VEÐURSTOFA ÍSLANDS

Report
01009

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Hazard zoning for Ísafjörður, Siglufjörður and Neskaupstaður
General report

VÍ-ÚR04
Reykjavík
May 2001

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Contents

1 Introduction

This report describes the project *Pilot hazard zoning for Ísafjörður, Siglufjörður and Neskaupstaður* (Tilraunahættumat fyrir Ísafjörð, Siglufjörð og Neskaupstað). The report describes aspects of the project that are common for all the communities. Three additional reports describe in more detail the findings of the project for each of the communities and the technical basis of the results. The one for Neskaupstaður is published parallel to this report (Thorsteinn Arnalds *et al.*, 2001) and the other two for Ísafjörður and Siglufjörður will be published in the next few months in cooperation with hazard zoning committees that have been established for the respective communities. A revised edition of this report will be published after the three technical reports have been published. The revised report will contain, in addition to the current content, an overview of the results for each of the communities and general conclusions of the project as a whole.

The organization of the project is described by Thorsteinn Arnalds (1998). The main purpose was to delineate hazard zones according to a proposal for Icelandic hazard zoning regulations. This delineation of hazard zones allows:

a) Estimation of the effect of the proposed regulations, that are the basis of the current regulations, on the settlement in the affected villages. How will the regulation affect the development of the communities involved? How many houses will be within the boundaries of the hazard zones, what will the legal rights of the owners of the houses be and how will they respond? In other words, it may be possible to see whether the proposed definition of acceptable risk leads to practical results.

b) Comparison between the estimated risk and "observed risk" in the past decades. Using the estimated risk, the expected number of fatalities in the past can be calculated and compared to the actual number of fatalities. That will enable the determination of whether the risk estimate is biased or not.

The main participants in this project were Thorsteinn Arnalds, Harpa Grímsdóttir and Leah Tracy (Icelandic Meteorological Office, IMO) and Siegfried Sauermoser (Austrian Foresttechnical Service in Avalanche and Torrent Control, WLV).

Other employees of the IMO contributed to the work. Thorsteinn Sæmundsson made geological maps of the areas and participated in the evaluation of debris flow hazard. He also took part in the preparation of an avalanche chronicle for Siglufjörður. Thóranna Pálsdóttir supervised the preparation of climatic data. Jón Gunnar Egilsson took part in the compilation of an avalanche chronicle for Ísafjörður while Svanbjörg Helga Haraldsdóttir compiled a chronicle for Neskaupstaður. Tómas Jóhannesson assisted on various tasks including model estimates and took part in a discussion of the final delimitation of hazard zones together with Sigurjón Hauksson (Verkfræðistofa Austurlands).

Halldór Pétursson at the Icelandic Institute of Natural History (Náttúrufræðistofnun) compiled debris flow chronicles.

2 Work process

Work on the project started in the autumn of 1998 at the IMO with the collection of basis data. An avalanche map and an accompanying list were made for each avalanche path. Model calculations were performed and aerial photos of the areas under investigation were examined.

In December 1998, the three communities were visited to inform the local authorities of the project plan, and discuss the hazard situation with representatives of the communities. Local snow observers were consulted and brief field investigation were carried out.

On December 10–11 1998 Thorsteinn, Harpa and Leah visited Ísafjörður. A meeting was held with the city council on December 11. While in Ísafjörður, the group made a preliminary field investigation accompanied by the local snow observer, Oddur Pétursson.

On the 15–16 December 1998, Thorsteinn and Harpa visited Siglufjörður. A meeting was held with the city council on December 16. While in Siglufjörður, they made a preliminary field investigation and had a meeting with the local snow observer, Örlygur Kristfinnsson.

On the 16–18 December 1998, Thorsteinn and Harpa visited in Neskaupstaður. A meeting was held with the city council on December 17.

In May 1998, Siegfried Sauermoser traveled to Iceland for field investigation. At the beginning of the field investigations, the scope and extent of the investigations were defined.

i) **Inspection of avalanche conditions.** The group would examine the relevant areas in the field, review avalanche chronicles and climatic information and describe:

  a) *Topographic conditions*, i.e. the topography of the starting zone, track and runout area.

  b) *Climatic conditions* would be dealt with mostly on a regional basis, but locally the effect of the regional climate on snow accumulation in starting areas would be discussed.

  c) *Assessment*. The group would give its general opinion of the avalanche hazard in the path. This would be done by quantifying the size of the starting areas and their relative frequency in respect to other paths.

ii) **Hazard zoning.** The project group would develop 2 separate zoning proposals. Siegfried would derive hazard zones based on field investigations, using Austrian regulation and methods as guidelines while Harpa, Leah, and Thorsteinn would estimate risk in accordance with the proposed Icelandic regulations using the Avalanche Risk Assessment methods (Kristján Jónasson *et al.*, 1999) together with other models and subjective judgement. Neither of these assessments would be presented formally in the final project reports as they were primarily intended to be the basis for discussion in the project group.

