**174**	94.3	**222**	8.7
31	18	**79**	0	**127**	16.6	**175**	69.3	**223**	0
32	0	**80**	0	**128**	48.6	**176**	215.8	**224**	23.5
33	11.7	**81**	362	**129**	70.6	**177**	104.3	**225**	33.9
34	11.7	**82**	125.1	**130**	121.2	**178**	115.5	**226**	28
35	0	**83**	0	**131**	41.5	**179**	249.5	**227**	25.9
36	17.2	**84**	0	**132**	104.2	**180**	258.4	**228**	30
37	0	**85**	109	**133**	32.6	**181**	116.6	**229**	172.6
38	0	**86**	0	**134**	177	**182**	267.5	**230**	120.4
39	26.7	**87**	0	**135**	117.2	**183**	37	**231**	0
40	0	**88**	102.6	**136**	86.8	**184**	146.6	**232**	291.1
41	101.4	**89**	83.3	**137**	365	**185**	128.4	**233**	12.3
42	0	**90**	14.7	**138**	324	**186**	164	**234**	45.2
43	0	**91**	11.7	**139**	0	**187**	0	**235**	0
44	0	**92**	128	**140**	156.6	**188**	253	**236**	60.8
45	0	**93**	0	**141**	247.5	**189**	0	**237**	0

46	0	**94**	33.3	**142**	128.9	**190**	66.9	**238**	0
47	0	**95**	27	**143**	0	**191**	39.2	**239**	31.5
48	7.1	**96**	12	**144**	77	**192**	100.2	**240**	36.7

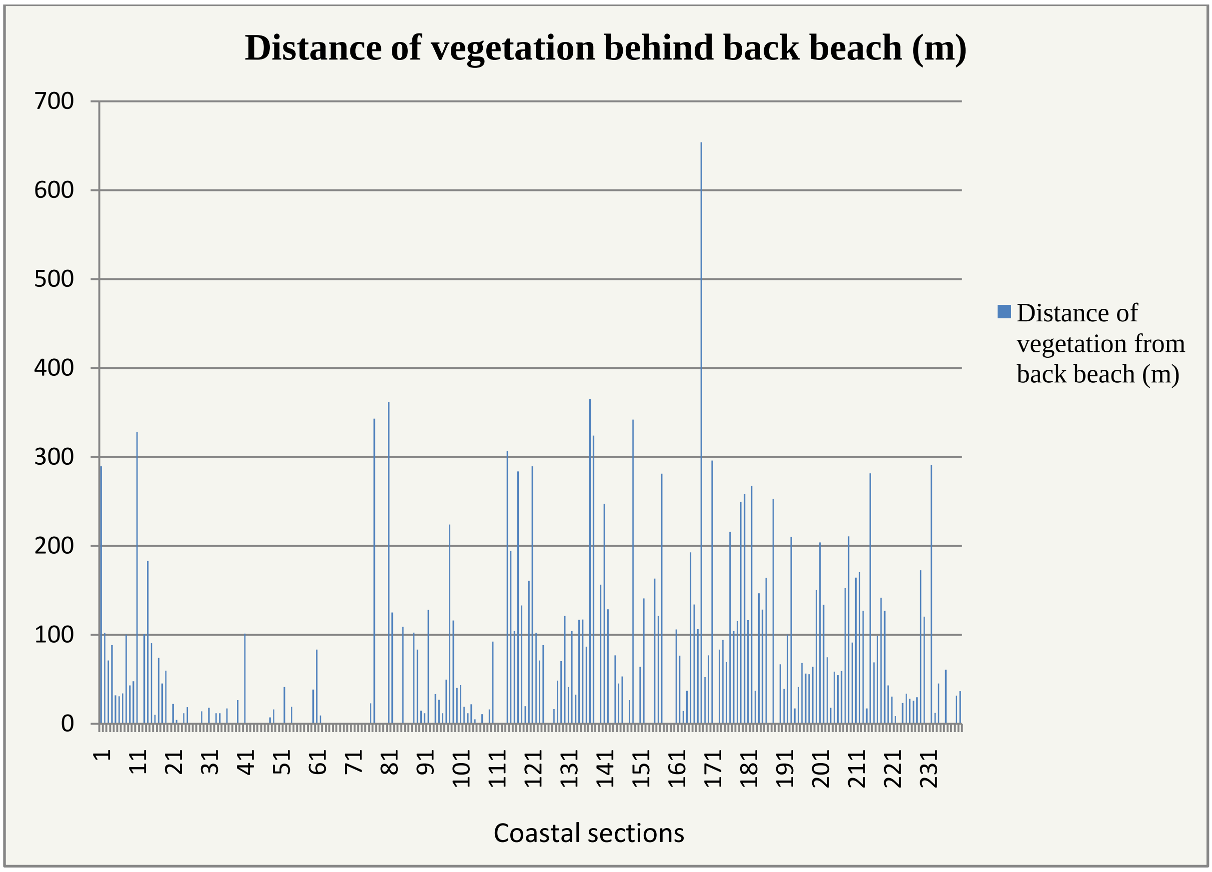


Figure 5.13Distance of vegetation behind back beach graph

A large disparity was found in the measurements for this parameter. The average measurementwas 73.16m. The mid-range (between the 25% and 75% percentile) ranged from 0-104.2m. 69 transect measurements (28.75% of the total study area) showed no signs of vegetation from the back beach. That distance of vegetation was measured from the back beach to the nearest infrastructure was another significant influence, as much of the coastal infrastructure was found relatively close to the shoreline, therefore not allowing for great distances of vegetation to exist before the coastal road, if at all. An exemplar of this can be seen in Figure 5.14, where a measurement of 18m was recorded. However, if the road had not been present, a higher measurementwould have been recorded.

Figure 5.14Distance of vegetation behind back beach measurement for coastal section 31(LoftMyndir)

The highest measurement recorded was 654m for coastal section 168. As Figure 5.16 shows, this measurement was located in a remote section of relatively low relief land near the mouth of Dýrafjörður (Fjallaskagi). The next two highest measurements were 365m and 362m for transects representing coastal sections 137 and 81 respectively. Coastal section 137 is located in the estuarial environment of Önundarfjörður and coastal section 81 in the bay of Keflavik near the mouth of Súgandafjörður. The presence of fresh water rivers and relatively low relief are present in these coastal sections with the exception of coastal section168. These transect measurements are presented in Figure 5.15.

Figure 5.15Examples of the highest measurements for vegetation behind the back beach. From top-left, transect measurements for coastal sections168, 137, and 81 (Loftmyndir)

Many coastal sections recorded 0m for this parameter. The reasons for this were mainly two-fold: the cell was either located in one of the region's towns where the road runs adjacent to the coastline with little space in between, or the cell was located on one of the steep fjord walls where no soil could build up. Examples of these occurrences are presented in Figure 5.16.

Figure 5.16Examples of 0m of vegetation behind the back beach recorded, left; coastal section 125, right; coastal section 73(Loftmyndir)

5.5 Percentage rocky outcrop

Table 5.5 and Figure 5.17present the measurements of percentage rocky outcrop in both table and chart format.

Table 5.5 Percentage rocky outcrop measurements

Coastal section	% rocky outcrop	Coastal section	% rocky outcrop	Coastal section	% rocky outcrop	Coastal section	% rocky outcrop	Coastal section	% rocky outcrop
1	10 – 20	**49**	<10	**97**	10 – 20	**145**	<10	**193**	10 – 20
2	>50	**50**	10 – 20	**98**	10 – 20	**146**	20 –50	**194**	10 – 20
3	20 –50	**51**	20 –50	**99**	10 – 20	**147**	20 –50	**195**	20 –50
4	10 – 20	**52**	>50	**100**	10 – 20	**148**	10 – 20	**196**	20 –50
5	10 – 20	**53**	10-20	**101**	10 – 20	**149**	<10	**197**	20 –50
6	20 –50	**54**	>50	**102**	10 – 20	**150**	20 –50	**198**	10 – 20
7	20 –50	**55**	20 –50	**103**	10 – 20	**151**	20 –50	**199**	10 – 20
8	20 –50	**56**	20 –50	**104**	10 – 20	**152**	20 –50	**200**	<10
9	20 –50	**57**	20 –50	**105**	20 –50	**153**	20 –50	**201**	10 – 20
10	>50	**58**	>50	**106**	<10	**154**	20 –50	**202**	20 –50
11	20 –50	**59**	20 –50	**107**	<10	**155**	20 –50	**203**	10 – 20
12	20 –50	**60**	>50	**108**	20 –50	**156**	>50	**204**	20 –50
13	20 –50	**61**	<10	**109**	20 –50	**157**	20 –50	**205**	10 – 20
14	20 –50	**62**	<10	**110**	20 –50	**158**	20 –50	**206**	<10
15	20 –50	**63**	20 –50	**111**	10 – 20	**159**	20 –50	**207**	<10
16	>50	**64**	20 –50	**112**	20 –50	**160**	10 – 20	**208**	20 –50
17	>50	**65**	20 –50	**113**	20 –50	**161**	20 –50	**209**	10 – 20
18	20 –50	**66**	20 –50	**114**	20 –50	**162**	10 – 20	**210**	10 – 20
19	20 –50	**67**	20 –50	**115**	20 –50	**163**	10 – 20	**211**	10 – 20
20	>50	**68**	20-50	**116**	20 –50	**164**	20 –50	**212**	10 – 20
21	20 –50	**69**	20 –50	**117**	20 –50	**165**	20 –50	**213**	20 –50
22	>50	**70**	20 –50	**118**	20 –50	**166**	20 –50	**214**	20 –50
23	20 –50	**71**	20 –50	**119**	20 –50	**167**	>50	**215**	20 –50
24	20 –50	**72**	10 – 20	**120**	20 –50	**168**	>50	**216**	10 – 20
25	20 –50	**73**	10 – 20	**121**	10 – 20	**169**	20 –50	**217**	10 – 20
26	20 –50	**74**	10 – 20	**122**	20-50	**170**	20 –50	**218**	10 – 20
27	10 – 20	**75**	20 –50	**123**	>50	**171**	20 –50	**219**	<10
28	<10	**76**	<10	**124**	10 – 20	**172**	10 – 20	**220**	>50
29	<10	**77**	<10	**125**	>50	**173**	10 – 20	**221**	20 –50
30	<10	**78**	20 –50	**126**	>50	**174**	10 – 20	**222**	20 –50
31	10 – 20	**79**	10 – 20	**127**	10 – 20	**175**	20 –50	**223**	20 –50
32	10 – 20	**80**	20 –50	**128**	10 – 20	**176**	10 – 20	**224**	10 – 20
33	20 –50	**81**	20 –50	**129**	<10	**177**	10 – 20	**225**	20 –50
34	20 –50	**82**	20 –50	**130**	<10	**178**	20 –50	**226**	<10
35	20 –50	**83**	10 – 20	**131**	<10	**179**	10 – 20	**227**	10 – 20
36	>50	**84**	20 –50	**132**	<10	**180**	>50	**228**	<10
37	>50	**85**	<10	**133**	<10	**181**	20 –50	**229**	20 –50
38	>50	**86**	20 –50	**134**	<10	**182**	10 – 20	**230**	10 – 20
39	<10	**87**	10 – 20	**135**	<10	**183**	20 –50	**231**	<10
40	<10	**88**	20 –50	**136**	<10	**184**	20 –50	**232**	10 – 20
41	10 – 20	**89**	<10	**137**	<10	**185**	20 –50	**233**	20 –50
42	<10	**90**	20 –50	**138**	<10	**186**	10 – 20	**234**	>50
43	20-50	**91**	10 – 20	**139**	<10	**187**	10 – 20	**235**	20 –50
44	20-50	**92**	10 – 20	**140**	<10	**188**	<10	**236**	10 – 20
45	>50	**93**	10 – 20	**141**	<10	**189**	<10	**237**	20 –50
46	>50	**94**	20 –50	**142**	<10	**190**	10 – 20	**238**	20 –50
47	>50	**95**	20 –50	**143**	<10	**191**	20 –50	**239**	20 –50

