Department of Geography
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GEO 511 Master's Thesis

Assessing the Potential of Satellite Rapid Mapping for Mitigating Flood Events in Switzerland

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10-736-585

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Submission Date: 30 June 2015

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Summary

Satellite remote sensing has experienced tremendous development in recent years. Possibilities in earth observation have rapidly improved in terms of spatial and temporal data acquisition. A spatial resolution in the sub-meter area and daily situation updates from numerous sensors offer new possibilities for disaster management. Particularly in case of a large scale flood event, satellite rapid mapping has repeatedly proven its effectiveness. The last application in Switzerland dates back to the flood event of 2005. Furthermore, a lack of end-user studies on the cantonal level was asserted. An assessment of the current potential of satellite rapid mapping was therefore demanded.

In this master's thesis, a user survey was conducted among cantonal representatives of emergency management and incidence documentation. Overall, the answers reveal tremendous differences in terms of interest in the topic, remote sensing knowledge and available financial and technical means in case of a flood event. The most demanded information are the clear delineation of affected areas, the determination of the current water table and the detection of affected traffic lines. The most favorable remote sensing products to detect these features are large scale orthophotos, delineation maps and vector files of the inundated areas. Differences between persons responsible for emergency management and persons responsible for incidence documentation occurred in terms of the temporal availability of data. For emergency management, data should be delivered as soon as possible but at the latest 24 hours after a crisis hit. Incidence documentation on the other hand is less dependent on quick delivery but favors spatially high resolute data.

The development of a map prototype demonstrated the challenging points within the rapid mapping processing chain. First and foremost, there is a lack of knowledge regarding the potential of satellite remote sensing. An awareness-building process thus has to take place within the cantonal crisis staff to illustrate the potential and the limitations of satellite remote sensing. Furthermore, much time was lost in the stage of pre-processing and map production. Optimization in these stages is necessary to guarantee a timely delivery. Despite these points of improvement, the National Point of Contact for Satellite Images (NPOC) would be able to develop remote sensing products that meet the needs of cantonal emergency management and incidence documentation.

Various ways of applying remote sensing data could be assessed whereas the added value remains difficult to determine. The limiting factor for emergency management is the delivery time. Federal authorities and persons responsible for incidence documentation, however, underlined the benefits of such products. This master's thesis provides a holistic view of the potential and limitation of satellite rapid mapping in Switzerland.

Zusammenfassung

Die Satellitenfernerkundung hat sich in den letzten Jahren rasant entwickelt. Die Verbesserungen in der zeitlichen und räumlichen Auflösung von Erdbeobachtungsdaten sind beachtlich. Die räumliche Auflösung von Satellitenbildern ist mittlerweile vergleichbar mit Luftbildaufnahmen und tägliche Aufnahmen sind möglich. Dies bringt auch neue Möglichkeiten für das Katastrophenmanagement. Bei grossflächigen Hochwassern haben sich Satellitenbilder bereits in mehreren Ländern bewährt. In der Schweiz dagegen wurden solche Bilder zum letzten Mal beim Hochwasser von 2005 eingesetzt. Es fehlte zudem eine Studie zu deren Nutzen im Katastrophenfall auf kantonaler Ebene. Unter diesen Voraussetzungen war eine aktuelle Beurteilung des Potentials von Satellitendaten erwünscht.

Im Rahmen dieser Masterarbeit wurde eine Umfrage bei den kantonalen Verantwortlichen für die Lagebeurteilung und die Ereignisdokumentation durchgeführt. Die Antworten zeigen ein unterschiedlich starkes Interesse am Thema, geringe Vertrautheit mit den Methoden der Fernerkundung und grosse Unterschiede in den zur Verfügung stehenden finanziellen und technischen Mitteln im Falle eines Hochwassers. Am dringendsten benötigt werden eine klare räumliche Abgrenzung der überschwemmten Flächen, der korrespondierende Pegelstand, sowie Angaben zu betroffenen Verkehrslinien. Dafür geeignete Produkte der Fernerkundung wären detaillierte Orthophotos, Übersichtskarten und ein Vektordatensatz der überfluteten Flächen. Die Rückmeldungen wurden in die Bereiche Lagebeurteilung und Ereignisdokumentation unterteilt. Deren Anforderungen unterscheiden sich am stärksten in der zeitlichen Nachfrage. Für die Lagebeurteilung müssen Produkte innerhalb von 24 Stunden geliefert werden. Für die Ereignisdokumentation spielt rasche Verfügbarkeit eine untergeordnete Rolle, jedoch sollten die Daten höchstaufgelöst sein.

Die Entwicklung eines Kartenprototyps zeigte kritische Punkte in der Rapid Mapping Prozesskette auf. Die befragten Stellen waren mehrheitlich nicht vertraut mit Satellitendaten. Eine Sensibilisierung der kantonalen Krisenstäbe und damit das Aufzeigen von Stärken und Schwächen der Satellitenfernerkundung sollten stattfinden. Eine Optimierung weiterer Prozessbereiche wäre notwendig, um eine rasche Datenlieferung zu garantieren. Dennoch wäre der National Point of Contact for Satellite Images (NPOC) bereits heute bereit um Fernerkundungsprodukte zu generieren, die den Nutzerbedürfnissen entsprechen.

Diverse Anwendungsbereiche konnten im Rahmen dieser Arbeit ermittelt werden. Die Bestimmung des Mehrwerts ist schwierig und meist abhängig von der Lieferzeit. Die vorliegende Arbeit zeigt die aktuellen Möglichkeiten und Limitierungen der Satellitenfernerkundung auf.

Acknowledgements

First and foremost I would like to thank my two supervisors Dr. Philip Claudio Jörg and Dr. Wolfgang Ruf. I am thankful for all the fruitful discussions we had, based on their comprehensive knowledge of their fields. Owing to their commitment, I was able to bring representatives of different fields together; this led to the interdisciplinary dimension of this thesis, for which I am particularly grateful. My thanks also go to Prof. Dr. Michael E. Schaepman, for the faculty representation and the initial acceptance of the topic of this master's thesis. I am also thankful to Arzu Çöltekin, who supported my idea from the beginning and gave me initial motivation for this project.

The foundations of this thesis are to be attributed to the large response rate of the cantonal authorities. I would like to thank all the respondents for their extensive feedback. Norina Andres provided access to the Swiss flood and landslide database. Prof. Dr. Norman Backhaus reviewed the questionnaire and Dr. David Small pre-processed the Sentinel-1 scenes. I would like to thank them for their effort. In addition, I greatly appreciated the participation of Francesco Wyss, Mathias Gross and Stephan Zellmeyer in the focus group meeting. Furthermore, I would like to thank Phyllis Chiffelle for taking the time to proofread the thesis.

Special thanks go to my parents for their support throughout my entire studies at the University of Zurich. I am grateful for their confidence, patience and generosity all through these years. Last but not least, I thank my girlfriend for the motivating talks and the continuous support during the intensive time of this master's thesis.

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Abbreviations

DEM	Digital Elevation Model
EM	Emergency Management (Lagebeurteilung)
EMS	Emergency Management System
EO	Earth Observation
FO BAFU	Führungsorganisation des Bundesamtes für Umwelt
FOEN	Federal Office of the Environment
ID	Incidence Documentation (Ereignisdokumentation)
NEOC (NAZ)	National Emergency Operations Center (Nationale Alarmzentrale)
RSL	Remote Sensing Laboratories
WMS	Web Mapping Service
WSL	Swiss Federal Institute for Forest, Snow and Landscape Research
UZH	University of Zurich

1. Introduction

1.1. Motivation

Large scale flood events, such as the incident of 2005, portray the catastrophic effects of natural disasters in Switzerland. Disasters strike on a smaller scale in comparison to other countries, yet cause large amounts of damage (Badoux et al. 2014). Well-trained emergency management increases preparedness and resilience during such events. Increasingly, Earth Observation techniques are used for disaster management (van Oosterom et al. 2005). Assistance from space can thereby provide valuable support in every phase of disaster management (response, recovery, mitigation and preparedness) (Voigt et al. 2007). Recent developments in remote sensing provide better and faster access to satellite imagery. This also offers new opportunities for disaster management. Spatial information on the flood extent is now delivered faster and with higher accuracy than ever before (Li et al. 2015). The last comprehensive evaluation of the potential of satellite imagery for disaster management dates back to 2007 (Buehler & Kellenberger 2007). Under these circumstances, a reevaluation of the opportunities provided by satellite images for disaster management in Switzerland needs to be undertaken. Flood events have a high damage potential and a frequent occurrence in Switzerland (Hilker et al. 2009). This is why the scope of this master's thesis is limited to flood events.