On May 19–29, the project group visited Ísafjörður. Thorsteinn Sæmundsson and the local snow observer Oddur Pétursson participated in part of the fieldwork. At the end of the stay in Ísafjörður, Siegfried and Thorsteinn A. held an informal meeting with the mayor Halldór Halldórsson to discuss the preliminary findings of the project.

From May 30 to June 5, the project group visited Siglufjörður. Thorsteinn Sæmundsson and the local snow observer Örlygur Kristfinnsson participated in part of the fieldwork. At the end of the stay in Siglufjörður, Siegfried and Thorsteinn A. held an informal meeting with the mayor Guðmundur Guðlaugsson and the town engineer Sigurður Hlöðversson to discuss the preliminary findings of the project.

On June 6–11, the group visited Neskaupstaður. Thorsteinn Sæmundsson and the local snow observer Guðmundur Helgi Sigfússon participated in part of the fieldwork. At the end of the stay in Neskaupstaður, the group held an informal meeting with the mayor Guðmundur Bjarnason and the chief of environmental issues in Neskaupstaður, Guðmundur Helgi Sigfússon, to discuss the preliminary findings of the project.

Following the field investigations, the information that was obtained before and during the field trips was examined. A discussion group including Thorsteinn, Harpa, Sigurjón, and Tómas was formed to propose hazard zoning. Harpa and Thorsteinn presented their suggestions and based on those and a subsequent discussion the group proposed zoning.

The result is the sole responsibility of the IMO and should be considered the result of the institute. Siegfried and Sigurjón were consulted for their professional experience and are not responsible for the final result.

A meeting was held on August 10, 1999 with the board of the Avalanche fund (Ofanflóðasjóður) to present the results of the project. On August 16, a similar meeting was held with the local authorities of the three settlements in the project and a representative from the Union of Icelandic communities (Samband íslenskra sveitarfélaga). It was decided that the results should not be published until regulation on hazard zoning had been finalized so the hazard maps would get a formal status and be approved by the Minister of the environment. The representatives of the local authorities requested that before the regulation would be finalized the legal rights of the parties involved, i.e. individuals that own houses in hazard zones, local governments and the state would be clarified.

In the winter 1999/2000 Guðrún Gauksdóttir (2000) prepared a legal brief addressing the legal rights concerning hazard zoning. Following that the hazard zoning regulation was finalized and issued in July 2000 (The ministry of the Environment, 2000).

In the winter 2000/2001 hazard zoning committees were appointed for the communities. The IMO presented their work and proposed hazard zoning. A final map has now been approved by the hazard zoning committee in Neskaupstaður and is due to be presented to the public on May 8. The committees for Siglufjörður and Ísafjörður have started their work and they will probably present the respective hazard maps in the next few months.

3 Development of Avalanche Hazard Management in Iceland

In the last century, 107 people were killed by avalanches in populated areas in Iceland. The biggest such events before 1995 were in 1910 in Hnífsdalur (20 people killed), in 1919 in Siglufjörður (18 people killed in 4 accidents, including one person outside the populated areas, those accidents were outside of the present settlement) and in 1974 in Neskaupstaður (12 people killed in two accidents). Finally, two avalanche accidents shook Iceland in 1995. First in January, the village of Súðavík in Vestfirðir (Northwest peninsula of Iceland) was hit by an avalanche and 14 people died. In October, an avalanche killed 20 people in Flateyri, also in Vestfirðir.

After the accident in Neskaupstaður in 1974, some steps were taken to increase avalanche research and monitoring. Regional and national committees were founded and in 1978, the IMO became responsible for cataloguing avalanches.

In 1985 the first Icelandic law concerning protection against avalanches, debris flows and rockfall was passed. According to the law, a hazard map should be prepared for all current and future settlements. The Icelandic civil defense became responsible for making regulations to define and manage hazard zones. In the following years, hazard maps were prepared for several villages in Iceland by independent contractors hired by a supervisory committee called "Ofanflóðanefnd".

When the avalanche hit Súðavík in 1995, it ran far into an area that was defined "safe" on the hazard map. This happened again in Flateyri later in 1995. These accidents prompted a new effort to expand avalanche research. The avalanche protection law was revised in 1995, and the current version of the law passed in 1997.