48	>50	**96**	10 – 20	**144**	<10	**192**	10 – 20	**240**	20 –50

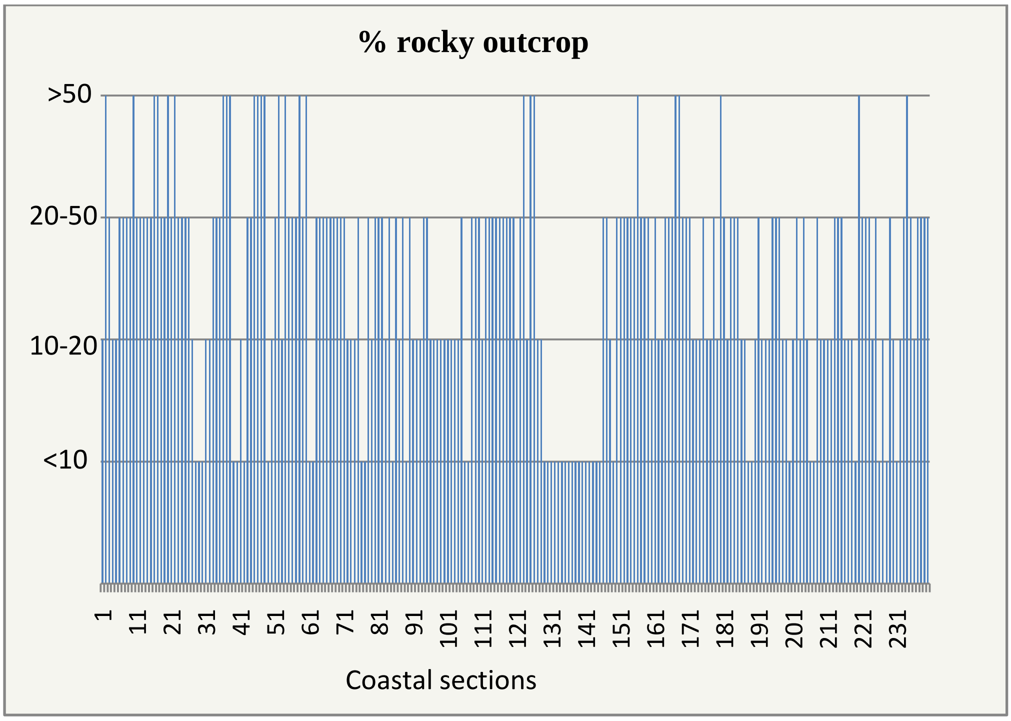


Figure 5.17 Percentage rocky outcrop measurements graph

Of all the physical parameters, measuring the percentage of rocky outcrop was the most difficult. This was mainly due to the difficulty in differentiating between large, mobile rocks that constituted much of the coastline's beaches and identifying what was rocky outcrop. However, a reasonable estimation could be taken. Overall, 103 transect measurements were found to have '20-50%' rocky outcrop, (42.9% of the total) and 66 were found to have '10-20%' rocky outcrop (27.5% of the total). The percentage rocky outcrop was fairly evenly spread across the study area, with some clusters of coastal sectionsrecording either <10% and >50%. Generally, the areas that scored >50% were found on the shoreline of towns where there was no beach visible, only a habour or sea wall (e.g. cells 45-48). As the parameter was chosen to help signify the susceptibility to erosion, it was decided that for these occurrences the highest rocky outcrop estimation should be allocated, as such infrastructure is not an erosion risk. As the graph in Figure 5.17shows, there is one notable cluster of cells allocated with >10% rocky outcrop (cells 129-145). This is the region where the sandy beach of Holt is located with an estuarine region situated behind it (as shown in part of Figure 5.18).

Figure 5.18Examples of % rock outcrop; Left, coastal section 124 where a high percentage of rocky outcrop is present. Right, Holt beach where minimal rocky outcrop is present (coastal section 141-143(LoftMyndir))

5.6 Avalanche frequency

Using SnjóflóðagagnasafnVeðurstofuÍslands (The Icelandic Meteorological Office Avalanche Database), the location of where avalanches had impacted the region's main roads from 1996-2011 could be identified. These are presented in Table 5.6.

Table 5.6 Records of avalanches impact major roads (1996-2011)

Coastal section	Frequency of avalanche impact of road (1996-2011)	Coastal section	Frequency of avalanche impact of road (1996-2011)	Coastal section	Frequency of avalanche impact of road (1996-2011)	Coastal section	Frequency of avalanche impact of road (1996-2011)	Coastal section	Frequency of avalanche impact of road (1996-2011)
1	-	**49**	-	**97**	-	**145**	-	**193**	-
2	-	**50**	-	**98**	-	**146**	-	**194**	-
3	-	**51**	7	**99**	-	**147**	-	**195**	-
4	-	**52**	18	**100**	-	**148**	-	**196**	-
5	-	**53**	1	**101**	-	**149**	-	**197**	-
6	1	**54**	3	**102**	-	**150**	-	**198**	-
7	12	**55**	45	**103**	-	**151**	-	**199**	-
8	7	**56**	42	**104**	-	**152**	-	**200**	-
9	-	**57**	64	**105**	-	**153**	-	**201**	-
10	1	**58**	-	**106**	-	**154**	-	**202**	-
11	-	**59**	36	**107**	-	**155**	-	**203**	-
12	-	**60**	22	**108**	-	**156**	-	**204**	-
13	-	**61**	-	**109**	-	**157**	-	**205**	-

14	-	62	-	110	-	158	-	206	-
15	-	63	-	111	-	159	-	207	-
16	-	64	-	112	-	160	-	208	-
17	-	65	-	113	-	161	-	209	-
18	-	66	-	114	-	162	-	210	-
19	-	67	-	115	-	163	-	211	-
20	-	68	-	116	-	164	-	212	-
21	-	69	-	117	-	165	-	213	-
22	-	70	-	118	-	166	-	214	-
23	-	71	-	119	-	167	-	215	-
24	2	72	-	120	-	168	-	216	-
25	-	73	-	121	-	169	-	217	-
26	192	74	-	122	-	170	-	218	-
27	197	75	-	123	-	171	-	219	-
28	9	76	-	124	-	172	-	220	-
29	7	77	-	125	-	173	-	221	-
30	-	78	-	126	-	174	-	222	-
31	-	79	-	127	3	175	-	223	-
32	-	80	-	128	1	176	-	224	-
33	-	81	-	129	-	177	-	225	-
34	8	82	-	130	-	178	-	226	-
35	15	83	-	131	6	179	-	227	-
36	4	84	-	132	6	180	-	228	-
37	6	85	-	133	-	181	-	229	-
38	2	86	-	134	-	182	-	230	-
39	-	87	-	135	-	183	-	231	-
40	-	88	-	136	-	184	-	232	-
41	-	89	-	137	-	185	-	233	-
42	-	90	-	138	-	186	-	234	-
43	-	91	-	139	-	187	-	235	-
44	-	92	-	140	-	188	-	236	-
45	-	93	-	141	-	189	-	237	-
46	-	94	-	142	-	190	-	238	-
47	-	95	-	143	-	191	-	239	-
48	-	96	-	144	-	192	-	240	-

The coastal sections 26 and 27 possessed the most avalanche frequency, recording 192 and 197 avalanches respectively. These coastal sections are located in Súðavíkurhlíð, just north of the town of Súðavík. This frequency is considerably higher than the frequency recorded for other areas of the coast. Four other coastal sections (55, 56, 57 and 59) recorded notable avalanche activity, these coastal sections being situated in Óshlíð, the coastline between Hnífsdalur and Bolungarvík in the north-west of the study area.

The vast majority of coastal sections recorded no avalanches (213 coastal sections, 88.8% of the total). This could be influenced by the data available: the database available only recorded avalanches that had impacted major roads in the region. Considerable sections of the study area possessed no main roads so no records were available for these areas. However, by consulting with the Icelandic Meteorological Office, a general overview of the avalanche risk for these areas could be deduced. Four areas were highlighted that were known to have avalanche activity or were susceptible due to their topography and aspect. It was decided to incorporate this into the avalanche parameter to create a more complete picture of avalanche activity in the region. These four areas are outlined in Table 5.7 with a short description as to why they are deemed to be at risk of avalanches and their ranking.

Table 5.7Description of coastal sections at risk of avalanches after personal communication with JónKristinnHelgason and MagniHreinnHelgason at the Icelandic Meteorological Office, 22nd November 2011.

Coastal sections	Area	Description	Ranking
86-91	Göltur(Súgandafjörður)	Severe avalanches recorded in October 1995, to the extent that a tsunami 10m in height was created when an avalanche reached the water, damaging infrastructure in Suðureyri on the opposite side of the fjord (Helgason and Helgason, 2011). A combination of a large area of flat land found at the top of the fjord and an aspect susceptible to Northerly winds (the most frequent and strong winds in the winter time (Jónsson, 2003)) contributed to this.	4
104-107	Spiller (Súgandafjörður)	Notable rockfall has been known in the area	2
118-124	Sauðanes (Önundarfjörður)	Similar aspect to Göltur and the high number of gullies present allows large amounts of snow to build up.	3
201-203	Lambadalshlið (Dýrafjörður)	Avalanches have been recorded in this area. Despite the presence of a road, it is only a minor road so are not present in the records	3

5.7Estuary presence

Thirty-eight coastal sectionswere found to have an estuary present (15.8% of the total). These coastal sectionswere generally spread across the study area. One particular trend was evident: estuaries were located in the upper reaches of every fjord. Figure 5.19 presents examples of estuaries recorded.

Figure 5.19 Examples of estuaries found in the study area. From top-left, clockwise; coastal sections 136-139, coastal section 98 and coastal section 61(LoftMyndir)

6. Coastal Vulnerability Assessment

6.1 Coastal Vulnerability Index – Calculation

Table 6.1 presents the CVI scores calculated for all cells. The minimum CVI score a coastal section could attain was 6, the maximum being 28. Scores for this assessment ranged from 11-24, the average score calculated as 17.1. This value was close to the median value of 17 and the mode value of 17. The mid-range (between the 25% percentile and the 75% percentile) was 16-18.