1.2. Objectives and research questions

The objective of this master's thesis is to analyze the process of satellite rapid mapping for flood events in Switzerland and to determine the added value of satellite data in a large scale flood situation. By these means this master's thesis provides a holistic view of satellite rapid mapping and the potential of remote sensing products. An integral approach was adopted to cover all segments of the processing chain with the following purposes:

- To assess requirements of cantonal crisis management
- To design a map prototype derived from satellite images based on user requirements
- To determine the scope of application for satellite derived data in case of a flood event in Switzerland.
- To strengthen the link among key players of rapid mapping in Switzerland.

The research questions are formulated as follows:

1) What are the cantonal user requirements in case of a large scale flood event in Switzerland?
    a) What kind of spatial information is needed and on what scale?
    b) When is this information needed? Is there a change in demand over time?
2) Which satellite remote sensing products would suit these requirements?
3) What are the challenges within the rapid mapping processing chain?
4) What is the added value of satellite derived data in comparison to today's applications in terms of content, timeliness and cost?

2. Theoretical basics

2.1. Floods in Switzerland

Floods are a common and repeatedly experienced natural hazard in Switzerland (Badoux et al. 2014). There are different types such as river floods, flash floods, lake floods or dam-break floods, each having different characteristics in their temporal and spatial occurrence (Bello & Aina 2014). Particularly the large scale events are responsible for high amounts of damage (Hilker et al. 2009). Within the last 40 years, large scale flood events occurred in 1978, 1987, 1993, 1999, 2000 and 2005 causing an aggregated damage of approximately 9.6 billion Swiss Francs. The event of 2005 even exceeded the expectations of the weather forecast team of MeteoSchweiz in its intensity (Bezzola & Hegg 2008). Wet conditions in early August led to saturated soils. An additional intense precipitation was then forecasted for the last weekend in August. In some parts of the country, however, almost double the estimated rainfall occurred. Nearly one third of the Swiss communes were affected by floods. Collateral processes such as erosion, landslides, debris flows and overbank sedimentation caused additional damage in alpine valleys (Bezzola & Hegg 2008). Six people lost their lives and the total damages added up to 3 billion Swiss francs. This event caused by far the most damage over the past decades. However, in comparison to historical records, the event was not a singularity and is likely to happen again (Bezzola & Hegg 2007).

As in many other countries, the population, the urban settlements and the amount of valuable infrastructure have increased and with that the damage potential (Swiss Federal Statistical Office (SFSO) 2012). Financial damage data of floods, debris flows and landslides that occurred after 1972 are collected in a spatial database by the Swiss Federal Institute for Forest, Snow and Landscape Research WSL (Hilker et al. 2009). There is an uneven distribution of damage within the cantons, as an extract of the database illustrates (see Figure 1). The cantons with the 8 highest amounts of damage account for 80% of the total damage. Cantons in Central Switzerland or the Alps experience higher damages by floods, debris flows and landslides. This is due to a combination of relief energy and national infrastructure according to Hilker et al. (2009).

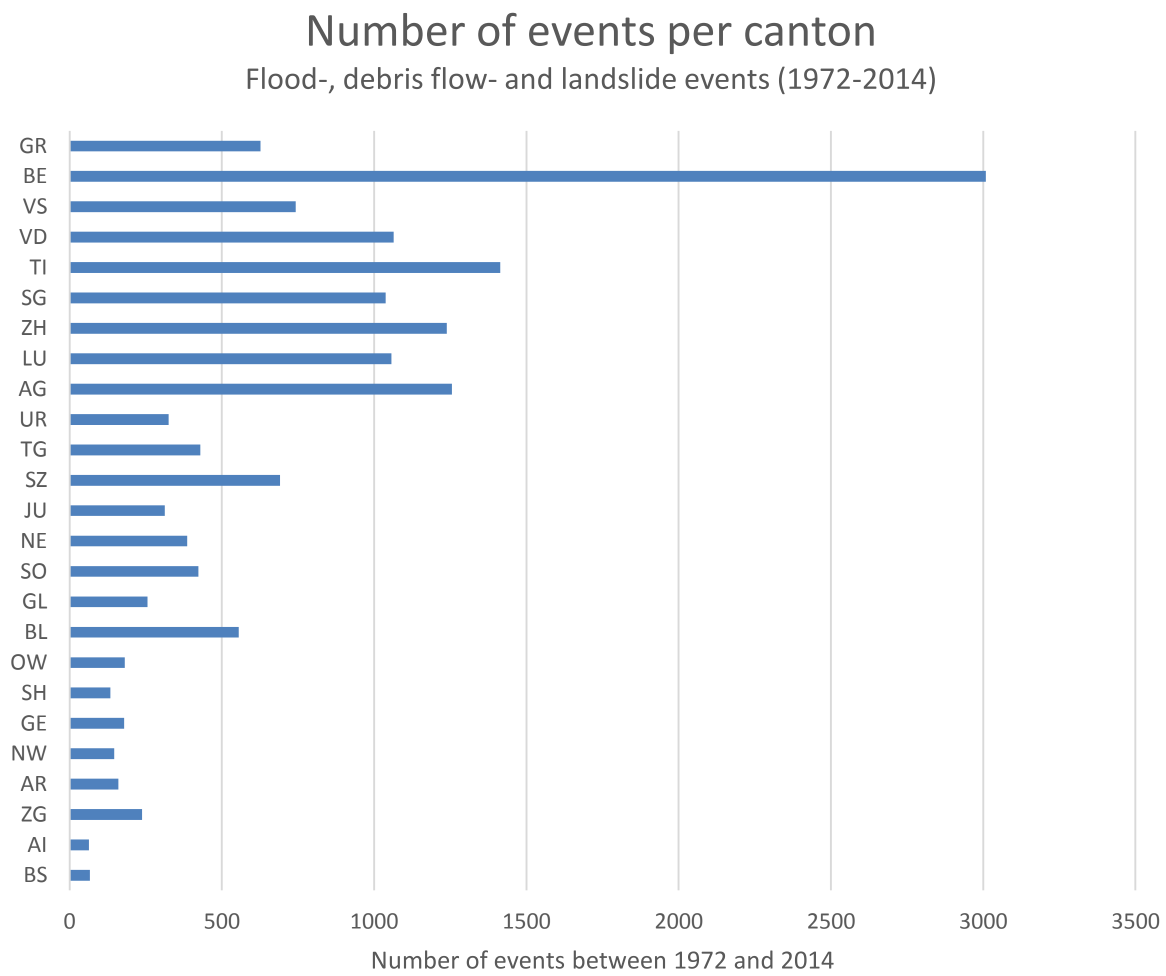


Figure 1: Number of flood- debris flow- and landslide events per canton. Cantons ordered by size whereupon Graubünden (GR) is the largest and Basel-Stadt (BS) the smallest (Hilker et al. 2009).

2.2. Emergency management

Adequate emergency management involves a variety of public and private actors. The civil protection system is responsible for the preparedness and response phase and consists of five partner organizations: police, fire brigade, healthcare system, technical services and protection and support service (Hess & Schmid 2012). These rescue and relief units depend on information and early warning provided by the specialist authorities. Local natural hazard experts or research institutions are only two out of many supporting organizations. Private actors such as telecommunication companies or the media often play a significant role in informing the public (Roth et al. 2013). Constant commitment is needed to guarantee an uninterrupted communication in times of crisis. The coordination of these public and private actors is challenging.