The changes resulted in a much broader role of the IMO in avalanche hazard management. It became responsible for avalanche research, evacuations (IMO, 1997), and hazard zoning. The IMO also advises the government regarding permanent protection measures (Tómas Jóhannesson *et al.*, 1996).

Shortly after the accident in Súðavík, a research project began at the University of Iceland (UI) to establish statistical foundations for hazard zoning under the direction of Kristján Jónasson, then professor of mathematics at UI. He became project manager of hazard zoning at the IMO in 1997, and the methods developed at the UI (Kristján Jónasson *et al.*, 1999) became the basis of avalanche hazard zoning at the IMO.

After the IMO became responsible for hazard zoning, the institute first focused on the foundations of the zoning work by collecting data and developing methods to evaluate avalanche hazard. Parallel to this effort, some preliminary hazard zoning was done where new houses were about to be built. The first hazard zoning project was *Pilot hazard zoning for Seyðisfjörður* (Tilraunahættumat fyrir Seyðisfjörð). It was intended to present a comparison between the results of Icelandic methods versus Austrian and Norwegian methods. Hazard maps were first prepared according to Norwegian (NGI, 1997), Austrian (WLV, 1997), and Icelandic (Kristján Jónasson and Thorsteinn Arnalds, 1997) regulations and methods. The overall results of the project are described by Thorsteinn Arnalds (2001).

4 Present risk as indicated by the avalanche history

The present avalanche risk to individuals in avalanche prone areas in Iceland has been addressed by, among others, Kristján Jónasson (1995) and Tómas Jóhannesson *et al.* (1996). While the discussion will not be repeated, their results can be used to shed light on the present avalanche situation in Iceland. Roughly 5000 people live in densely populated areas of Iceland with considerable avalanche hazard. In the past decades, on average about 2 people per year have been killed in these areas. The average risk in those areas may thus be estimated about $4 \cdot 10^{-4}$ per year. This is twenty times more than the acceptable risk level established in the Icelandic hazard zoning regulations from July 2000. Furthermore, the average risk to the 5000 people is comparable to the level of risk near the border of a category C hazard zone according to the regulations (see below). Research at the IMO indicates that avalanche risk is reduced about twofold by going 50–100 m farther away from the mountain when the avalanche path is a comparatively high hill. Using level of acceptable risk established by the new regulations, the hazard zones will typically extend several hundred meters into the settlements where the 5000 people at risk are living.

5 Investigated areas

Figure 1 shows an overview map of Ísafjörður, Siglufjörður, and Neskaupstaður and their location in Iceland.

In Ísafjörður (see Map 1 in Appendix A), the project focused on the main settlements in the old Ísafjarðarbær and Hnífsdalur. This includes Holtahverfi (the residential area below the mountain Kubbi), Seljalandshverfi (the residential area below Seljalandshlíð), the residential area under Gleiðarhjalli, and the settlement in Hnífsdalur. In addition, a general statement is made about the area under Seljalandshlíð between the farm Seljaland and Gleiðarhjalli without performing similar work as in the neighboring areas because this area is not densely settled.

In Siglufjörður (see Map 2), the entire settlement was examined from the south below Jörundarskál to the north below Gróuskarðshnjúkur.

In Neskaupstaður (see Map 3), the main residential area from below Miðstrandarskarð in the west to below Stóralækjargil in the east was investigated. In addition, the new industrial area from Gunnólfsskarð to Ytri-Sultarbotnagjá was also evaluated. A general statement is made about the area between Ytri-Sultarbotnagjá and Miðstrandarskarð similar to what was done in Seljalandshlíð in Ísafjörður without performing all the investigations that were done in areas nearby.

6 Methodologies and regulations

The hazard zoning presented in this report is based on Icelandic hazard zoning regulations that were issued in July 2000 after having been under development for several years. A summary of these regulations is included below. Although the project was not intended to present a formal