Table 6.1 CVI scores for coastal sections 1-240

Coastal section	CVI	Coastal section	CVI	Coastal section	CVI	Coastal section	CVI	Coastal section	CVI
1	17	**49**	20	**97**	16	**145**	19	**193**	18
2	15	**50**	17	**98**	22	**146**	16	**194**	18
3	16	**51**	17	**99**	15	**147**	19	**195**	16
4	17	**52**	16	**100**	17	**148**	17	**196**	16
5	18	**53**	19	**101**	17	**149**	22	**197**	16
6	20	**54**	20	**102**	18	**150**	15	**198**	15
7	21	**55**	17	**103**	16	**151**	17	**199**	18
8	16	**56**	18	**104**	18	**152**	18	**200**	21
9	16	**57**	19	**105**	17	**153**	16	**201**	19
10	20	**58**	14	**106**	21	**154**	15	**202**	14
11	23	**59**	18	**107**	19	**155**	15	**203**	20
12	19	**60**	20	**108**	14	**156**	18	**204**	15
13	20	**61**	23	**109**	16	**157**	14	**205**	17
14	16	**62**	20	**110**	19	**158**	16	**206**	16
15	16	**63**	20	**111**	17	**159**	16	**207**	21
16	14	**64**	16	**112**	16	**160**	17	**208**	16
17	18	**65**	16	**113**	15	**161**	15	**209**	16
18	16	**66**	16	**114**	13	**162**	17	**210**	18
19	17	**67**	15	**115**	15	**163**	17	**211**	16
20	17	**68**	16	**116**	15	**164**	21	**212**	18
21	17	**69**	15	**117**	13	**165**	15	**213**	20
22	19	**70**	16	**118**	17	**166**	15	**214**	18
23	17	**71**	15	**119**	18	**167**	14	**215**	20
24	17	**72**	18	**120**	17	**168**	15	**216**	17
25	16	**73**	17	**121**	17	**169**	16	**217**	17
26	19	**74**	17	**122**	17	**170**	15	**218**	20
27	20	**75**	14	**123**	17	**171**	13	**219**	23
28	19	**76**	17	**124**	22	**172**	17	**220**	14
29	19	**77**	23	**125**	17	**173**	17	**221**	17
30	16	**78**	14	**126**	18	**174**	17	**222**	15

31	17	**79**	17	**127**	17	**175**	15	**223**	16
32	20	**80**	15	**128**	20	**176**	15	**224**	20
33	16	**81**	13	**129**	16	**177**	18	**225**	16
34	17	**82**	14	**130**	14	**178**	14	**226**	19
35	20	**83**	17	**131**	16	**179**	15	**227**	23
36	16	**84**	16	**132**	16	**180**	12	**228**	18
37	17	**85**	17	**133**	14	**181**	14	**229**	16
38	17	**86**	17	**134**	14	**182**	17	**230**	22
39	18	**87**	17	**135**	11	**183**	20	**231**	16
40	19	**88**	19	**136**	18	**184**	15	**232**	18
41	16	**89**	20	**137**	18	**185**	15	**233**	22
42	21	**90**	19	**138**	17	**186**	18	**234**	14
43	15	**91**	20	**139**	19	**187**	20	**235**	16
44	17	**92**	16	**140**	18	**188**	16	**236**	16
45	17	**93**	16	**141**	14	**189**	22	**237**	20
46	16	**94**	16	**142**	16	**190**	23	**238**	18
47	17	**95**	15	**143**	18	**191**	18	**239**	18
48	16	**96**	17	**144**	18	**192**	22	**240**	19

As outlined in Chapter 4, the following ranking system was used:

Very low = 6-12 *High = 19-22*

Low = 13-15 *Very High = 23-28*

Moderate = 16-18

Figure 6.1 presents the distribution of CVI scores recorded along with the vulnerability grades.

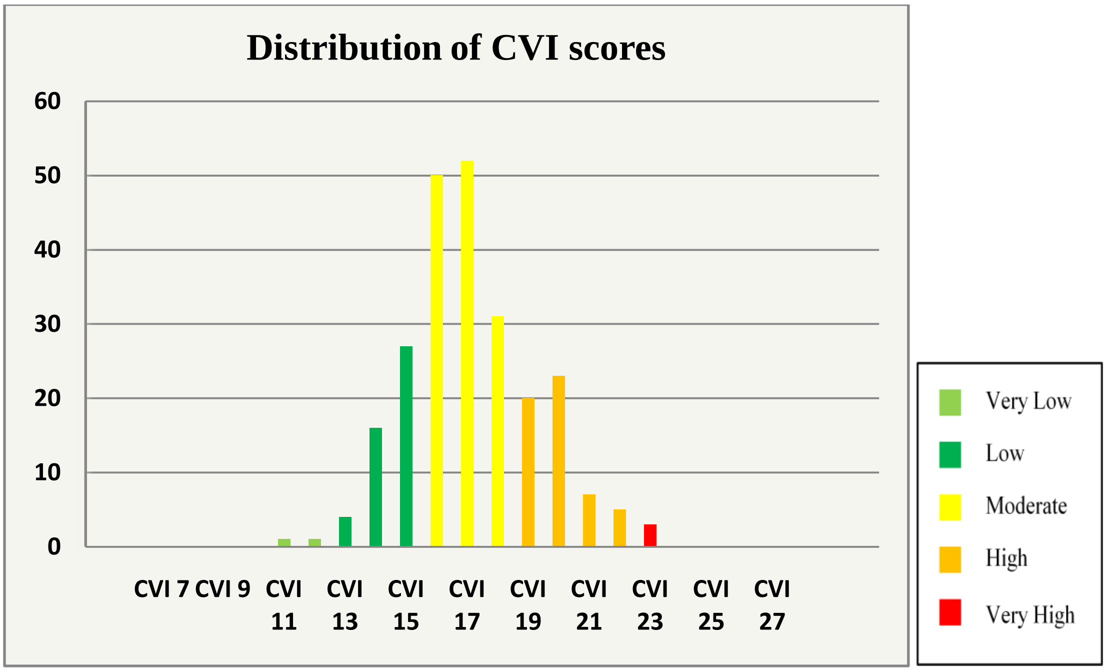


Figure 6.1 Distributiongraph of CVI scores

Figure 6.2 present a line graph presenting each coastal section's CVI score, from coastal section 1 starting in Kambsnes to coastal section 240 in Hafnardalur. As can be seen, there are no clusters of coastal sections that are 'very high' vulnerability, or 'very low' vulnerability. Clusters of four coastal sections where 'high/very high' vulnerability were situated in close proximity to one another were found in coastal sections 10-13, 26-29, 60-63 and 88-91. One interesting trend highlighted in Figure 6.2 is how the CVI scores can differ greatly between coastal sections in close proximity to one another. For example, the coastal section 149 scored 22 (high) with the two coastal sections adjacent scoring comparatively lower, 17 (moderate) and 15 (low).

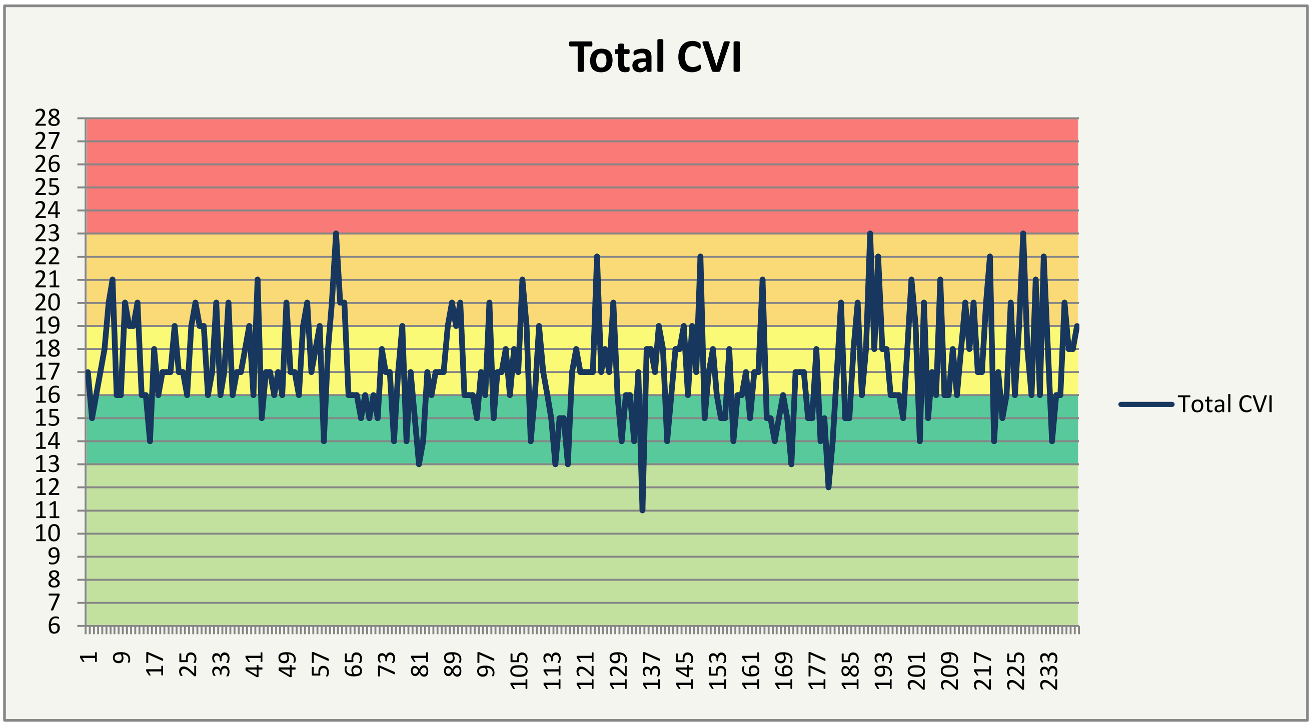
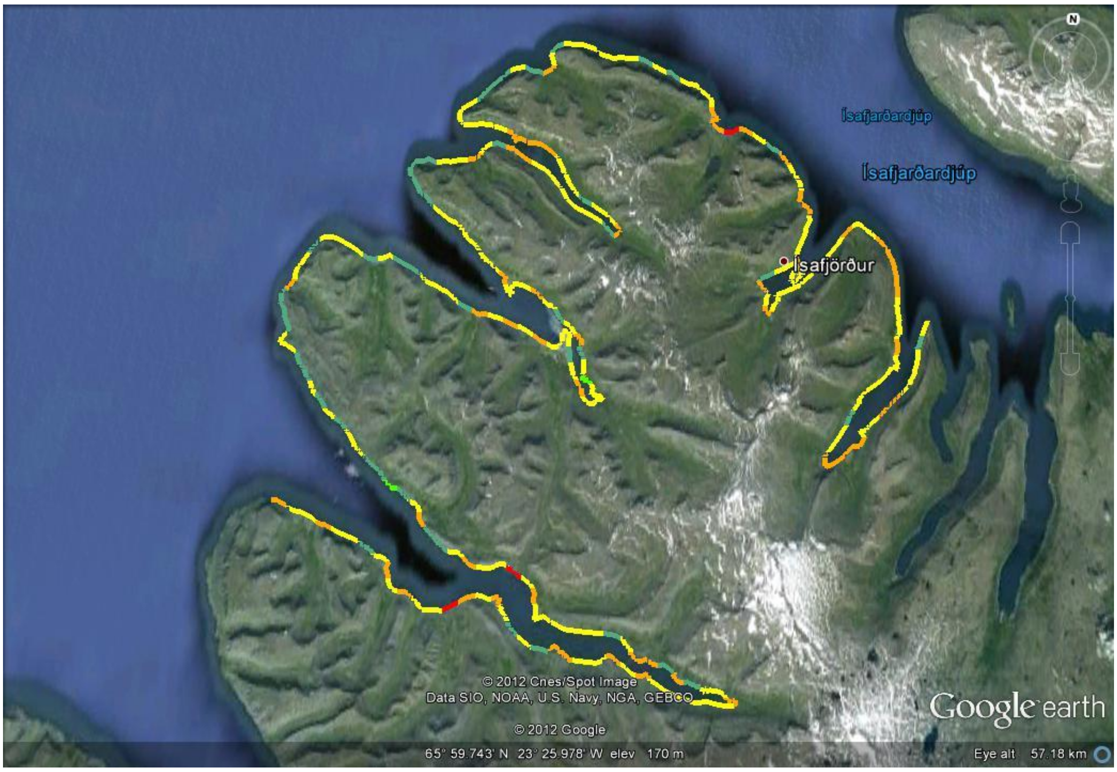


Figure 6.2 Line graph representing CVI scores for coastal sections 1-240

Figure 6.3 visually represents the CVI scores found along the coastline, colour-coding each 1km with its assigned vulnerability ranking. The few pockets of red emphasising how the areas deemed 'very high' were few andscattered across the study area.