Tasks are also shared among the different levels of the Swiss state. Responsibility for local events lies with the municipalities (or communes). In case of an emergency across communal borders, the cantonal emergency management provides support. If several cantons are affected, the Federal authorities get involved as well. This cascading system guarantees adequate response according to the respective size of an event (Bischof et al. 2012).

The large scale flood event of 2005 put the Swiss emergency management to a test. Subsequent analysis revealed that damage could have been avoided by implementing enhanced measures in the areas of preparedness, early warning and response (Hess 2010). A lack in coordination between the responsible federal authorities resulted in delayed warnings. Furthermore, there was limited exchange between the crisis staff and experts of meteorology, hydrology, geology and engineering at all state levels. In addition it was found that the flood forecasting service was not well enough developed for such an event (Hess & Schmid 2012). Hence, a set of measures was elaborated through a project named OWARNA (Hess 2010). The lack of a single contact center and the delay in adequate and timely information was solved by establishing a "single official voice" for warnings from the federal authority. The crisis staff FO BAFU was formed for internal crisis management at the FOEN (Federal Office for the Environment (FOEN) 2014). In case of a flood event on national scale, the FO BAFU is enlarged to the so-called "Fachstab Naturgefahren" also involving the National Emergency Operations Center (NEOC), MeteoSchweiz and WSL. A newly developed business continuity management ensures 24-hour preparedness. The crisis staff continually publishes situation reports and warnings. A five level hazard scale for flowing waters was adopted based on the recurrent period of runoff (HQ_x) (Hess & Schmid 2012). Statistical recurrent rates were calculated for each water body starting at 2 years (HQ_2) followed by HQ_{10}, HQ_{30} and HQ_{100}. A different classification is applied for lakes. The variance between summer high and flood limit is divided into three equal parts which represent level 1 through 3. The flood limit sets the transition between danger level 3 and 4. Danger level 5 is reached, if the water table surpasses another 25cm. The hazard level is constantly adapted by the FOEN and published on the new platform for natural hazards (also see www.naturgefahren.ch). Owing to these improvements in preparedness and early warning, the Swiss emergency management is now better prepared for upcoming flood events.

Over the course of a flood event, multiple actors are involved as mentioned earlier in this chapter. A way of categorizing these actors is the division into emergency management and incidence documentation. The *emergency management* includes rescue services, operational headquarters, and other institutions that respond to the crisis immediately. Mainly two types of information are demanded according to Allenbach et al. (2005): spatial extent of affected areas and an assessment of human and material impacts. The data is often displayed in an emergency management information system (van Oosterom et al. 2005). Timeliness is crucial for decision-making within the emergency management: information is needed as fast as possible. The focus of *incidence documentation* on the other hand relies upon the accuracy of the spatial information.

Division of competencies between NEOC and FO BAFU (focus group meeting, 8 May, 2015)

The FO BAFU acts as the single point of contact for natural hazard emergency situations. In case of a natural hazard emergency such as flooding, FO BAFU coordinates demands for aerial or satellite date with Swisstopo. The decision about the proper way of data acquisition lies with the Swisstopo (i.e. aerial image, satellite imagery, Charter call, etc.)

For non-natural hazard emergencies, the NEOC acts as the single point of contact and coordinates the contact with Swisstopo. Besides that, the NEOC is responsible for activating a Charter Call. Requests for satellite imagery are usually triggered by cantonal authorities. Grave unique situations (i.e. earthquake) would be the only disaster type where the NEOC itself triggers an activation. Besides these coordinated processes, the NEOC always notifies Swisstopo in case of a hazard event of 4 or higher. Mechanisms for preparedness and adequate response are thus exemplarily implemented.

Detailed documentation in the aftermath of an event is usually carried out by all participants. Pre- and post-disaster spatial data is used for an in-depth analysis of the preceding incident. A crucial point in data gathering is the recording at the peak of a crisis. Data analysis as a following step is however not a time critical task. Requirements on spatial data thus vary between emergency management and incident documentation. Both shared the need to display the entire event in one system or on one map. Valuable support in gathering this information comes increasingly from spaceborne data (Allenbach et al. 2005).

2.3. Remote sensing and disaster management

Satellite remote sensing sensors can be divided into optical and radar sensors (Lillesand et al. 2015). Optical sensors capture the solar reflectance of the earth's surface. They are passives sensors, since they only measure received radiation. The optical image is in different color bands and can thus be used for flood detection. Conversely, radar sensors send out microwave beams and measure their reflectance (Albertz 2009). The actively measured values represent the surface roughness and are displayed in a speckled grayscale image. Urban areas for example, appear bright, since the radar beam is reflected towards the sensor by corner reflectors. Flat water surfaces appear dark because beams are reflected away from the sensor. Water detection with a so-called synthetic aperture radar (SAR) have thus become common for flood mapping (Long et al. 2014). An additional advantage of radar sensors is their all-weather day-and-night capability (Malenovský et al. 2012). The microwave beams can be sent and retrieved in cloudy conditions and also at night. A disadvantage is the difficult image interpretation of the grayscale image for laypersons, which is why experts are needed for flood data retrieval. Both acquisition methods have their advantages and disadvantages and are currently applied for flood detection (Serpico et al. 2012).

Satellite remote sensing has experienced a tremendous development in recent years. The possibilities of earth observation (EO) have rapidly improved in terms of their spatial and temporal acquisition. Spatial resolution is defined as the size of a pixel on a satellite image (Lillesand et al. 2015). For example, SPOT-5, a satellite launched in 2002, had a 5 meter spatial resolution (Voigt et al. 2007). The recently launched WorldView-3 satellite acquires images on a resolution of 0.31 meters (Digital Globe 2014). The images acquired in the sub-meter area yield new ways of satellite image application (also see Figure 2). Revisiting times (defined as the time that elapses between the first and the next possible image acquisition) has been cut down as well (Serpico et al. 2012). This can be done in two ways. One way is to maintain a constellation of multiple satellites. Multiple satellites on different orbits offer better coverage (Razoumny et al. 2004). Examples are the Pleiades mission by Airbus Defense and Space (Baudoin et al. 2002) or the Sentinel missions by the European Space Agency (Malenovský et al. 2012). Another method is the pointing ability of satellites (Torres et al. 2012). Instead of collecting transects aligned with the space craft, a selected orientation of the sensor enlarges the field of coverage (Pang et al. 2011). These two options considerably increase reactivity in case of a disaster. Acquisition of satellite data with higher spatial and temporal resolutions than ever before now offer new possibilities for applying remote sensing for disaster management.