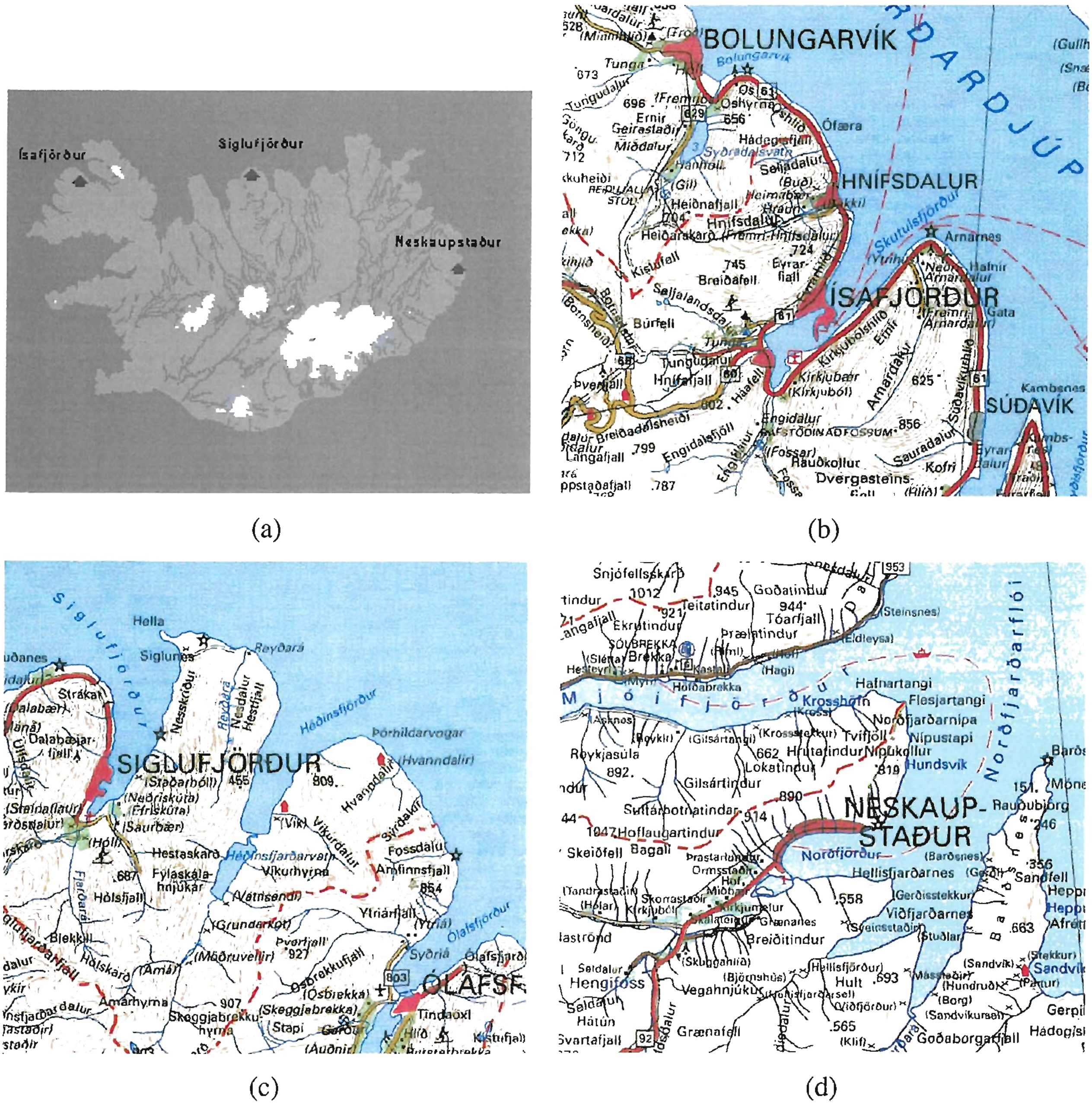

Figure 1. *(a) Iceland with the location of Ísafjörður, Siglufjörður and Neskaupstaður indicated. (b)–(d) An overview of Ísafjörður, Siglufjörður and Neskaupstaður respectively. Scale 1:250 000.* © *The National Land Survey of Iceland.*

Table 1. *Icelandic hazard zone definitions*

Zone	Lower level of local risk	Upper level of local risk	Construction allowed
C	$3 \cdot 10^{-4}$/yr	$1 \cdot 10^{-4}$/yr	No new buildings, except for summer houses*, and buildings where people are seldom present.
B	$1 \cdot 10^{-4}$/yr	$0.3 \cdot 10^{-4}$/yr	Industrial buildings may be built without reinforcements. Domestic houses have to be reinforced and hospitals, schools *etc.* can only be enlarged and have to be reinforced.
A	$0.3 \cdot 10^{-4}$/yr	–	Houses where large gatherings are expected, such as chools, hospitals *etc.*, have to be reinforced.

*If the risk is less than $5 \cdot 10^{-4}$ per year.

comparison of Icelandic versus Austrian/Swiss hazard zoning regulations, it is important to understand the basic concepts and background of both of these methodologies. A brief summary of these methods is presented below.