Ísafjarðardjúp
Ísafjarðardjúp
Ísafjörður
© 2012 Cnes/Spot Image
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2012 Google
Google earth
65° 59.743' N 23° 25.978' W elev 170 m
Eye alt 57.18 km

(a)


Efri Engidalur
Súðavík
Seyðisfjörður
Kolbeinseyri
Dvergasteinn
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2012 DigitalGlobe
© 2012 Google
Google earth
Imagery Date: 6/13/2002
66° 0.637' N 23° 0.308' W elev 39 m
Eye alt 16.00 km

(b)

(c)


Ísafjarðardjúp
Hnífsdalur
Neðri Arnardalur
Ísafjörður
Efri Engidalur
Súðavík
Seyðisfj
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2012 DigitalGlobe
© 2012 Google
Google earth
Imagery Date: 6/13/2002
66° 4.337' N 23° 6.986' W elev 1 m
Eye alt 16.79 km

(d)


Bolungarvík
Suðureyri
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2012 DigitalGlobe
© 2012 Cnes/Spot Image
© 2012 Google
Google earth
Imagery Date: 6/13/2002
66° 7.903' N 23° 23.540' W elev 626 m
Eye alt 19.70 km

(e)

(f)

Very low	6 to 12	
Low	13 to 15	
Moderate	16 to 18	
High	19 to 22	
Very high	23 to 28	

Figure 6.3 Maps visually representing CVI scores found across study area. (a) Total study area, (b) Álftafjörður, (c) Skutulsfjörður, (d) Óshlíð, Bolungarvík, Skálavík and Súgandafjörður, (e) Önundarfjörður, (f) Dýrafjörður (Google Earth)

6.2 CVI analysis

6.2.1 'Very High' vulnerability

Three of the 240 coastal sections were categorised as 'very-high' vulnerability, each scoring 23. Table 6.2 presents the measurements recorded for these coastal sections to see if there are any similarities between them.

Table 6.2Physical parameter measurements and CVI rankings for coastal sections scoring 'very high' vulnerability

Coastal section	Beach Width (m)	Beach Width CVI	Distance to 20m Isobath (km)	Distance to 20m Isobath CVI	Coastal slope (%)	Coastal slope CVI	Distance of vegetation behind back beach (m)	Distance of vegetation behind back beach CVI	% rocky outcrop	% rocky outcrop CVI	Estuary presence	Avalanche frequency	Total CVI
61	63	3	1-2	3	2.5	4	83.3	4	<10	4	4	1	23
190	34.9	4	<1	4	7.4074	3	66.9	4	10 – 20	3	4	1	23
227	61.6	3	<1	4	1.02564	4	25.9	4	10 – 20	3	4	1	23

Firstly, it is evident that all these coastal sections have an estuary present. Similarly, every coastal section scored a maximum 4 for distance of vegetation behind back beach (<100m). For beach width, coastal slope and distance to the 20m isobath, the coastal section scores ranged from 3 – 4. Interestingly, all the coastal sections scored the lowest possible for avalanche frequency, emphasising that any vulnerability determined for these coastal sections is a result of conventional coastal vulnerability parameters and not from the unique avalanche parameter incorporated into this study. Indeed, if these coastal sectionswere to have scored highly for avalanche frequency, they would have been close to attaining the maximum CVI score of 28.

As only a few coastal sections recorded a 'very high' vulnerability, it is not possible to observe a geographical association between where they were located. However, two of the three coastal sections are located in Dýrafjörður. Figure 6.4 presentsorthophotgraph images of the coastal sections scoring ‘very high’.

Figure 6.4Orthophotograph images of ‘very high’ vulnerability coastal sections. From top left; coastal sections 61, 190 and 227(LoftMyndir)

6.2.2 Coastal sections scoring 22

Five coastal sections scored 22, the highest score possible in the 'high' vulnerability category. As this score was close to the 'very high' vulnerability, it was felt appropriate to analyse these coastal sections in a similar fashion to the 'very high' coastal sections. As Table 6.3 shows, four out of the five coastal sections have an estuary present. The coastal sectionnot possessing an estuary, coastal section 124, scored maximum for all parameters with the exception of % rocky outcrop and scored 3 for avalanche risk. With the exception of coastal slope 219, all coastal slopes were measured less than 4% and subsequently scored 4 for this parameter.

Table 6.3Physical parameter measurements for coastal sections scoring 22

Coastal section	Beach Width (m)	Beach Width (CVI)	Distance to 20m Isobaths (km)	Distance to 20m Isobaths (CVI)	Coastal slope	Coastal slope CVI	Distance of vegetation behind back beach (m)	Distance of vegetation behind back beach CVI	% rocky outcrop	% rocky outcrop CVI	Estuary	Avalanche frequency	Total CVI
124	24	4	<1	4	3.64	4	0	4	10 – 20	3	-	3	22
149	52.2	3	<1	4	0.90	4	342	2	<10	4	4	1	22
192	70.6	3	<1	4	2.76	4	100.2	3	10 – 20	3	4	1	22
219	94	3	<1	4	5.19	3	127	3	<10	4	4	1	22
232	55	4	<1	4	1.50	4	291.1	2	10 – 20	3	4	1	22

Of these five coastal sections, three were situated in Dýrafjörður, and two were situated in Önundarfjörður. This means that of the eight highest scoring coastal sections, five were situated in Dýrafjörður. Figure 6.5 presents orthophotograph imagesfor these coastal sections.

Figure 6.5Orthophotogaph images of coastal sections scoring '22'. From top left; 124, 149, 192, 219 and 232(LoftMyndir)

6.2.3 Clusters of higher vulnerability

Along the coastline there were four areas where a cluster of coastal sections (four in succession) scored high vulnerability. A closer inspection of the physical parameter measurements/vulnerability rankings for these areas provides an opportunity to see if it is similar parameters that are contributing to their high scores.

Coastal sections 10-13

Situated in the upper reaches of Álftafjörður, three-quarters of these coastal sections possessed an estuary presence. Coastal section 12 did not have an estuary present, although scored highly on all other parameters, with a low coastal slope (2.70%) and 0m vegetation recorded behind the back beach due to road being so close to the shoreline. There was a wide range of measurements recorded for beach width and distance vegetation behind back beach, as shown in Table 6.4. Ultimately, it is clear estuary presence is the prominent reason for these coastal sections scoring in the ‘high’ vulnerability category.

Table 6.4 Physical parameter measurements and vulnerability ranking: coastal sections 10-13

Coastal section	Beach Width (m)	Beach Width (CVI)	Distance to 20m Isobath (km)	Distance to 20m Isobath (CVI)	Coastal slope (%)	Coastal slope CVI	Distance of vegetation behind back beach (m)	Distance of vegetation behind back beach CVI	% rocky outcrop	% rocky outcrop CVI	Estuary	Avalanche frequency	Total CVI
10	449.8	1	<1	4	0.5	4	48	4	>50	1	4	2	20
11	34.6	4	<1	4	9.5	2	328	2	20 –50	2	4	1	19
12	11.5	4	<1	4	2.69542	4	0	4	20 –50	2	-	1	19
13	91.4	3	<1	4	6.21469	3	100.8	3	20 –50	2	4	1	20

Figure 6.6Orthophotographimage of coastal sections 10-13(LoftMyndir)

Coastal sections 26-29

This stretch of coastline is situated towards the mouth of Álftafjörður a few kilometres north of Súðavík. Interestingly, the cluster scores highly for a few parameters (beach width, distance vegetation behind back beach, and distance to 20m isobaths) but for other parameters it scores a low vulnerability (coastal slope and no estuary presence). This is markedly different to the results for coastal sections 10-13, whichare situated only 13km away in the same fjord. Two coastal sections scored the highest ranking for avalanche frequency, 26 and 27. This particular area is very prone to avalanches, recording 192 and 197 avalanches impacting the road from 1996 until present day. The road is very close to shoreline in these coastal sections and explains the low distance of vegetation behind back beach scores. However, unlike coastal sections 10-13, the road is much more elevated, explaining the high coastal slope percentages recorded.

Table 6.5 Physical parameter measurements and vulnerability ranking: coastal sections 26-29

Coastal section	Beach Width (m)	Beach Width (CVI)	Distance to 20m Isobath (km)	Distance to 20m Isobath (CVI)	Coastal slope (%)	Coastal slope CVI	Distance of vegetation behind back beach (m)	Distance of vegetation behind back beach CVI	% rocky outcrop	% rocky outcrop CVI	Estuary	Avalanche frequency	Total CVI
26	19.7	4	<1	4	35.3982	1	0	4	20 –50	2	-	4	19
27	21.5	4	<1	4	49.5186	1	0	4	10 – 20	3	-	4	20
28	24.4	4	<1	4	30.0971	1	0	4	<10	4	-	2	19
29	10.3	4	<1	4	32.3529	1	14	4	<10	4	-	2	19

Figure 6.7 Orthophotographimageof coastal sections26-29 (LoftMyndir)

Coastal sections 60-63

This stretch of coastline includes the town of Bolungarvík. Beach widths were fairly small, with all coastal sections recording a score of <50m except for coastal section 61 that recorded 63m. Coastal slope was low with the notable exception of coastal section 63, where it was considerably high (56%). This was due to the transect measurement taking place at the far north-west of the town where the steep fjord wall of Stigahlíð begins. Estuaries were present for two of the coastal sections (61 and 63) and a reasonably high ranking for avalanche frequency recorded for coastal section 60 (where 22 avalanches have been recorded impacting the road since 1996 until present day). Measurements for the distance of vegetation behind back beach parameter were low, in part to the relatively high amounts of urban infrastructure present due to the town of Bolungarvík. Generally though, there was no unifying reason why all these coastal sections ranked as 'high' vulnerability, it was the result of various different parameters within each coastal section.

Table 6.6 Physical parameter measurements and vulnerability ranking: coastal sections 60-63

Coastal section	Beach Width (m)	Beach Width (CVI)	Distance to 20m Isobath (km)	Distance to 20m Isobath (CVI)	Coastal slope (%)	Coastal slope CVI	Distance of vegetation behind back beach (m)	Distance of vegetation behind back beach CVI	% rocky outcrop	% rocky outcrop CVI	Estuary	Avalanche frequency	Total CVI
60	31.5	4	<1	4	2.44499	4	38.5	4	>50	1	-	3	20
61	63	3	1-2	3	2.5	4	83.3	4	<10	4	4	1	23
62	24.2	4	1-2	3	3.66972	4	9.3	4	<10	4	-	1	20
63	15	4	<1	4	56.5	1	0	4	20 –50	2	4	1	20

Figure 6.8 Orthophotographimage of coastal sections 60-63(LoftMyndir)

Coastal section 88-91

For this area, beach width measurements were generally low as were the distance vegetation behind back beach measurements, with a few notable exceptions. Apart from coastal section 88 which recorded a very low coastal slope, the coastal slopes recorded were high, perhaps helping to explain the low vegetation measurements (the steep fjord walls offering a less optimum environment for soil/vegetation to build up). Clearly, it is the high avalanche frequency scores that are the reason why these coastal sections scored so highly. This ranking of 4 was allocated in consultation with the Icelandic Meteorological Office due to the topography of the coastline (its considerable flat-top topography allows for large amounts of snow to build up, coupled with an aspect that makes it vulnerable to the strong northerly winds) contributed to a high avalanche frequency.

Table 6.7Physical parameter measurements and vulnerability ranking: coastal section 88-91

Coastal section	Beach Width (m)	Beach Width (CVI)	Distan-ce to 20m Isobath (km)	Distance to 20m Isobath (CVI)	Coastal slope (%)	Coastal slope CVI	Distance of vegetation behind back beach (m)	Distance of vegetation behind back beach CVI	% rocky outcrop	% rocky outcrop CVI	Estuary	Avalanche frequency	Total CVI
88	52.9	3	1-2	3	3.8	4	102.6	3	20 –50	2	-	4	19

89	27.6	4	1-2	3	22	1	83.3	4	<10	4	-	4	20
90	30.1	4	<1	4	49.5	1	14.7	4	20 –50	2	-	4	19
91	49.4	4	<1	4	38	1	11.7	4	10 – 20	3	-	4	20

Figure 6.9Orthophotographimageof coastal sections 88-91 (located on the northern coastline of the fjord) (LoftMyndir)

6.3 Socio-economic assessment

In this section, the extent in which socio-economic features are present in the ‘cells’ of higher-scoring coastal sections will be assessed. The coastal sections chosen for further analysis all scored 21-23. The key features that will be observed are shown in Table 6.8.