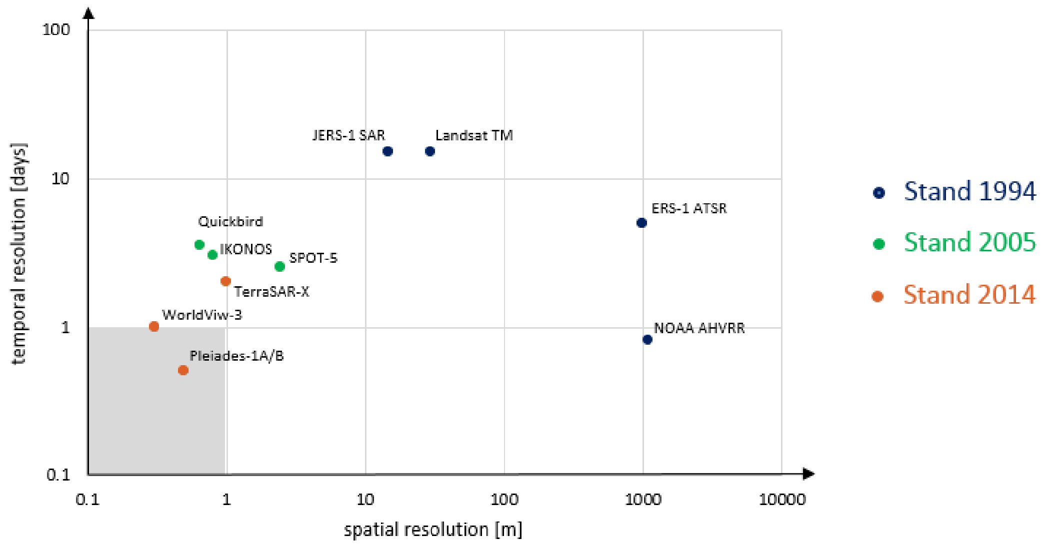


Figure 2: Development of spatial and temporal resolution in remote Sensing (Rasmussen et al. 1994; Satellite Imaging Corporation 2015)

The provision of EO data for emergency management is organized through different national and international initiatives such as the International Charter on Space and Major Disasters (short form *Charter*) or the Copernicus Emergency Management System (EMS) (Martinis et al. 2014). Since its foundation in 2000, the Charter provides satellite data in case of a disaster. The aim is to enable the international community, and in particular countries with no access to EO data, to benefit from the space resources in times of a disaster (Ito 2005). In comparison to the Copernicus EMS program, countries do not have to sign the Charter to benefit from it. The service is free of charge for every user. Up to the current date, 23 agencies, institutions and private space companies are members of the Charter (International Charter 2015). The recent earthquake in Nepal on 25 April 2015 triggered the 530th activation since its foundation. Overall, the Charter can be seen as a success story in international cooperation for improving disaster management. Once a Charter call is activated, the members participate in the elaboration of the data. The value adding step, however, is executed by a specialized operator such as UNOSAT, DLR ZKI (Germany), SERTIT (France) or the National Point of Contact for Satellite Images (NPOC) in Switzerland (Allenbach et al. 2005). Crucial is the time between the disaster and the final delivery of the spatial information (Serpico et al. 2012). By developing a semi-automated data processing chain, satellite data can quickly be transformed into required products. This process is also known as rapid mapping (Dumitru et al. 2014). Rapid mapping products are ready-to-use maps or datasets of the disaster area. Valuable spatial information such as delineation of affected areas or impact intensity supports emergency managers in their decision-making process.

The German Center for Satellite Based Crisis Information (DLR ZKI) divides the rapid mapping process into 5 phases: mobilization, data acquisition, pre-processing, analysis and rapid mapping production (see Figure 2) (Center for Satellite Based Crisis Information 2015). A different classification was proposed by Allenbach et al. (2005) with four phases. In this master's thesis, the nomenclature of DLR ZKI was adapted:

1. Mobilization: Once a disaster strikes, a request for satellite images has to be activated by a potential user. The triggering of the rapid mapping process thus lies with the data user.
2. Data Acquisition: Satellite data can either be acquired through the Charter or commercially online. Different levels of products can be ordered depending on the intended further analysis. In addition, archive data can be valuable to compare the pre- and the post-disaster areas (i.e. for change detection).
3. Pre-Processing: The raw satellite data has to be run through geometric correction and if needed radiometric calibration. Only after this step is the image ready for further analysis.
4. Analysis: Information extraction such as location and extent of affected areas or human and material impact assessments are applied in this step.
5. Rapid mapping production: Adding supplementary cartographic information is the final step for a ready-to-use product. In this master's thesis, this final step will be named *map production*.

Charter Call activation in Switzerland (focus group meeting, 8 May, 2015)

In Switzerland, the National Emergency Operations Center (NEOC) is responsible for activating a Charter Call. Nonetheless, an activation is only triggered if requested by a canton, or the confederation in case of a large scale flood event. The National Point of Contact for satellite Images (NPOC) acts as contact point for satellite images and is currently responsible for steps 2 through 5. The NPOC is a joint venture by the Remote Sensing Laboratories (RSL) at the University of Zurich and the Federal Office of Topography Swisstopo. The RSL is responsible for the scientific part and Swisstopo for the operational part. Yet, in case of a Charter Call both are involved.

Within the rapid mapping workflow, the production time remains crucial. Recent innovations in remote sensing have already reduced the process time. On average, most time is taken up by the mobilization and the data acquisition phase (Allenbach et al. 2005). The automation processes of the pre-processing and analysis phases are continuously refined (Martinis et al. 2014; Lanaras et al. 2014; Cho et al. 2014; Buehler et al. 2006).

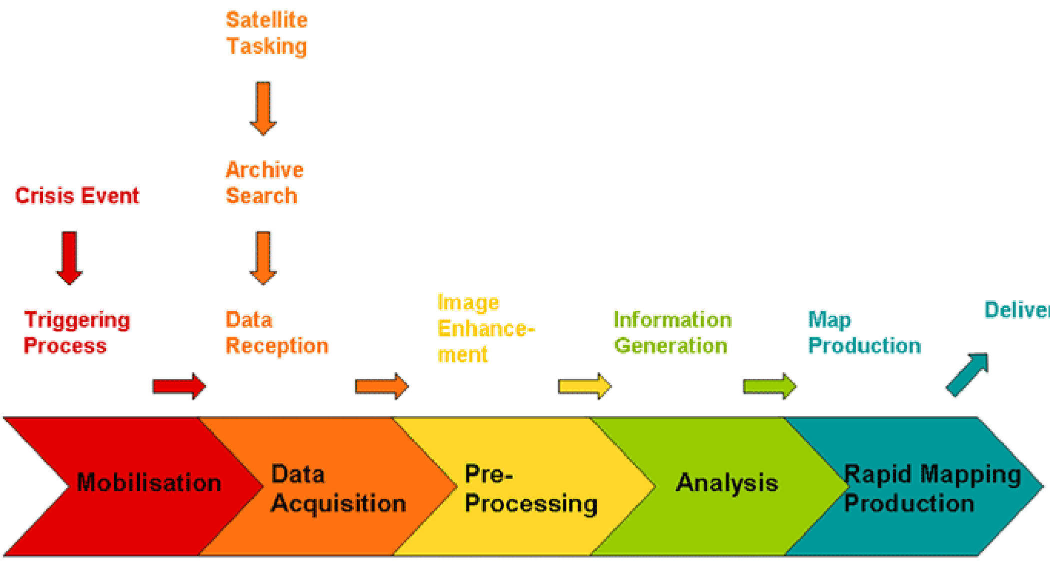


Figure 2: Rapid Mapping Workflow (DLR ZKI, 2015)

2.3.1. Rapid mapping products

Orthorectified satellite images, meaning distortion-free images, are combined with additional spatial information along the rapid mapping process (Serpico et al. 2012). Additional cartographic information such as reference grid, inset map or event summary facilitate the interpretation of the map for the end-user. Moreover, the flooded areas can be further analyzed. For example, inundated areas can be intersected with the local road network. Flooded streets can be highlighted on the map or water depths determined. Such subsequent spatial analysis upgrades the value of satellite data. The final products are thus categorized according to their level of refinement (Lemoine & Giovalli 2013):

1. Reference map: Geographical reference maps cover little known areas and are used as a support for foreign map readers in case of a disaster. Access to topographical maps is often difficult to obtain. Hence, reference maps are usually the first types of rapid mapping products. The bases are archived satellite data, combined with place names, street network and infrastructure information.

2. Delineation map: A satellite captures an up-to-date image of the crisis situation. The currently inundated areas are then derived from the image and highlighted on the map. The purpose of a delineation map is to deliver a quick and clear view of the flood extent.
3. Grading map: Detailed spatial information such as damage distribution, affected population, critical infrastructure, etc. display the degree of severity. By combining the flood extent with spatial data, further thematic information can be provided on this map. Prerequisites are accurate geo-data of the targeted area.