6.1 Iceland

Hazard zoning in Iceland has since 1995 been based on individual risk which is the yearly probability that a person living at a given place will be killed by an avalanche. The definition of hazard zones is based on the *local risk* defined as the annual probability of being killed given that a person is staying all the time in an unreinforced house. The *actual risk* can be found by taking into account the probability of the person being present in a house when an avalanche hits and the safety increase that is obtained by reinforcing houses. Increased safety by evacuations and other non-permanent safety measures are not taken into account in the hazard zoning. The authorities in Iceland have adopted the value $0.2 \cdot 10^{-4}$ as an accepted actual risk for avalanche hazard zoning (The Ministry of the Environment, 1997). This value corresponds to different values of the local risk for different types of constructions depending on the fraction of time people may be expected to spend in the buildings (typical values are assumed to be 75% in domestic houses, and 40% in commercial buildings). The regulations on hazard zoning (The Ministry of the Environment, 2000) defines three types of hazard zones, see Table 1.

These guidelines for zoning are tailored to attain the acceptable risk level of $0.2 \cdot 10^{-4}$ in residences when presence probability and increased safety provided by reinforcements have been taken into account. The risk in industrial buildings is probably somewhat higher.

The methodology used here to estimate avalanche risk in Ísafjörður, Siglufjörður and Neskaupstaður was developed at the University of Iceland and the Icelandic Meteorological Office in the period 1995–1998. The methods are described by Kristján Jónasson *et al.* (1999).

This discussion is concluded by quoting §10 of the Icelandic regulations on how to proceed where formal risk calculation is impossible: "In areas, where it is not possible to estimate the risk formally due to insufficient information, a hazard map shall nevertheless be prepared according to §12 [§12 describes the risk zones of a hazard map]. In the preparation of the map an attempt should be made to estimate risk."

6.2 Austria and Switzerland

In other countries, especially Norway and to some extent Austria and Switzerland hazard zoning is based on avalanche return periods. In order to find the individual risk it is in addition necessary to estimate the probability of an avalanche striking a building and the probability that people in the building are killed as a consequence.

Austrian avalanche hazard zoning regulations define two main types of hazard zones (Sauermoser, 1997) which are

Red zone: No new constructions are allowed. The border of this zone is defined where an avalanche can be expected on average every ten years, or the impact pressure of the 150 year avalanche is more than 25 kN/m^2.[1]

Yellow zone: Construction of reinforced buildings is allowed. In general, it is not permitted to build constructions in the yellow zone where many people may gather. The edge of the yellow zone is where an avalanche can be expected on average every 150 years.

The return periods mentioned in the regulation are noteworthy. If the return period is interpreted in terms of the yearly probability that an avalanche passes a given point in a similar way as is done in Icelandic hazard zoning methods, the zoning would mean that on average, an avalanche passes any given point on the red line every tenth year. The Austrian regulation is based on Swiss hazard zoning guidelines.

In the Swiss hazard zoning guidelines (Salm, *et al.*, 1990), the borders of the hazard zones are defined by 30 and 300 year return periods. A physical model is used to calculate the runout of a theoretical avalanche with an assumed fracture height. The fracture height is defined by the increase in snowdepth in the starting zone over a period of three days corresponding to the return periods. Kristján Jónasson (1997) gives an overview on the procedure used in these calculations.

An avalanche corresponding to a 3 day increase in snowdepth in the starting zone with a 30 or 300 year return period does not correspond to avalanches with 30 or 300 year return period. This is mainly due to two reasons. The first reason is that even though a certain amount of snow may accumulate in a starting zone, it is not certain than an avalanche will fall. Secondly, it is uncertain that the applied physical model will give the "correct runout" of an avalanche with the given fracture height. It should be emphasized that the term "correct runout" does not have an exact

[1]The reference value of 25 kN/m^2 has recently been changed to 10 kN/m^2 in the regulations. Little hazard zoning has been carried out since the change and 25 kN/m^2 is thus the effective value for most of the present hazard zones in Austria.

meaning in this context, because all avalanches with a given fracture height are not equally long and rather obey some probability distribution. It is more appropriate to interpret "correct runout" as the expected (average) runout of an avalanche with the given fracture height.

During discussions between staff of the IMO and Siegfried Sauermoser while working on the projects *Pilot hazard zoning for Seyðisfjörður* and *Pilot hazard zoning for Ísafjörður, Siglufjörður and Neskaupstaður*, it has been noted that an observation that a house has been standing at a certain point for up to several hundred years does not prevent its location in the red hazard zone according Austrian hazard zoning. This does not fit well with the assumption that an avalanche will hit a certain point on the red line on average every 10–150 years and indicates that an informal safety margin is built into the Austrian hazard zoning practice.