Table 6.8Potential socio-economic features to located within cells of coastal sections

Residency and Recreational	Strategic / Transport Infrastructure	Industrial and Commercial	Waste disposal	Agricultural	Aquaculture and Fishing	Conservation
Housing areas/ built urban areas Isolated housing/buildings Boat launch sites	Major roads Minor roads Harbours Airstrip Lighthouses	Supermarkets Factories, e.g. fish-processing plants Power stations	Waste-water treatment plants Sewage-treatment plants	Farm houses Arable land	Fishing hot-spots Aquaculture sites	Designated nature reserves

6.3.1 'Very high' vulnerability

Table 6.9Socio-economic features located in 'very high' vulnerability coastal sections

Coastal section	Residency and Recreational	Strategic / Transport Infrastructure	Industrial and Commercial	Waste disposal	Agricultural	Aquaculture and Fishing	Conservation
61	-	-	-	-	-	-	-
190	Isolated housing Boat launch site	Major road (~ 100m from shoreline)	-	-	Small farm / arable land	-	-
227	-	-	-	-	Small farms / arable land	-	-

Coastal section 61, situated in close proximity to the town of Bolungarvík, contained a lighthouse located close to the back beach line (Figure 6.10 (a)). A minor road (categorised as minor due to its closure since 2010 (see Chapter 3)) is situated approximately 110m back from the shoreline (Figure 6.10 (b)). No other socio-economic features are present within the 200m inward boundary of the cell. The major road, Djúpvegur (the only on-land transport route into the town of Bolungarvík) was situated approximately 500m from the inland boundary of the cell (Figure 6.10 (c)). The town of Bolungarvík is approximately 1km away from this cell.

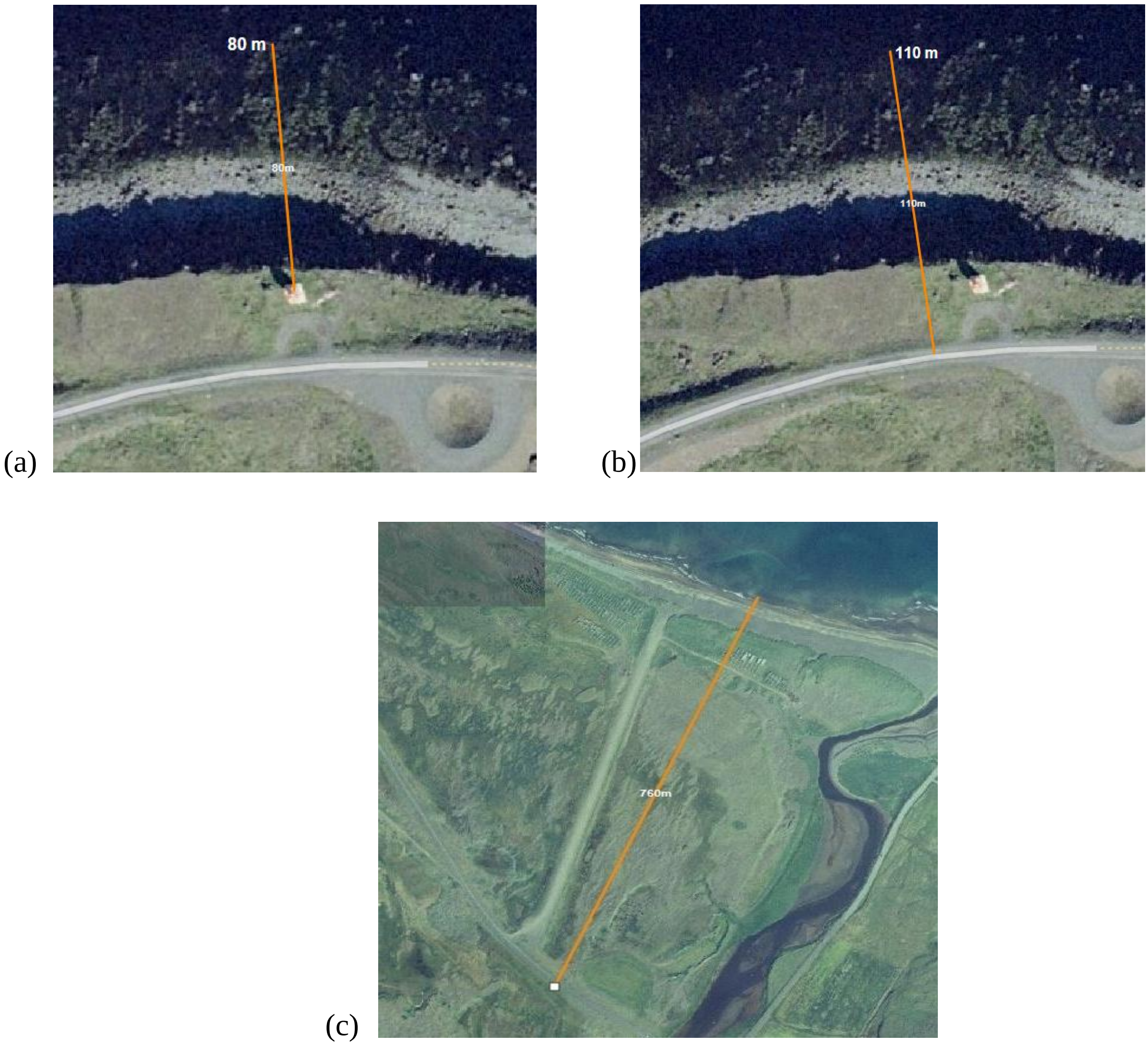


Figure 6.10Orthophotograph images of socio-economic features present in coastal section 61 (a) lighthouse, (b) minor road, (c) Djúpvegur (LoftMyndir)

Coastal section 190, situated in Dýrafjörður, contained important road infrastructure within 100m of the shoreline (Vestfjarðarvegur is the only direct road to the fjord from the towns of Flateyri, Suðureyri and Ísafjörður) (Figure 6.10 (a)).Seaward of the shoreline, a pier 71m in length is located adjacent a small building. This is most likely a boat launch site (Figure 6.19 (b)). 100m behind the inland boundary of the cell,a collection of buildings,most likely a small farm, is located.

(a) 

(b) 

Figure 6.11Orthophotograph images of socio-economic features present in coastal section 190. (a) Vestfjarðarvegur, (b) boat launch site (LoftMyndir)

Coastal section 227 is situated on the southern side of Dýrafjörður. No socio-economic features were found within the cell.However, Þingeyri airstrip was located in approximately 550minland at the most western point of the coastal section (Figure 6.12).

Figure 6.12 Orthophotograph images of the Þingeyri airstrip, ~550m inland from the shoreline at the western edge of coastal section 227 (LoftMyndir)

6.3.2 Coastal sections scoring '21-22'

Table 6.10Socio-economic features located in coastal sections scoring 21-22

Coastal section(21)	Residency and Recreational	Strategic / Transport Infrastructure	Industrial and Commercial	Waste disposal	Agricultural	Aquaculture and Fishing	Conservation
7	-	Major road (~80m from shoreline at nearest point)	-	-	-	-	-
42	Built urban area (~100m from shoreline) Isolated housing (~10m from shoreline)	Major road (~10m from shoreline at nearest point)	Supermarket (~80m from shoreline)	-	-	-	-
106	-	Major road (<10m from shoreline at nearest point) Road raised from the water	-	-	-	-	-
164	-	-	-	-	-	-	-
200	-	Minor road (~50m from shoreline at nearest point)	-	-	-	-	-
207	-	Minor road (~50m from shoreline at nearest point)	-	-	-	-	-
230	-	Minor road (~200m from shoreline at nearest point)	-	-	-	-	-

Coastal section (22)	Residency and Recreational	Strategic / Transport Infrastructure	Industrial and Commercial	Waste disposal	Agricultural	Aquaculture and Fishing	Conservation
124	Built urban area (~10m from shoreline) Isolated housing (~60m from shoreline)	Minor road (~10m from shoreline at nearest point)	-	-	-	-	-
149	Isolated housing (~150m from shoreline)	Minor road (~60m from shoreline at nearest point)	-	-	Small farms / arable land (~200m from shoreline)	-	
192	-	Major road (~50m from shoreline at nearest point)	-	-	-	-	-
219	Isolated housing (~50m from shoreline)	Major road (~50m from shoreline at nearest point)	-	-	Small farms / arable land (~100m from shoreline)	-	-
232	-	Minor road (~100m from shoreline at nearest point)	-	-	-	-	-

Coastal sections scoring 21-22 possessed no waste disposal, aquaculture and fishing and conservation features. Only one coastal section (42) had what could be described as commercial property: a supermarket on the outskirts of Ísafjörður. With the exception ofcoastal section 230, all coastal sectionspossessed road infrastructure within ~100m of the shoreline. The nearest major roads were found in coastal sections 42 and 124:coastal sections located inÍsafjörður and Flateyri respectively. Five of the twelve coastal sectionspossessed major roads, the remaining seven possessing minor roads. Small farms and presence of arable land was found in coastal sections 149, 192 and 219. The small farm and the surrounding arable land in coastal section 219 was notably close to the back beach and shoreline. Generally, few socio-economic features were present in coastal sections deemed higher vulnerability. Given the sparse population of the Westfjords, it perhaps not surprising few socio-economic features other than road infrastructure and the occasional isolated building and farm/arable land were located.

6.4 Coastal defence assessment

Having identified the areas of higher vulnerability, the type and extent of any coastal defence present wasbriefly assessed. Practical limitations meant site visits could not be undertaken to measure the exact crest elevation and average stone size. However, the organisation responsible for coastal defence in the Westfjords (the Icelandic Road Administration) explained how only one approach was taken regarding coastal defence management: rock armour seawalls. The crest elevation and average stone size of these rock armour seawalls were homogenous throughout the region: consisting of quarried rock ranging from 50-150cm in diameter and a crest elevation approximately 3-4m in height[2]. In Table 6.11, the highest scoring coastal sections (22-23) were assessed for coastal defence presence.

Table 6.11 Coastal defence assessment for coastal sections scoring 22-23

Coastal sections scoring 22-23	Coastal defence present	Type	Extent	Infrastructure
61	No	-	-	Lighthouse
190	No	-	-	Isolated housing Boat launch site Major road (~ 100m from shoreline) Small farm / arable land
227	Yes	Rock armour seawall	Minimal	-
124	Yes	Rock armour seawall	Extensive	Built urban area (~10m from shoreline) Isolated housing (~60m from shoreline) Minor road (~10m from shoreline at nearest point)
149	No	-	-	Isolated housing (~150m from shoreline) Minor road (~60m from shoreline at nearest point) Small farms / arable land (~200m from shoreline)
192	Yes	Rock armour seawall	Minimal	Major road (~50m from shoreline at nearest point)
219	No	-	-	Isolated housing (~50m from shoreline) Major road (~50m from shoreline at nearest point) Small farms / arable land (~100m from shoreline)
232	No	-	-	Minor road (~100m from shoreline at nearest point)

Of the eight highest scoring coastal sections, three were found to have coastal defence infrastructure in the form of rock armour sea wall. One of these coastal sections (124) had extensive rock armour present, whilst the other two (192 and 227) the presence of coastal defence was notably less. It is perhaps not surprising that more rock armour is present in coastal section 124 given the close proximity of the town Flateyri to the shoreline. When comparing the infrastructure along coastal sections with rock armour against those without,

[2]Personal communication with GeirSigurðsson at the Icelandic Road Administration, November / December 2011

it is assumed coastal sections with coastal defence would possess more important infrastructure or have a major road in closer proximity to the shoreline. It is certainly the case for coastal sections 124 and 192 there is important infrastructure located (the town of Flateyri (124), a major road approximately 50m from shoreline (192) and an airstrip (227)). However, it is surprising thenfor coastal sections 190 and 219 not to possess similar levels of rock armour defence given a major road is located within 50-100m of the shoreline. Furthermore, despite small farm / arable land being located in cells 149, 190 and 219, rock armour defence has not been considered necessary as a coastal management option for these sections.

In Table 6.12, the clusters of high vulnerability cells were assessed for coastal defence presence.