These map types are used by the Copernicus Emergency Management Service (Lemoine & Giovalli 2013). Allenbach et al. (2005) divided *grading maps* into event *intensity maps* and *impact maps*. However, in this thesis the nomenclature of Copernicus EMS was adopted. It is important to mention that the production time of grading maps is longer than for delineation maps.

The range of remote sensing products surpasses plain maps. Digital elevation models (DEM's) were already successfully applied in flood situations for mitigation measurements or inundation estimation (Dumitru et al. 2014; Serpico et al. 2012; Hess & Schmid 2012). The provision of earth observation data in different formats (shapefile, webmap, geodatabase, etc.) enables customized adjustments by end-users (UNOSAT 2015). A wide variety of rapid mapping products are thus available and increasingly used for disaster management (van Oosterom et al. 2005).

2.3.2. Charter Call 100

As mentioned in Chapter 2.1, the flood event of 2005 affected large parts of Switzerland. For the first and only time, the Charter was activated for the country (Buehler et al. 2006). The NPOC at the University of Zurich acted as specialized operator and developed rapid mapping products. A suggestion concerning the development of a rapid mapping processing chain was later elaborated by Bühler and Kellenberger (2007). Difficulties were faced in the mobilization-, analysis- and map production-phase. As mentioned above, the point in time of activation is decisive. The actual request was not initiated until three days after the event peaked. Data reception of the RADARSAT-1 and SPOT5 satellite took another three days. For a smooth analysis, several assets have to be available. These include easily accessible and pre-processed geo-data, high capacity hardware, adequate image processing software and skilled staff members.

Moreover, Bühler and Kellenberger (2007) moreover concluded that:

- The time-delay in the mobilization phase can be minimized if the authorized user is better aware of the potential of EO capabilities.
- A detailed rapid mapping process has to be established to guarantee accurate and timely rapid mapping products.
- The link between the NPOC and the end-user was not established well enough and there were barely any end-user studies.

2.3.3. Previous user surveys

At the start of this master's thesis in fall 2014, key persons of the RSL and the Federal Office of Topography Swisstopo were questioned about the current state of the art. The NPOC conducted three surveys on the needs of EO services. Federal authorities have been questioned on their needs of certain products (Treichler & Seidel 2007; Seidel & Treichler 2010). The most recent report of 2012 asserted widespread demand for satellite derived products (Odermatt et al. 2012). In case of an emergency, federal and cantonal emergency managements would be potential users of rapid mapping products. A representative of Swisstopo underlined a lack of knowledge in terms of cantonal user requirements (F. Wyss, Swisstopo, personal communication, November 27, 2014). Furthermore, a user study on the cantonal level has not yet been undertaken and therefore seemed to be urgently needed. In addition, key players of the RSL, Swisstopo, FOEN and NEOC have not held a collaborative meeting in years. It was therefore concluded, that up to now, the three points criticized by Bühler and Kellenberger (2007) have not yet been fully put into practice.

3. Methods

This master's thesis intends to provide an integral perspective of the potential of satellite rapid mapping in Switzerland. Because of that, several methods were applied to provide a deeper insight into the entire processing chain. Cantonal emergency management and incidence documentation are potential users of satellite derived flood data. Therefore, a questionnaire was developed in collaboration with the FOEN to assess their user requirements. The results from the questionnaire led to the creation of a map prototype. In this process, raw satellite data was converted to delineate flood information in a remote sensing application. The pre-processed image was then combined with additional spatial information to create a map prototype. Ultimately, a focus group meeting of key stakeholders took place to first, determine the applicability of such a product and second, to discuss their added value. The application of these diverse methods should finally lead to a holistic view of the current potential of satellite rapid mapping and should outline the added value of satellite derived data.

3.1. Questionnaire Cantonal representatives

The questionnaire was developed through an iterative process. Both the RSL and the FOEN were involved to address the targeted audience appropriately. Studies on user requirements can be done in two ways. Either a predefined product is presented and potential users evaluate its usefulness or users are given the chance to freely formulate their needs and the designer subsequently creates the product (Courage & Baxter 2004). On one hand, satellite derived flood maps are already being produced, for example by DLR ZKI or UNOSAT. Three types of flood maps were portrayed and the targeted audience had to determine their usefulness. On the other hand, an open expression of the cantonal authorities was perceived. Open questions were thus integrated to gain qualitative feedback as well. The questionnaire thus contained a mixture of both methods. By incorporating quantitative and qualitative answers, an in-depth analysis of the user's temporal and spatial requirements could be generated. The answers not only presented demands for the three map types, but also asked for other spatial user requirements. In this way, the need for other rapid mapping products could be assessed as well.

3.1.1. Targeted audience

Satellite data of emergency situations could be used by the civil protection, fire departments, the army, individuals, natural hazard experts, insurance companies, media etc. (Hess & Schmid 2012). A limitation in scope was therefore necessary. In spite of the fact that federal authorities have been repeatedly questioned in recent years, a user requirement of cantonal crisis management was still lacking (Treichler & Seidel 2007; Seidel & Treichler 2010; Odermatt et al. 2012). The survey was therefore developed with the FOEN and distributed solely within the cantonal administrations. The target audience were people within these administrations who were responsible either for the incident documentation or the emergency management. Both are potential users but have different requirements (Allenbach et al. 2005). It was expected that persons in charge of emergency management need spatial information as soon as possible. Persons responsible for incidence documentation were expected to attach less importance to a quick delivery. Their focus would rather be on accuracy and precision of data. Based on these assumptions, a clear assignment of each response to one of the two classes could be made.

The cantons as targeted audience were further analyzed. The Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) was thus contacted in order to get access to their natural hazard database (N. Andreas, WSL, personal communication, 27 January, 2015). Fortunately, N. Andres provided a direct output from the database over the period of 1972 to 2014. The excerpt contained statistics on the frequency of events and the damage amounts. In terms of frequency, the following conclusions could be made:

- The spatial distribution of flood events in Switzerland is spread unequally within the cantons.
- Between 1972 and 2014 seven cantons recorded more than 1000 incidents (see Figure 1).
- Due to their size, smaller cantons are affected less frequently than larger cantons. However, with an increase in size, the spatial extent turns out to be less important. Relatively few events occurred in the cantons of Basel-Stadt and Appenzell Innerrhoden.
- With a total number of 3009 events, the canton of Bern was by far the most damage-prone canton according to the dataset, followed by Ticino with 1414 events.

The database contained two datasets: one on the damage amounts with the effective costs and another with the damage amounts taking inflation into account. Both insured property damage and not-insured or not-insurable material damage were considered (Hilker et al. 2009). If information on the direct financial loss was not available, damage was estimated based on empirical values (insurance evaluations, damage experts, emergency task forces and official sites). Figure 3 displays both datasets.

The following remarks rely on the inflation corrected dataset, since these are more comparable (Hilker et al. 2009):

- Aggregated damages per canton between 1972 and 2014 show an uneven distribution of damage across the cantons.
- The largest amount of damage was experienced in Bern (2'896 Mio CHF) and the lowest in the two smallest cantons in size (AI: 5.7 Mio CHF, BS: 19.6 Mio CHF).
- Large scale events considerably influence the statistics. Over 50% of the damage recorded was caused by the single flood events of 1978, 1987, 1993, 1999, 2000 and 2005.
- Limiting factors for high damage amounts are low relief energy and a relatively small amount of valuable infrastructure.