Even though the reference values in Austrian and Swiss regulations are different, there is evidence that the risk in Austrian hazard zones is comparable to the risk in Swiss hazard zones and the probability of an avalanche hitting the areas is similar. The staff of the IMO have discussed risk and return periods in Swiss hazard zones with their Swiss colleagues, mainly Stefan Margreth and Christian Wilhelm. These discussions and other information suggest that the return period of avalanches on the boundary between the red and the blue zone are in the magnitude of 100 years, and 1000 years on the outer boundary of the blue zone, indicating that a substantial informal safety margin is also built into the Swiss hazard zoning practice.

Swiss and Austrian regulations were discussed during a meeting in Neskaupstaður in 1997 with the participation of Stefan Margreth and Joseph Hopf (Tómas Jóhannesson and Sigurður Kiernan, 1997). In his Ph.D. thesis, Christian Wilhelm (1997) discusses the risk in avalanche hazard zones in Switzerland and the cost efficiency of protective measures. He presents estimates of risk at different locations within avalanche hazard zones before and after the construction of protective measures.

7 Uncertainty

The estimation of avalanche risk is difficult in many areas. This is especially the case when dealing with a slope that from the topographical point of view has the characteristics of an avalanche path, but where no avalanches have yet been recorded. Accurate records of avalanches have only been kept for a few years or decades in many areas and the settlement may be quite recent. In such a situation, it is almost impossible to rule out the possibility that an avalanche hitting the settlement might be released from the slope. An attempt must then be made to strike a compromise that balances the lack of recorded avalanches and the possibility of avalanche release.

Another problem that must be addressed is the estimation of avalanche hazard in non-typical or low avalanche tracks. The available data about Icelandic avalanches was mostly collected from hills between 500 and 800 m high with large starting areas. The runout potential of avalanches from smaller slopes, both with a lower fall height and smaller starting areas, is not as well investigated.

While delimiting the hazard zones, an attempt has been made to classify the uncertainty in each area by dividing the uncertainty into three classes according to the level of uncertainty in the area. An uncertainty of $\frac{1}{2}$ means that the estimation could be wrong up to the degree of half a hazard zone, i.e. the hazard lines may misalign by approximately $\frac{1}{2}$ of a hazard zone. Since the risk varies by a factor of 3 between the risk lines of the hazard map, the risk may be over- or underestimated by factor of $\sqrt{3}$. Similarly, class 1 and 2 certainty means that the zoning could be wrong by 1 and 2 zones respectively in either direction, meaning that the risk could be over- or underestimated by factor of 3 or 3^2 respectively. Considering the "nominal" nature of avalanche risk estimates, it is not possible to attach a given significance level in a statistical sense to these uncertainty indicators. They are intended to mean that the work group considers it "unlikely" that the risk is over- or underestimated by the indicated uncertainty, but the meaning of "unlikely" is not further quantified.

The three chosen classes of uncertainty and their characteristics are:

$\frac{1}{2}$ Records of avalanches are available and the avalanche path is large and typical.

1 Some records of avalanches are available and the avalanche path is small or atypical.

2 No records of avalanches are available, but the topography indicates avalanche hazard.

The uncertainty of hazard zoning in areas where protective measures have been built will probably be in class 1 or 2.

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A Maps

Map 1. An overview map of Ísafjörður, showing the names of some landmarks.

Map 2. An overview map of Siglufjörður, showing the names of some landmarks.

Map 3. An overview map of Neskaupstaður, showing the names of some landmarks.