Table 6.12 Coastal defence assessment for clusters of high vulnerability coastal sections

Clusters of high vulnerability coastal sections	Coastal defence present	Type	Extent	Infrastructure
10-13	Yes	Rock armour seawall	Extensive	Major road (~50m from shoreline at nearest point)
26-29	Yes	Rock armour seawall	Extensive	Major road (~50m from shoreline at nearest point)
60-63	Yes	Rock armour seawall	Extensive	Built urban area (~10m from shoreline) Isolated housing (~60m from shoreline)
88-91	No	-	-	-

Three out of four of these clusters have rock armour defence present;perhaps unsurprising given the infrastructure that is in close proximity to the shoreline and at particular risk from SLR and extreme weather events. For coastal sections 10-13 and coastal sections 26-29, (both situated in Álftafjörður), the main road to the municipal capital of the region (Ísafjörður) is located approximately 50m from the shoreline and it is therefore critical that there is adequate coastal defence. Similarly, built urban infrastructure is present in coastal sections 60-63 (Bolungarvík). There is no infrastructure present in coastal sections 88-91 and subsequently there is no coastal defence located in this cluster. Of particular interest are coastal sections 10-13 and 26-29, situated in the upper reaches and mouth of Álftafjörður respectively. These stretches of coastline have suffered notable damage in recent decades[3]. The road within cells 10-13 had to be rebuilt due to damage from coastal processes. Coastal sections 26-29 are particularly vulnerable for two reasons. Firstly, its location towards the mouth of the fjord means it is more exposed to the higher energy environment of the open ocean. Secondly, its aspect faces the north-easterly winds, the most frequently strong winds in the region, and is therefore susceptible to high energy waves impacting its shoreline.

[3]Personal communication with GeirSigurðsson at the Icelandic Road Administration, November / December 2011

7. Conclusion

The purpose of this preliminary assessment was to apply a CVI to the Westfjords, Iceland: a region particularly 'coastal' due to vast majority of settlement and infrastructure being located in the narrow space between steep fjordicwalls and the coastline. Palmer et al.'s (2011) CVI method was used as it included the use of physical parameters that are well-documented as offering indication of coastal vulnerability. Furthermore, these parameters could be measured using the limited available data. Upon applying this CVI method to the northernWestfjords, the majority of coastal sections scored similarly: in a possible range of 6-28, 66% of coastal sections scored between 15-18.For the vast number of cells, the parameters for beach width, distance to 20m isobath, and % rocky outcrop were fairly similarMore disparity existed for coastal slope measurements: it was not uncommon to see a sudden contrast between sections of coastline with a low-lying relief in close proximity to those of a very steep relief, indicating topographical contrast along the coastline. As outlined in Chapter 6, often the only common theme found in the highest scoring coastal cells was an estuary presence. Palmer et al(2011) assigned a ranking of 4 (the highest score any parameter could receive) for any estuary presence was 'due to their sensitive and dynamic nature and increased risk' from seal level rise, erosion and extreme weather events (Palmer et al., 2011, p1393). For this reason, it is understandable that a weighting should be placed on areas where they are present. However, as a single weighting of 4 is used for estuary presence, the methodology does not differentiate between smaller and larger estuaries. Therefore, a range (1-4) could be introduced to discriminate coastal sections based on estuary size and energy.

There was no geographical association between highest scoring coastalareas and these werefoundscattered across the Westfjords. Similarly, there does not appear to be any association between outer and inner fjord coastlines.Nevertheless, clusters of high vulnerability areas were identified. With the exception of one of these clusters (coastal sections 60-63 located near Bolungarvík) these stretches of coastline scored highly due to possessing similar physical attributes (e.g. short beach width, low coastal slope, high avalanche frequencyetc). By highlighting these vulnerable areas, analysing what parameters are responsible for their high scores and determining what infrastructure is present within this area, a CVI of this nature has the potential to facilitate coastal management. For example, coastal sections 26-29 (situated in Súðavíkurhlíð) scored relatively highly, but on closer inspection it is due more to the high avalanche risk assigned to the area than from the traditional parameters used to assess coastal vulnerability. The major road in the region, Djúpvegur, is located in this cluster. With this in mind, it could be argued that more effort should be put into avalanche protection than coastal defence. However, the road's close proximity to the coast (~50m from coastline), the low levels of vegetation behind the back beach, the short distance to the 20m isobath and short beach width indicate a vulnerability to coastal processes, especially in the event of RSLR and more extreme weather events. In this fashion, this CVI method allows for a general overview of where the potential problem areas may lie and then for more in-depth inquiry: (e.g. is infrastructure important enough to warrant the economic expense of protection? Would retreat or stabilisation be the most appropriate action?etc).

Transport infrastructure was present in all but one of the high-scoring coastal sections,a combination of minor, less-commonly used roads and major, more often-used roads. In a sparsely-populated region like the Westfjords, the diversity of infrastructure located was expected to be fairly low and this proved to be the case. Furthermore, that rock armour was the coastal defence option of choice was similarly unsurprising given the predominance of this form of coastal defence in Iceland (see Chapter 3). One notable observation when assessing coastal defence in the higher vulnerability areas was how rock armour defence was prevalent near the region's towns and, for a large part, the major roads but was not present in some coastal sectionsdespite the presence of socio-economic components. Coastal section 219 is an exemplar of this, with a building located extremely close to the back beach (see Figure 6.5). This building is clearly in a vulnerable position but it raises the debate discussed by Cooper and McKenna (2008) about coastal erosion and 'social justice' and whether efforts should be made to maintain its position or should it ultimately succumb to coastal processes such as erosion and inundation.

As outlined in Chapter 2, efforts have been made to synthesise the CVI process globally but with little success, mainly due to variation in methodologies, scenarios and assumptions made by researchers. This lack of success is understandable given the diversity of coastlines worldwide. Whilst CVI methodologies tend to follow the conceptual framework based on Gornitz's original formula, expecting a universal method that caters for all coastlines is unlikely and something this study highlights. Dune width is a well-documented parameter in assessing coastal vulnerability but a completely inappropriate parameter in a Westfjords context. Similarly, avalanche risk is parameter of considerable merit in this study but unnecessary in a South African context. This is not to suggest that attempts to unify CVI methodologies are not a worthwhile endeavour: suchattemptsat synthesis provide benefits by offering the opportunity for global comparison. However, there should be an acceptance that different coastal environments may require a different approach.

For some parameters, assigning a score proved problematic. For example, for beach width to score 3 or 4, measurements of 50-100m and <50mwere required. As previously mentioned, many of the measurements lay close to the 50m mark. The consequence being only a minor difference in width could alter the CVI score by 1. Such a methodological flaw is worthy of note. An additional problem involved using the criteria for parameter ranking (borrowed predominantly from Palmer et al.'s study). For example, the ranking for 'distance from the 20m isobath'meant most of the scores were predominantly high (80% of cell measurements scoring 4). Whilst the criteria for this parameter's ranking was the result of specialist consultation, it could be argued that an adapted ranking criteria that acknowledges the bathymetry of the Westfjords context would have allowed for better comparison along the coastline. As mentioned in Chapter 2, there will always be issues with the semi-qualitative nature of CVIs.High scores for parameters may indicate 'higher vulnerability' to erosion, inundation and extreme weather events, but it must be remembered that CVI methods are in essence semi-qualitative processes, where decisions on what constitutes high, moderate and low is made by the researcher (Abuodha and Woodroffe, 2006). However, whilst caution should be used when assigning subjective labels such 'high' and 'low' vulnerability regarding comparisons with other worldwide coastlines, the method does allow for 'relative' coastal vulnerability to be measured along a specific coastline and is therefore a useful tool in this respect.

As aforementioned, CVI studies are often limited by data availability and quality. This preliminary assessment is no exception. Indeed, for a remote, understudied region like the Westfjords, data availability will always be an issue. The study's limitations are numerous: low spatial resolution orthophotographs, crude precision of digital elevation models, transect measurements being representative for 1km stretches of coastline, difficulty in measuring parameters such as rocky outcrop and the need for qualitative consultation with experts to fill in data gaps. For this reason, findings from this study cannot provide more than a generalisation of coastal vulnerability to coastal process such as erosion and inundation. As such, findings of this study are limited and to be viewed with considerable caution. However, despite these limitations this study can act as a foundation for further work, incorporating ideas used elsewhere and modifying them to suit the Westfjords. Indeed, beyond obvious improvements such as using higher resolution orthophotographs, having shorter distances between transect measurements and using more detailed bathymetry and avalanche data, there is great potential to expand the scope of the methodology. One facet this CVI methodology does not cover is what McLaughlin and Cooper (2011) describe as 'coastal forcing' parameters. Such parameters include significant wave-height, tidal range, storm frequency and difference in storm and modal wave height. By incorporating these parameters into the methodology, it would offer further insight into areas that are particularly at risk not just due to their coastal characteristics but also the forces that act upon them. Furthermore, parameters could be adjusted to better account for the fjordic environment. For example, it could account for areas of coastline well within the fjord which are less exposed to a high energy wave environment of the open ocean compared with areas towards the fjord mouth.

Whilst the CVI method used here was designed to be a quick and cost-effective means of measuring coastal vulnerability which kept the number of measured parameters to a minimum, there are benefits in incorporating as many measurable parameters as possible. Ideally a coastal vulnerability database utilising GIS software could be created and this would be an ideal tool for those involved in the region's coastal management. With a database established, information could be added incrementally as and when it becomes available therefore making the tool both dynamic and continually pertinent. Ultimately, there remains a vast potential for the application of CVI methods to the Westfjords. As a tool, it can be easily integrated into an overall coastal management strategy, facilitating effective management of a uniquely 'coastal' part of the world.

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Appendix A

Transects measurements across the study area(Google Earth)

Transects1-57

Transects 58-123

Transects124-189

Transects 190-240

Appendix B

Physical parameter measurements and vulnerability rankings for coastal sections 1-240