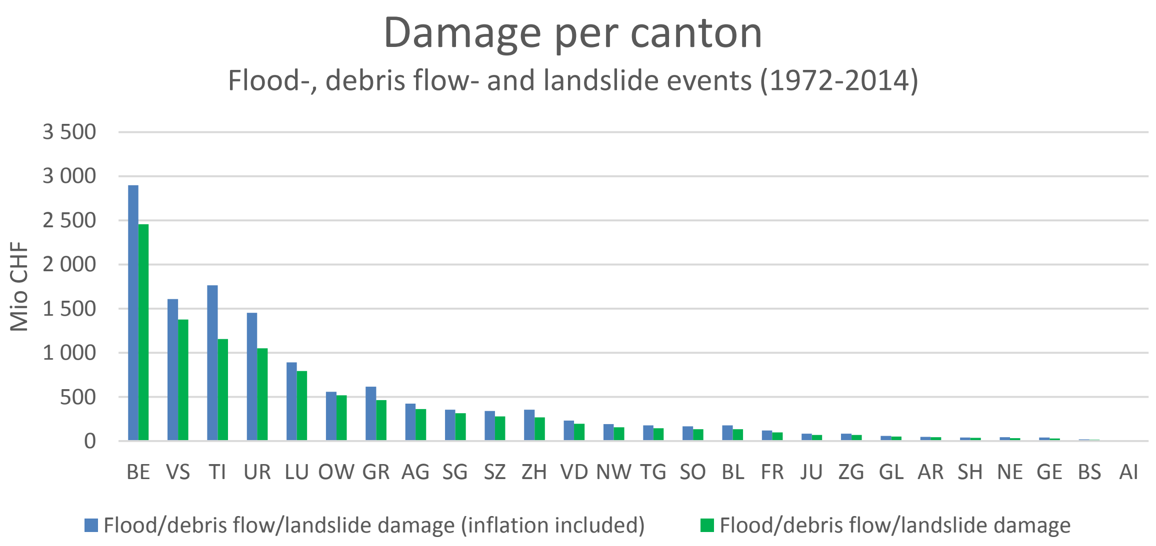


Figure 3: Damage distribution of floods, debris flows and landslides damage per canton (Hilker et al. 2009).

It has to be considered that not every event that took place was actually documented in this database. In addition, Hilker et al. (2009) noticed regional and temporal variations in the quality of documented events. Nonetheless, the relatively long-term dataset includes data for all of Switzerland at a spatial resolution down to community level and is thus a valuable source to locate flood, debris flow and landslide damage within Switzerland.

Based on this information, it was decided that cantons with 1000 incidents or more were "must haves" in the final population of the user study. Four cantons registered damages of more than 1 billion Swiss Francs (BE, VS, TI and UR). The cantons of Valais and Uri experienced an extraordinarily high amount of damage which is why those two cantons were also categorized as "must haves". The final “must have” population contained Aargau, Bern, Lucerne, St Gallen, Ticino, Uri, Valais, Vaud and Zurich.

Damage (>1000 Mio CHF)	Incidents (>1000)
BE	BE
VS	TI
TI	AG
UR	ZH
	VD
	LU
	SG

Table 1: List of incidents and damages of flood affected cantons (source: WSL damage database)

3.1.2. Structure

The questionnaire was divided into three parts: (1) questions on the current type of spatial data use, (2) the evaluation of sample products including their usability and (3) questions on the data quality and delivery method.

3.1.2.1. Current spatial data use

The aim of the first section (questions 1 through 3) was to gain more insight into the present use of spatial data. Knowing what information sources are used would help to develop rapid mapping products that fit the cantons’ existing processes. Questions 1 and 2 thus dealt with information sources (rescue workers, media, drone data, etc.) and their means of display/modification (physical map, digital map, tablet etc.). In addition, a controlling question was added to determine whether the person was responsible for incidence documentation or emergency management (see Chapter 2.2 Emergency management).

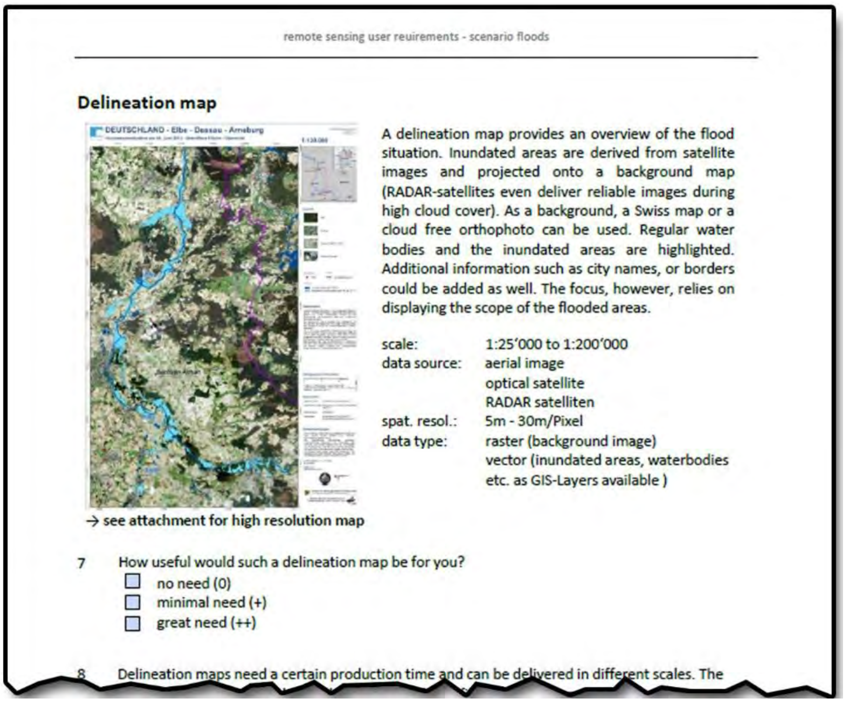
3.1.2.2. Sample products and usability

The responders were then introduced to three potential products: (1) Orthophoto, (2) delineation map and (3) grading map. Each of these represents a further refining step of satellite or aerial images and thus also takes more time to produce. The Orthophoto was included instead of the usually produced reference map. Such maps are not needed in Switzerland due to the outstanding high quality of Swiss national maps. The Federal Office of Topography Swisstopo regularly update their map products delivered from small to large scales. An orthophoto was incorporated as an alternative (Albertz 2009).

Earlier user studies already applied a scale for user demands. (Treichler & Seidel 2007; Seidel & Treichler 2010b; Odermatt et al. 2012). The rating scale of Seidel&Treichler (2010b) was slightly adapted:

- 0 = no need - No added value in comparison to currently used means.
- \+ = minimal need - Could be used but equivalent options are available.
- ++ = great need - Would be an improvement in comparison to the currently used means.

The cantonal crisis staffs were expected to have little knowledge of potential remote sensing products. Thus, a specification on each map type was given at the beginning of each chapter. A short sample of the type of map and a portrayal of its applicability, strengths and weaknesses was provided. In addition, these short descriptions and the attached remote sensing fact sheet promoted remote sensing within the cantonal authorities. The short samples were thus also a means of sensitization on remote sensing. The sample was followed by asking how useful such a map would be for the responder’s purposes (see Figure 4).



remote sensing user reuirements - scenario floods

Delineation map

A delineation map provides an overview of the flood situation. Inundated areas are derived from satellite images and projected onto a background map (RADAR-satellites even deliver reliable images during high cloud cover). As a background, a Swiss map or a cloud free orthophoto can be used. Regular water bodies and the inundated areas are highlighted. Additional information such as city names, or borders could be added as well. The focus, however, relies on displaying the scope of the flooded areas.

scale:	1:25'000 to 1:200'000
data source:	aerial image optical satellite RADAR satelliten
spat. resol.:	5m - 30m/Pixel
data type:	raster (background image) vector (inundated areas, waterbodies etc. as GIS-Layers available)

→ see attachment for high resolution map

7 How useful would such a delineation map be for you?
- ☐ no need (0)
- ☐ minimal need (+)
- ☐ great need (++)

8 Delineation maps need a certain production time and can be delivered in different scales. The

Figure 4: Sample of the delineation map portrayed in the questionnaire.

One of the main goals was to define at which point in time a specific kind of map product was needed. A scale-availability-matrix was created to reach that goal (Figure 5). Responders had to evaluate whether the corresponding map product would be of "great need" (++), "minimal need" (+) or "no need" (0). Time steps and map scales varied between map types since the production time varied as well.