Tungudalur
Tunguskógur
Seljalandsdalur
Seljalandsmúli
Dagverðardalur
Kubbi
Holtahverfi
Seljalandshverfi
Seljaland
Breiðaskarð
Seljalandsgil
"Karlsárgil"
"Grænagarðsgil"
Hrafnagil
"Steiniðjugil"
Eyrarfjall
Gleiðarhjalli
Eyrarhlíð
Stakkanes
Torfnes
Krókur
Skutulsfjarðareyri
Kirkjubólshlíð innri
Kirkjubólshvilft
Flugvöllur
Kirkjubólsfjall
Naustahvilft
Kirkjubólshlíð ytri
Bakkahvilft
Bakkaskriðugil
Bakkahyrna
Langahryggsgil
Bólgil
Hnífsdalur
Hraunsgil
Búðarhyrna
Traðargil
Búðargil
Heimabær
N
Icelandic Meteorological Office
May 2001
Ísafjörður
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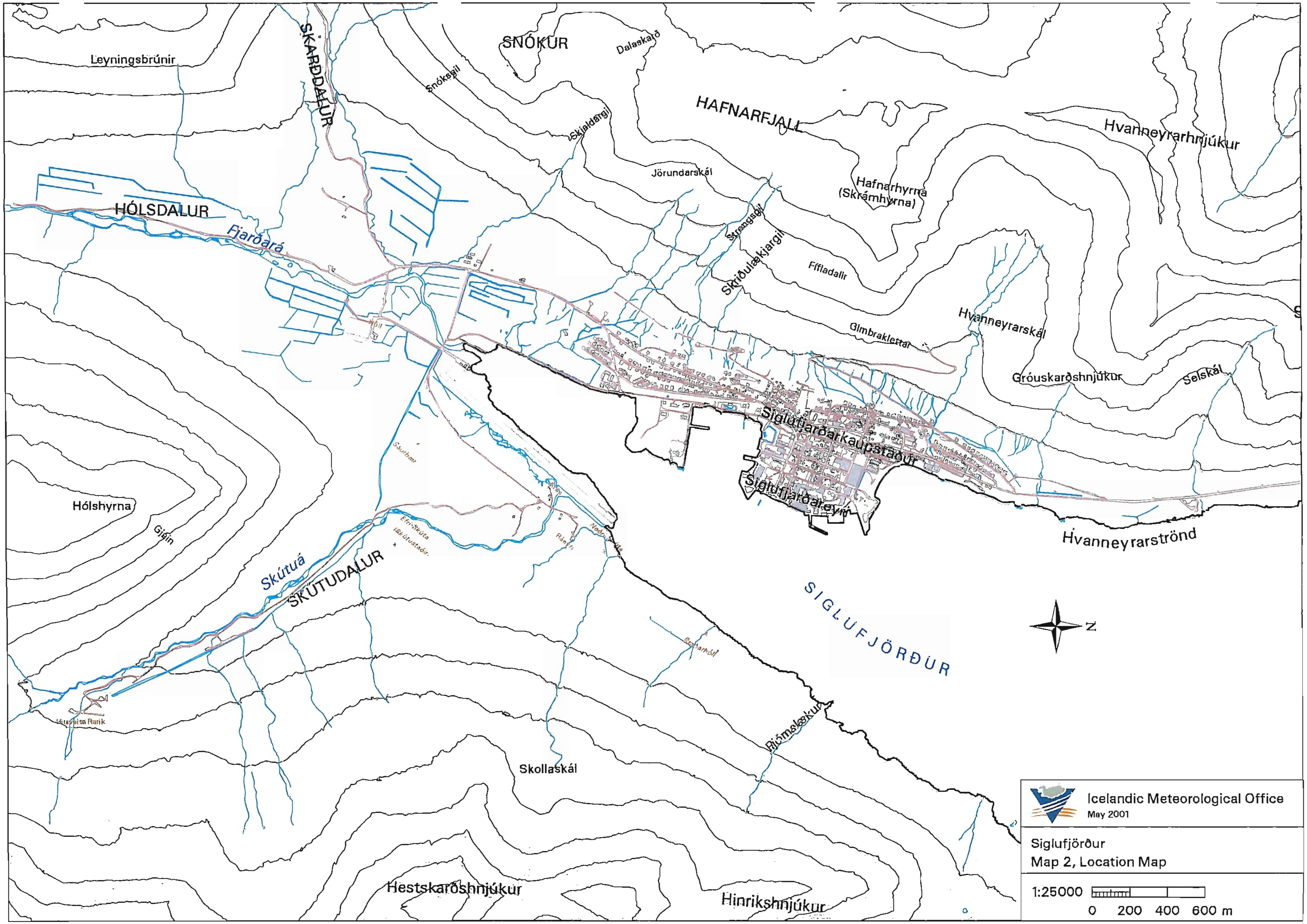
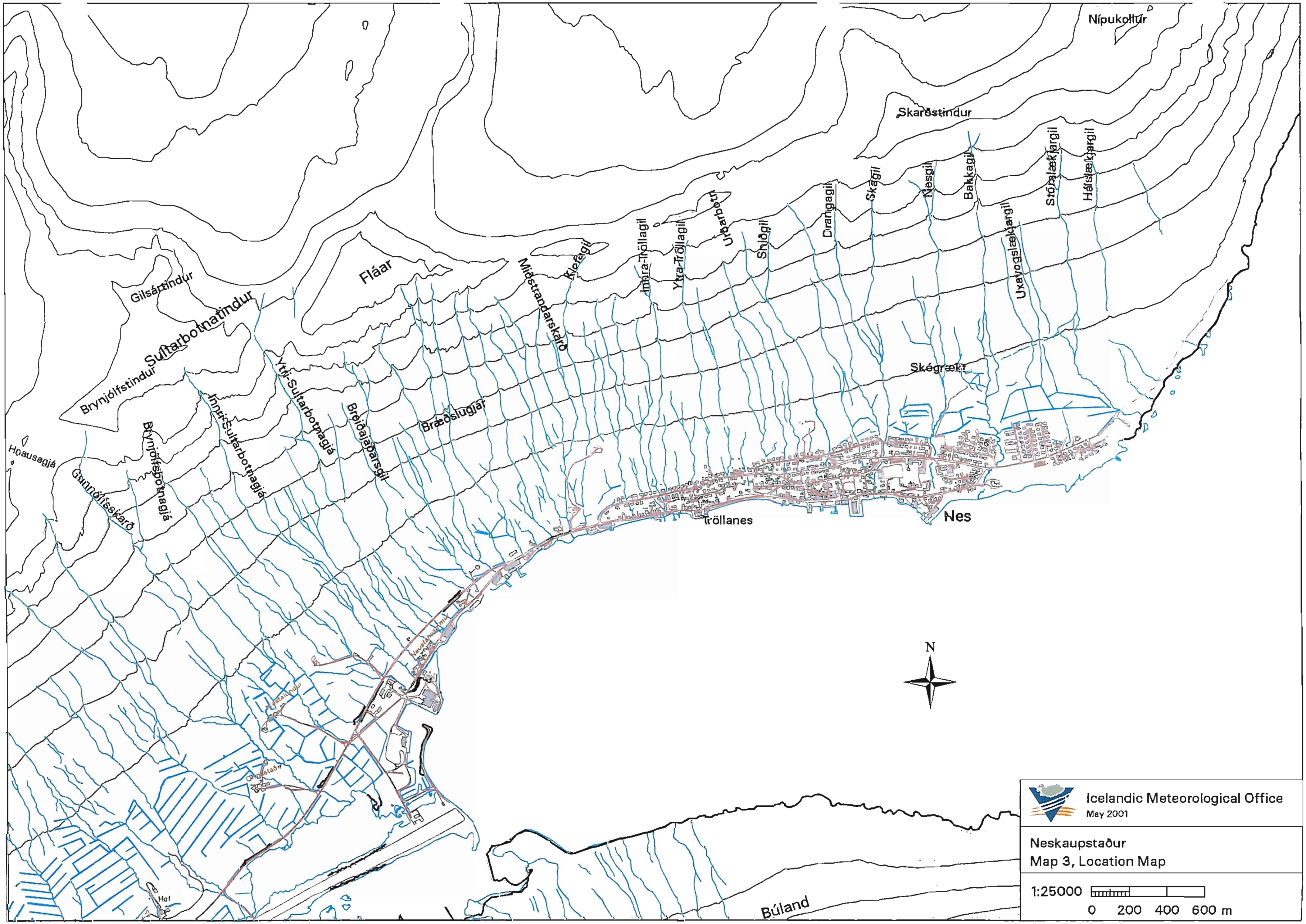