Coastal section	Beach Width (m)	Distance to 20m Isobath (km)	Coastal slope(%)	Distance of vegetation behind back beach (m)	% rocky outcrop	CVI score BW	CVI score IB	CVI score CS	CVI score VBB	CVI score PRO	Estuary	Avalanche risk	Total CVI without Estuary presence	Total CVI	Vulnerability ranking	Elevation	Distance of nearest infrastructure
1	42.1	<1	6.566	289.6	10 – 20	4	4	3	2	3		1	17	17	17	13	198
2	20.1	<1	11	102.1	>50	4	4	2	3	1		1	15	15	15	22	200
3	32.2	<1	19.53	71.2	20 –50	4	4	1	4	2		1	16	16	16	25	128
4	24	<1	22.52	88.6	10 – 20	4	4	1	4	3		1	17	17	17	34	151
5	37.2	<1	9.409	32	10 – 20	4	4	2	4	3		1	18	18	18	7	74.4
6	36.9	<1	2.625	31	20 –50	4	4	4	4	2		2	20	20	20	2	76.2
7	38.9	<1	1.157	34	20 –50	4	4	4	4	2		3	21	21	21	1	86.4
8	51.4	<1	9.357	100.4	20 –50	3	4	2	3	2		2	16	16	16	16	171
9	36.3	<1	11.4	43	20 –50	3	4	2	4	2		1	16	16	16	13	114
10	449.8	<1	0.5	48	>50	1	4	4	4	1	4	2	16	20	20	1	200
11	34.6	<1	9.5	328	20 –50	4	4	2	2	2	4	1	15	19	19	19	200
12	11.5	<1	2.695	0	20 –50	4	4	4	4	2		1	19	19	19	1	37.1
13	91.4	<1	6.215	100.8	20 –50	3	4	3	3	2	4	1	16	20	20	11	177
14	37.4	<1	12	183.1	20 –50	4	4	2	3	2		1	16	16	16	24	200
15	43.4	<1	12.5	90.5	20 –50	4	4	1	4	2		1	16	16	16	25	200
16	88.5	<1	22.02	10	>50	3	4	1	4	1		1	14	14	14	24	109
17	62.4	<1	16.9	74.1	>50	3	4	1	4	1	4	1	14	18	18	24	142
18	15.7	<1	15.65	45.4	20 –50	4	4	1	4	2		1	16	16	16	18	115
19	30.2	<1	9.91	59.7	20 –50	4	4	2	4	2		1	17	17	17	11	111
20	20.1	<1	4.95	0	>50	4	4	3	4	1		1	17	17	17	1	20.2
21	42.7	<1	10.42	22.3	20 –50	4	4	2	4	2		1	17	17	17	9	86.4
22	16.6	<1	20.27	4.4	>50	4	4	1	4	1	4	1	15	19	19	6	29.6
23	35	<1	9.009	0	20 –50	4	4	2	4	2		1	17	17	17	4	44.4
24	18.7	<1	34.33	12	20 –50	4	4	1	4	2		2	17	17	17	16	46.6
25	20.6	<1	38.4	18.7	20 –50	4	4	1	4	2		1	16	16	16	26	67.7
26	19.7	<1	35.4	0	20 –50	4	4	1	4	2		4	19	19	19	20	56.5
27	21.5	<1	49.52	0	10 – 20	4	4	1	4	3		4	20	20	20	36	72.7
28	24.4	<1	30.1	0	<10	4	4	1	4	4		2	19	19	19	31	103
29	10.3	<1	32.35	14	<10	4	4	1	4	4		2	19	19	19	33	102
30	68.5	1-2	40	0	<10	3	3	1	4	4		1	16	16	16	28	70
31	70	1-2	4.854	18	10 – 20	3	3	3	4	3		1	17	17	17	5	103
32	52.5	1-2	10.78	0	10 – 20	3	3	2	4	3	4	1	16	20	20	18	167
33	32.2	<1	20.57	11.7	20 –50	4	4	1	4	2		1	16	16	16	29	141
34	32.2	<1	15.79	11.7	20 –50	4	4	1	4	2		2	17	17	17	18	114
35	29.9	1-2	3.279	0	20 –50	4	3	4	4	2		3	20	20	20	2	61
36	20	2-4	6.16	17.2	>50	4	2	3	4	1		2	16	16	16	3	48.7
37	0	2-4	####	0	>50	4	2	4	4	1		2	17	17	17	n/a	n/a
38	0	2-4	####	0	>50	4	2	4	4	1		2	17	17	17	n/a	n/a
39	22.7	>4	1.698	26.7	<10	4	1	4	4	4		1	18	18	18	1	58.9
40	6.9	>4	16.39	0	<10	4	1	1	4	4	4	1	15	19	19	2	12.2
41	23.2	2-4	4.545	101.4	10 – 20	4	2	3	3	3		1	16	16	16	7	154
42	20.1	2-4	9.434	0	<10	4	2	2	4	4	4	1	17	21	21	3	31.8
43	7.9	2-4	9.174	0	20-50	4	2	2	4	2		1	15	15	15	1	10.9
44	21.2	1-2	5.155	0	20-50	4	3	3	4	2		1	17	17	17	1	19.4
45	0	1-2	####	0	>50	4	3	4	4	1		1	17	17	17	n/a	n/a
46	6.2	2-4	0.862	0	>50	4	2	4	4	1		1	16	16	16	1	116
47	0	1-2	0	0	>50	4	3	4	4	1		1	17	17	17	1	37.1
48	11.5	1-2	4.975	7.1	>50	4	3	3	4	1		1	16	16	16	1	20.1
49	22.9	<1	4.219	16.1	<10	4	4	3	4	4		1	20	20	20	2	47.4
50	21.3	<1	35.56	0	10 – 20	4	4	1	4	3		1	17	17	17	16	45

51	36.5	<1	36.17	0	20 –50	4	4	1	4	2		2	17	17	17	17	47
52	13.4	1-2	22.28	41.3	>50	4	3	1	4	1		3	16	16	16	16	71.8
53	17.9	1-2	5.831	0	10-20	4	3	3	4	3		2	19	19	19	2	34.3
54	29.9	<1	15.59	19	>50	4	4	1	4	1	4	2	16	20	20	8	51.3
55	52.5	<1	46.64	0	20 –50	3	4	1	4	2		3	17	17	17	34	72.9
56	23.2	<1	49.79	0	20 –50	4	4	1	4	2		3	18	18	18	36	72.3
57	43	<1	51.28	0	20 –50	4	4	1	4	2		4	19	19	19	28	54.6
58	65	<1	18.56	0	>50	3	4	1	4	1		1	14	14	14	9	48.5
59	34.7	<1	14.34	0	20 –50	4	4	1	4	2		3	18	18	18	8	55.8
60	31.5	<1	2.445	38.5	>50	4	4	4	4	1		3	20	20	20	2	81.8
61	63	1-2	2.5	83.3	<10	3	3	4	4	4	4	1	19	23	23	5	200
62	24.2	1-2	3.67	9.3	<10	4	3	4	4	4		1	20	20	20	2	54.5
63	15	<1	56.5	0	20 –50	4	4	1	4	2	4	1	16	20	20	113	200
64	29.9	<1	36.07	0	20 –50	4	4	1	4	2		1	16	16	16	42.2	117
65	43.2	<1	34.55	0	20 –50	4	4	1	4	2		1	16	16	16	38	110
66	37.9	<1	46.5	0	20 –50	4	4	1	4	2		1	16	16	16	93	200
67	55.6	<1	49	0	20 –50	3	4	1	4	2		1	15	15	15	98	200
68	49.6	<1	72	0	20-50	4	4	1	4	2		1	16	16	16	144	200
69	59.2	<1	31.5	0	20 –50	3	4	1	4	2		1	15	15	15	63	200
70	48.3	<1	35	0	20 –50	4	4	1	4	2		1	16	16	16	70	200
71	66	<1	33.5	0	20 –50	3	4	1	4	2		1	15	15	15	67	200
72	46.7	<1	12	0	10 – 20	4	4	2	4	3		1	18	18	18	24	200
73	49.4	<1	20.5	0	10 – 20	4	4	1	4	3		1	17	17	17	41	200
74	47.7	<1	61.5	0	10 – 20	4	4	1	4	3		1	17	17	17	123	200
75	74.6	1-2	30	0	20 –50	3	3	1	4	2		1	14	14	14	60	200
76	72.1	1-2	10.7	23.1	<10	3	3	2	4	4		1	17	17	17	10	93.5
77	61.8	<1	15	343	<10	3	4	1	2	4	4	1	15	19	19	30	200
78	143.6	<1	27.5	0	20 –50	2	4	1	4	2		1	14	14	14	55	200
79	38.3	<1	54.5	0	10 – 20	4	4	1	4	3		1	17	17	17	109	200
80	81.6	<1	65.5	0	20 –50	3	4	1	4	2		1	15	15	15	131	200
81	51.7	<1	13	362	20 –50	3	4	1	2	2		1	13	13	13	26	200
82	50.7	<1	23	125.1	20 –50	3	4	1	3	2		1	14	14	14	46	200
83	48.5	<1	41	0	10 – 20	4	4	1	4	3		1	17	17	17	82	200
84	17.4	<1	57.5	0	20 –50	4	4	1	4	2		1	16	16	16	115	200
85	34.6	<1	35.5	109	<10	4	4	1	3	4		1	17	17	17	71	200
86	46.8	2-4	41.5	0	20 –50	4	2	1	4	2		4	17	17	17	83	200
87	54	2-4	45	0	10 – 20	3	2	1	4	3		4	17	17	17	90	200
88	52.9	1-2	3.759	102.6	20 –50	3	3	4	3	2		4	19	19	19	3	79.8
89	27.6	1-2	22	83.3	<10	4	3	1	4	4		4	20	20	20	44	200
90	30.1	<1	49.5	14.7	20 –50	4	4	1	4	2		4	19	19	19	99	200
91	49.4	<1	38	11.7	10 – 20	4	4	1	4	3		4	20	20	20	76	200
92	40.7	<1	15.85	128	10 – 20	4	4	1	3	3		1	16	16	16	26	164
93	51.7	<1	36.5	0	10 – 20	3	4	1	4	3		1	16	16	16	73	200
94	37.3	<1	43	33.3	20 –50	4	4	1	4	2		1	16	16	16	86	200
95	99.3	<1	39	27	20 –50	3	4	1	4	2		1	15	15	15	78	200
96	40.9	<1	44.4	12	10 – 20	4	4	1	4	3		1	17	17	17	21	47.3
97	72.5	<1	55.74	49.7	10 – 20	3	4	1	4	3		1	16	16	16	51	91.5
98	71.1	<1	5.5	224	10 – 20	3	4	3	2	3	4	1	16	20	20	11	200
99	56.6	<1	19.85	116.2	10 – 20	3	4	1	3	3		1	15	15	15	27	136
100	45.8	<1	15.21	40.4	10 – 20	4	4	1	4	3		1	17	17	17	11	72.3
101	31.4	<1	19.53	43.4	10 – 20	4	4	1	4	3		1	17	17	17	15	76.8
102	30.4	<1	11.95	19.1	10 – 20	4	4	2	4	3		1	18	18	18	7	58.6
103	50.5	<1	27.47	11.7	10 – 20	3	4	1	4	3		1	16	16	16	25	91
104	13	<1	13.51	22	10 – 20	4	4	1	4	3		2	18	18	18	8	59.2
105	14.9	<1	15.72	4.9	20 –50	4	4	1	4	2		2	17	17	17	5	31.8
106	3.8	<1	4.098	0	<10	4	4	3	4	4		2	21	21	21	1	24.4
107	10.6	2-4	5.155	10.7	<10	4	2	3	4	4		2	19	19	19	1	19.4