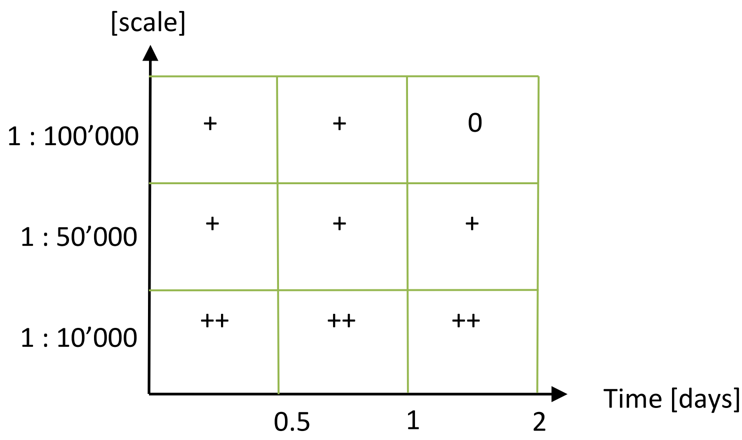


Figure 5: Example of a scale-availability-matrix

It was expected that the emergency management would prefer large scale maps at the beginning and small scale maps after some days. Additionally, a difference in preferences was expected between emergency management and incidence management.

3.1.2.3. Data delivery and data quality

This thesis should also reveal, how a potential product should be transmitted to the end-user. Therefore the last part focused on delivery preferences and data format. Furthermore, respondents were given the chance to formulate remarks, desires and expectations freely (question 21). This and other open questions gave chances for qualitative feedback. Overall, the questionnaire was an opportunity for the cantonal representatives to communicate their requirements, concerns and expectations on the use of satellite derived flood maps.

3.1.3. Pre-test

Piloting is a mandatory element for user-requirement testing and increases the quality of the results (Courage & Baxter 2004). For a last evaluation, the final questionnaire was therefore sent to the central command of the canton of Bern. They volunteered to fill out the questionnaire and to give extensive feedback. Their main critic concerned the difference between the map types. They did not actually realize how significant the production time of the three map types was. As a reaction, the map type descriptions were revised to better describe the duration of each product. The choice of examples of disaster maps from Germany and Pakistan were a bit out of their reach. Flood maps from Switzerland would be more tangible for cantonal emergency managers. Yet such examples did not exist for Switzerland. Developing a map prototype before the user requirement was refused since the map prototype should precisely result from these requirements. Prior surveys of the FOEN showed that the response rate was higher if a survey was distributed in several languages. Because of that, the questionnaire was translated into French (by the FOEN) and English (by the author).

3.1.4. Distribution

The questionnaire was distributed by means of two channels. The goal was to reach both representatives of emergency management and representatives of incident documentation. For that reason, the questionnaire was sent via email by the FOEN (W. Ruf) and the NEOC (M. Gross). Thereby, the questionnaire reached cantonal representatives of both segments directly. A window of three weeks was set for the reply.

3.1.5. Analysis

Incoming questionnaires were targeted with an ID and gathered in one raw-data-collector (excel-file). This file was the basis for all further analysis. In a couple of replies, some questions remained incomplete. In severe cases, the responders were repeatedly contacted for further information. One responder avoided an answer because he felt that the demand varies from case to case. The scale-availability matrix turned out to be too complicated to answer since most incomplete answers were given there (questions 5, 8 and 15). A lot of responders didn't fill in every field of the matrices. Therefore, deductions were made with the following assumptions:

> If a user is committed to wait 2 days for a product, he would be even more satisfied to have the product in advance. In this case, "+" or "++" were added to fill in the incomplete fields.

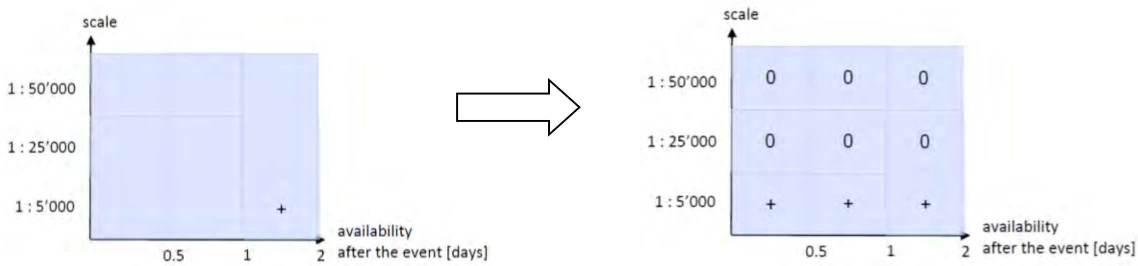


Figure 6: Dealing with incomplete matrices (questions 5, 8 and 15).

The matrices were then transformed to visualize the demand of each map over time. The answers were coded as followed (no need = 0, minimum need = 1, great need = 2). For each field, the sum was calculated. Afterwards, a ratio was established between the sum and the maximum number of points. The resulting ratio reflected the overall need of the corresponding field. As a result, a ratio between 0 (no need) and 1 (great need) was derived. The demand for each map scale was then plotted on a time axis as shown in Figure 7.

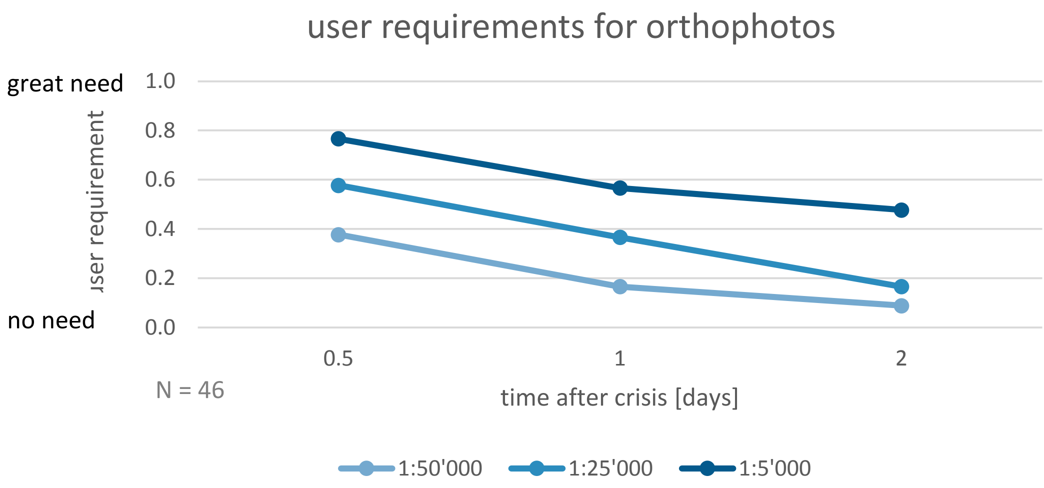


Figure 7: Example of a visualization of user requirement over time

From the raw data collector, charts and lists were created which first led to an adequate map prototype creation and second illustrated the results in the focus group.

3.2. Creation of map prototype

The integral view of satellite derived flood mapping also included the development of a flood map prototype. Flood maps are operationally produced by the German Center for Satellite Based Crisis Information (DLR ZKI), the United Nation's operational satellite application program (UNOSAT), the French Service régional de traitement d'image et de télédétection (SERTIT) and many more. There were several reasons for the development of such a prototype. First, to implement the obtained user requirements in an actual product. Second, to give a potential product to the decision-makers who took part in the focus group, and third to run through the entire map production process with the means provided by the RSL. In case of an emergency situation, they would collaborate with Swisstopo for a timely satellite data delivery. This would be an opportunity to investigate the entire process of rapid mapping at the RSL.