SNÓKUR
Dalaskarð
Leyningsbrúnir
SKARÐDALUR
Snóksgil
HAFNARFJALL
Skjaldargil
Hvanneyrarhnjúkur
Jörundarskál
Hafnarhyrna
(Skrámhyrna)
HÓLSDALUR
Fjarðará
Strengsgil
Skriðulækjargil
Fífladalir
Hvanneyrarskál
Gimbraklettar
Gróuskarðshnjúkur
Selskál
Siglufjarðarkaupstaður
Siglufjarðareyri
Saurbær
Hólshyrna
Gjáin
Efri-Skúta
Nedri-Skúta
Skútuá
SKÚTUDALUR
Hvanneyrarströnd
SIGLUFJÖRÐUR
N
Hitaveita Rarik
Skollaskál
Hestskarðshnjúkur
Hinrikshnjúkur
Icelandic Meteorological Office
May 2001
Siglufjörður
Map 2, Location Map
1:25000
0 200 400 600 m



Núpukollur
Skarðstindur
Hálslækjargil
Bakkagil
Nesgil
Skágil
Drangagil
Uxavogslækjargil
Urðarbotn
Ytra-Tröllagil
Innra-Tröllagil
Klofagil
Miðstrandarskarð
Skógrækt
Tröllanes
Nes
Fláar
Gilsártindur
Sultarbotnatindur
Brynjólfstindur
Ytri-Sultarbotnagjá
Innri-Sultarbotnagjá
Bræðslugjár
Brynjólfsbotnagjá
Gunnólfsskarð
Hnausagjá
Hof
Búland
N
Icelandic Meteorological Office
May 2001
Neskaupstaður
Map 3, Location Map
1:25000
0 200 400 600 m