108	39.6	2-4	16.7	0	20 –50	4	2	1	4	2		1	14	14	14	9	53.9
109	24.2	2-4	4.608	16.2	20 –50	4	2	3	4	2		1	16	16	16	4	86.8
110	38.5	1-2	27.5	92.6	20 –50	4	3	1	4	2	4	1	15	19	19	55	200
111	36.2	<1	21.5	0	10 – 20	4	4	1	4	3		1	17	17	17	43	200
112	29.6	<1	36.5	0	20 –50	4	4	1	4	2		1	16	16	16	73	200
113	25.8	1-2	15.5	0	20 –50	4	3	1	4	2		1	15	15	15	31	200
114	33.5	1-2	20.5	306.6	20 –50	4	3	1	2	2		1	13	13	13	41	200
115	34.4	<1	52	194.2	20 –50	4	4	1	3	2		1	15	15	15	104	200
116	29.3	<1	48.5	104.2	20 –50	4	4	1	3	2		1	15	15	15	97	200
117	53.1	<1	50	283.9	20 –50	3	4	1	2	2		1	13	13	13	100	200
118	32.1	<1	44.5	133	20 –50	4	4	1	3	2		3	17	17	17	89	200
119	13.7	<1	53	19.8	20 –50	4	4	1	4	2		3	18	18	18	106	200
120	30.4	<1	18.5	160.9	20 –50	4	4	1	3	2		3	17	17	17	37	200
121	42.1	<1	34	289.6	10 – 20	4	4	1	2	3		3	17	17	17	68	200
122	20.1	<1	20.69	102.1	20-50	4	4	1	3	2		3	17	17	17	24	116
123	32.2	<1	34.32	71.2	>50	4	4	1	4	1		3	17	17	17	29	84.5
124	24	<1	3.636	88.6	10 – 20	4	4	4	4	3		3	22	22	22	1	27.5
125	0	<1	7.092	0	>50	4	4	3	4	1		1	17	17	17	1	14.1
126	4.6	<1	3.145	0	>50	4	4	4	4	1		1	18	18	18	1	31.8
127	53.6	<1	11.67	16.6	10 – 20	3	4	1	4	3		2	17	17	17	6	51.4
128	32.8	<1	5.549	48.6	10 – 20	4	4	3	4	3		2	20	20	20	5	90.1
129	523.5	<1	10.32	70.6	<10	1	4	2	4	4		1	16	16	16	13	126
130	206.7	2-4	7.5	121.2	<10	1	2	3	3	4		1	14	14	14	15	200
131	197.8	2-4	6.522	41.5	<10	1	2	3	4	4		2	16	16	16	9	138
132	132.3	>4	1.829	104.2	<10	2	1	4	3	4		2	16	16	16	3	164
133	191.2	>4	6.076	32.6	<10	1	1	3	4	4		1	14	14	14	12	197.5
134	183.3	>4	5	117	<10	1	1	3	3	4	4	1	13	17	17	10	200
135	471.1	>4	12.84	117.2	<10	1	1	1	3	4		1	11	11	11	14	109
136	350.7	>4	7.5	86.8	<10	1	1	3	4	4	4	1	14	18	18	15	200
137	145.6	>4	0.521	365	<10	2	1	4	2	4	4	1	14	18	18	1	192
138	302.9	>4	3	324	<10	1	1	4	2	4	4	1	13	17	17	6	200
139	256.8	>4	0.5	0	<10	1	1	4	4	4	4	1	15	19	19	1	200
140	150.2	>4	0.5	156.6	<10	1	1	4	3	4	4	1	14	18	18	1	200
141	451	2-4	0.5	247.5	<10	1	2	4	2	4		1	14	14	14	1	200
142	525.7	1-2	0.5	128.9	<10	1	3	4	3	4		1	16	16	16	1	200
143	121	1-2	0.5	0	<10	2	3	4	4	4		1	18	18	18	1	200
144	122.7	1-2	2	77	<10	2	3	4	4	4		1	18	18	18	4	200
145	102.9	<1	3.409	45.4	<10	2	4	4	4	4		1	19	19	19	6	176
146	112.7	<1	4.412	53.3	20 –50	2	4	3	4	2		1	16	16	16	6	136
147	26.4	<1	1.054	0	20 –50	4	4	4	4	2		1	19	19	19	1	94.9
148	35.4	<1	22.77	26.6	10 – 20	4	4	1	4	3		1	17	17	17	22	96.6
149	52.2	<1	0.901	342	<10	3	4	4	2	4	4	1	18	22	22	1	111
150	50.9	<1	32.5	0	20 –50	3	4	1	4	2		1	15	15	15	65	200
151	72.8	<1	5.5	64.1	20 –50	3	4	3	4	2		1	17	17	17	11	200
152	65.9	<1	13	141	20 –50	3	4	1	3	2	4	1	14	18	18	26	200
153	55	<1	9	0	20 –50	3	4	2	4	2		1	16	16	16	18	200
154	55	<1	15.5	0	20 –50	3	4	1	4	2		1	15	15	15	31	200
155	50.8	<1	9.5	163.2	20 –50	3	4	2	3	2		1	15	15	15	19	200
156	182.7	<1	1	121.4	>50	1	4	4	3	1	4	1	14	18	18	2	200
157	31.3	<1	13	281.3	20 –50	4	4	1	2	2		1	14	14	14	26	200
158	36.5	<1	16.5	0	20 –50	4	4	1	4	2		1	16	16	16	33	200
159	42.1	<1	47.5	0	20 –50	4	4	1	4	2		1	16	16	16	95	200
160	36.2	<1	14	0	10 – 20	4	4	1	4	3		1	17	17	17	28	200
161	24.6	<1	56.5	106.2	20 –50	4	4	1	3	2		1	15	15	15	113	200

162	49.1	<1	18.5	76.5	10 – 20	4	4	1	4	3		1	17	17	17	37	200
163	25.1	<1	62	14.3	10 – 20	4	4	1	4	3		1	17	17	17	124	200
164	43.7	<1	10.5	36.9	20 – 50	4	4	2	4	2	4	1	17	21	21	21	200
165	29.2	<1	56.5	192.9	20 – 50	4	4	1	3	2		1	15	15	15	113	200
166	46	<1	38.5	134	20 – 50	4	4	1	3	2		1	15	15	15	77	200
167	36.4	<1	23	106.6	>50	4	4	1	3	1		1	14	14	14	46	200
168	33.4	<1	3	654	>50	4	4	4	1	1		1	15	15	15	6	200
169	20.7	<1	46	52.5	20 – 50	4	4	1	4	2		1	16	16	16	92	200
170	52.5	<1	44.5	77.1	20 – 50	3	4	1	4	2		1	15	15	15	89	200
171	54.9	<1	50	295.9	20 – 50	3	4	1	2	2		1	13	13	13	100	200
172	29.5	<1	35.5	0	10 – 20	4	4	1	4	3		1	17	17	17	71	200
173	41.5	<1	37.5	83.5	10 – 20	4	4	1	4	3		1	17	17	17	75	200
174	37.2	<1	33	94.3	10 – 20	4	4	1	4	3		1	17	17	17	66	200
175	59.8	<1	39	69.3	20 – 50	3	4	1	4	2		1	15	15	15	78	200
176	26.3	<1	21	215.8	10 – 20	4	4	1	2	3		1	15	15	15	42	200
177	27	<1	7.143	104.3	10 – 20	4	4	3	3	3		1	18	18	18	10	140
178	58.9	<1	26.09	115.5	20 – 50	3	4	1	3	2		1	14	14	14	36	138
179	30.7	<1	17	249.5	10 – 20	4	4	1	2	3		1	15	15	15	34	200
180	62.2	<1	23	258.4	>50	3	4	1	2	1		1	12	12	12	46	200
181	59.6	<1	17	116.6	20 – 50	3	4	1	3	2		1	14	14	14	34	200
182	65.4	<1	2.5	267.5	10 – 20	3	4	4	2	3		1	17	17	17	5	200
183	44.3	<1	17.5	37	20 – 50	4	4	1	4	2	4	1	16	20	20	35	200
184	35.9	<1	51	146.6	20 – 50	4	4	1	3	2		1	15	15	15	102	200
185	35.7	<1	32	128.4	20 – 50	4	4	1	3	2		1	15	15	15	64	200
186	35.4	<1	7.5	164	10 – 20	4	4	3	3	3		1	18	18	18	15	200
187	45.3	<1	2	0	10 – 20	4	4	4	4	3		1	20	20	20	4	200
188	290	<1	2.5	253	<10	1	4	4	2	4		1	16	16	16	5	200
189	301.5	<1	2.5	0	<10	1	4	4	4	4		1	18	18	18	5	200
190	34.9	<1	7.407	66.9	10 – 20	4	4	3	4	3	4	1	19	23	23	5	67.5
191	80.7	<1	2.055	39.2	20 – 50	3	4	4	4	2		1	18	18	18	2	97.3
192	70.6	<1	2.759	100.2	10 – 20	3	4	4	3	3	4	1	18	22	22	4	145
193	31.3	<1	0.5	210	10 – 20	4	4	4	2	3		1	18	18	18	1	200
194	68.7	<1	4.689	17.2	10 – 20	3	4	3	4	3		1	18	18	18	4	85.3
195	60.3	<1	9.626	41.5	20 – 50	3	4	2	4	2		1	16	16	16	9	93.5
196	36.8	<1	12.28	68.5	20 – 50	4	4	1	4	2		1	16	16	16	14	114
197	40.6	<1	22.73	56.4	20 – 50	4	4	1	4	2		1	16	16	16	22	96.8
198	122.9	<1	15.47	55.7	10 – 20	2	4	1	4	3		1	15	15	15	28	181
199	141.1	<1	2.083	64.2	10 – 20	2	4	4	4	3		1	18	18	18	4	192
200	248.6	<1	0.5	150.2	<10	1	4	4	3	4	4	1	17	21	21	1	200
201	31.1	<1	6.5	203.8	10 – 20	4	4	3	2	3		3	19	19	19	13	200
202	172.9	<1	24.8	133.7	20 – 50	1	4	1	3	2		3	14	14	14	31	125
203	59.8	<1	4.032	74.9	10 – 20	3	4	3	4	3		3	20	20	20	5	124
204	62	<1	19.93	18	20 – 50	3	4	1	4	2		1	15	15	15	12	60.2
205	35.3	<1	19.43	58.6	10 – 20	4	4	1	4	3		1	17	17	17	17	87.5
206	247.7	<1	8.333	54.5	<10	1	4	2	4	4		1	16	16	16	12	144
207	101.7	<1	10.2	59.5	<10	2	4	2	4	4	4	1	17	21	21	9	88.2
208	49.4	<1	11.17	152.6	20 – 50	4	4	2	3	2		1	16	16	16	21	188
209	45.9	<1	10	210.7	10 – 20	4	4	2	2	3		1	16	16	16	20	200
210	26.1	<1	10	91.2	10 – 20	4	4	2	4	3		1	18	18	18	20	200
211	38.4	<1	12.6	164.4	10 – 20	4	4	1	3	3		1	16	16	16	16	127
212	30.6	<1	5.5	170.4	10 – 20	4	4	3	3	3		1	18	18	18	11	200
213	41.4	<1	12	127	20 – 50	4	4	2	3	2	4	1	16	20	20	24	200

214	32.2	<1	5.413	17.3	20 –50	4	4	3	4	2		1	18	18	18	4	73.9
215	50.7	<1	2	281.5	20 –50	3	4	4	2	2	4	1	16	20	20	4	200
216	45.2	<1	18.06	69.2	10 – 20	4	4	1	4	3		1	17	17	17	28	155
217	37.4	<1	13.33	99.1	10 – 20	4	4	1	4	3		1	17	17	17	26	195
218	117.5	<1	4.828	141.9	10 – 20	2	4	3	3	3	4	1	16	20	20	7	145
219	94	<1	5.185	127	<10	3	4	3	3	4	4	1	18	22	22	7	135
220	98.4	<1	12.4	43.1	>50	3	4	1	4	1		1	14	14	14	15	121
221	85.5	<1	7.639	30.5	20 –50	3	4	3	4	2		1	17	17	17	11	144
222	63.2	<1	12.9	8.7	20 –50	3	4	1	4	2		1	15	15	15	10	77.5
223	10	<1	12.9	0	20 –50	4	4	1	4	2		1	16	16	16	2	15.5
224	19.7	<1	3.077	23.5	10 – 20	4	4	4	4	3		1	20	20	20	4	130
225	22.5	<1	10.78	33.9	20 –50	4	4	1	4	2		1	16	16	16	10	92.8
226	127	<1	3.061	28	<10	2	4	4	4	4		1	19	19	19	6	196
227	61.6	<1	1.026	25.9	10 – 20	3	4	4	4	3	4	1	19	23	23	2	195
228	32.5	<1	12.88	30	<10	4	4	1	4	4		1	18	18	18	11	85.4
229	42.5	<1	11.5	172.6	20 –50	4	4	2	3	2		1	16	16	16	23	200
230	51.9	<1	6.842	120.4	10 – 20	3	4	3	3	3	4	1	17	21	21	13	190
231	131.7	<1	12.64	0	<10	2	4	1	4	4		1	16	16	16	12	94.9
232	55	<1	1.5	291.1	10 – 20	4	4	4	2	3	4	1	18	22	22	3	200
233	34.1	<1	6.048	12.3	20 –50	4	4	3	4	2		1	18	18	18	3	49.6
234	52.8	<1	25.19	45.2	>50	3	4	1	4	1		1	14	14	14	23	91.3
235	30	<1	26.44	0	20 –50	4	4	1	4	2		1	16	16	16	23	87
236	52.7	<1	40.94	60.8	10 – 20	3	4	1	4	3		1	16	16	16	61	149
237	64.9	<1	12	0	20 –50	3	4	2	4	2	4	1	16	20	20	24	200
238	64.9	<1	1.412	0	20 –50	3	4	4	4	2		1	18	18	18	1	70.8
239	72.9	<1	0.826	31.5	20 –50	3	4	4	4	2		1	18	18	18	1	121
240	40.6	<1	0.962	36.7	20 –50	4	4	4	4	2		1	19	19	19	1	104

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