Data from the recently launched Sentinel-1 satellite are periodically processed at the RSL. The satellite captured scenes of a flood event in Ticino in November 2014. Severe rainfall led to floods around the lakes of Lago Maggiore and Lago di Lugano (BAFU (1), 2014). The two lakes first breached the critical flood level on 12 November 2014. After a slight recovery the lake level reached its peak on 16 November at 196.41 meters above sea level. The yearly lake level average in 2014 was at 193.84 m.a.s.l. (Federal Office for the Environment (FOEN) 2015)). For the first time since its implementation, a lake flood event was classified as level 5 on the new Swiss hazard scale. Lago Maggiore inundated adjacent parts of the city of Locarno and parts of the Magadino plain (Figure 8).

Figure 8: Aerial image of inundated Magadino plain on 16 November 2014 (Neue Obwaldner Zeitung 2015).

The processing chain of DLR ZKI was applied to develop a map product. A detailed flowchart is attached in Appendix 7.2. The mobilization phase is the first stage whereby a user sends a request for satellite imagery to the responsible contact point. The precondition is that the user knows of potential remote sensing products and initiates such a request as early as possible. As mentioned in Chapter 2.3, this is the part where most time is usually lost in case of an emergency. The mobilization step did not take place in this master's thesis. The residual steps are documented in-depth in the following chapters.

3.2.1. Data acquisition

Sentinel-1 is part of "European Copernicus satellite program" and was launched on 3 April 2014 (European Space Agency 2015). The onboard CSAR instrument provides all-weather, day- and night radar images (Torres et al. 2012). Sentinel-1 images were already successfully used for flood mapping in the Balkans and in Namibia (European Space Agency 2014). In November, the satellite captured a total of 11 scenes of the Lago Maggiore area (3., 4., 15., 16., 27., and 28. November). The flood peaked on November 16, 2014. The scenes of 15 November and 16 November precisely captured the flooded region and were further processed.

ID	Date	Time	Orbit	Product type	Polarization
05	15.11.2014	05:34 (UTC)	Descending	GRDH	VV
07	16.11.2014	17:23 (UTC)	Ascending	GRDH	VV

Table 2: Specifications on processed Sentinel-1 data

3.2.2. Pre-processing

Sentinel-1 ground range detected high resolution (GRDH) products were first geometrically and radiometrically corrected. In both cases, a 10m DEM (derived from the swissALTI3D 2013 dataset) was applied. With the high resolution elevation model (10m) the ground range radar coordinates were terrain-geocoded into the Swiss reference map coordinate system (Datum CH1903+). In a further step, radiometric terrain correction mitigated distractions from topography-induced distortions. These corrections were realized by Dr. David Small at the RSL of the University of Zurich.

The corrected images were then reformatted into the GIF file format. This step reduced the data size, and was compatible with the software ERDAS Imagine used for further image analysis. The data annotations were set to the projection coordinate system “CH1903+". The data were then reformatted into the ERDAS image format (.img) for further analysis. From this point, all image analysis was performed in ERDAS Imagine.

3.2.3. Analysis

An often-used approach in rapid mapping is called change detection (Cho et al. 2014). Differences between pre and post disaster images are thereby delineated as potentially damaged areas. Owing to significant differences in image reflectance between the different scenes, this approach was not yet possible. Instead an established and simple threshold method was applied. There are two challenges in applying a threshold: (1) SAR imagery is highly speckled due to different interference with the surface of objects. Equal object surfaces can have different reflectance values. This noisy effect is also known as speckle noise (Oliver & Quegan 1998). (2) Areas on the leeward side of mountains receive less or even no radar beams. This results in low reflectance values which is similar to water bodies (Song et al. 2007a). The speckled noise was slightly reduced with a mean filter (see following chapter). The misclassification due to topography was solved by applying a slope mask (see section 3.2.3.3).

3.2.3.1. Filtering

The adaption of a speckle filter on SAR images reduces noise. Numerous filters with different application methods exist. Standard speckle filters are Mean, Lee, Kuan, Frost, Geometric, Kalman, and Gaussian (Gagnon & Jouan 1997). These filters perform efficiently on most SAR images. A more sophisticated filtering method is wavelet-based, such as Gabor filters (Dumitru et al. 2014),

The Lago Maggiore Scene was filtered with a 5x5 moving window mean filter to reduce speckle noise. This filter was implemented in ERDAS Imagine 2014 and performed best out of several experimental applications. The performance of the filter was verified by comparing the flood extent with aerial images taken on the same date.

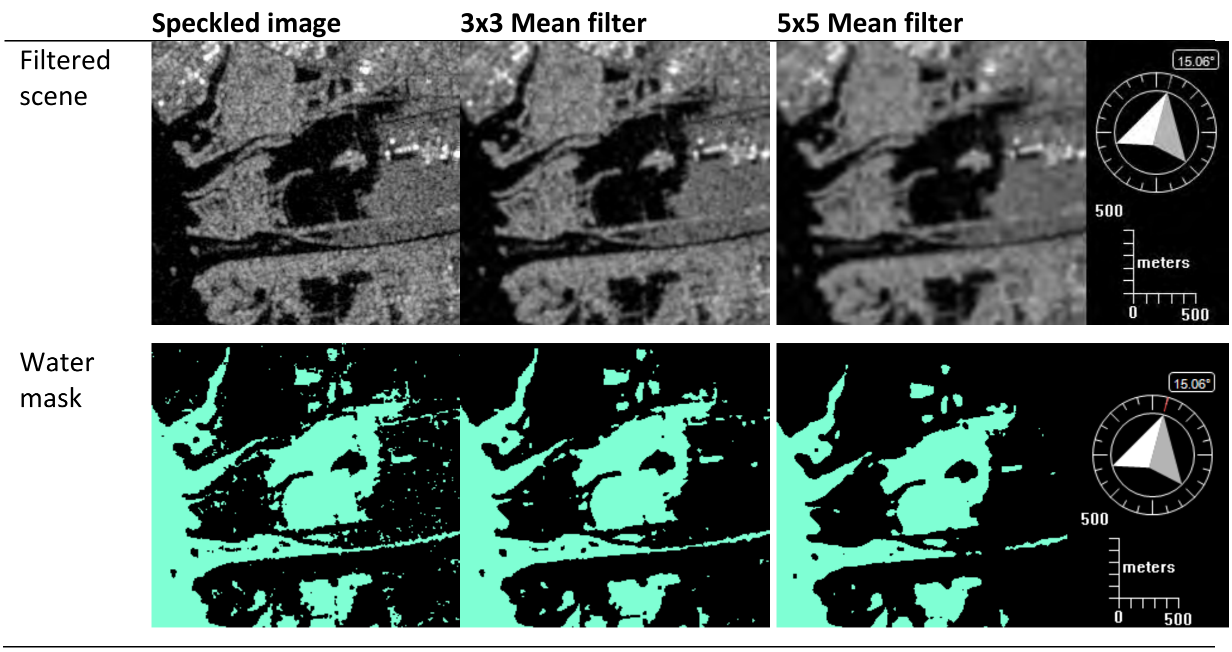


Figure 9: Comparison of filters for reducing speckle effects.

3.2.3.2. Threshold

A common way of extracting water areas from SAR images is histogram analysis with the definition of a threshold (Song et al. 2007b; Yang et al. 2014). A high inhomogeneity in pixel values of equal surfaces is due to different incidence angles and polarization (Voormansik et al. 2014). The threshold had to be adjusted manually and varied from case to case (Song et al. 2007a). Since the sentinel mission is relatively new (April 2014), there are hardly any publications on water detection thresholds. A threshold of 47 (digital numbers) was applied to RADARSAT images (Wang et al. 2011). However, the values of the Lago Maggiore scenes represent corrected terrain backscatter values and can thus not be compared. Finally, a threshold value of 60 was chosen for both scenes. Lower values underestimated flooded areas in urban areas. Higher values misclassified non-flooded areas. Furthermore, a contour line of the maximum lake level was extracted and areas below that level colored. This gave a rough estimation of the potentially flooded area.

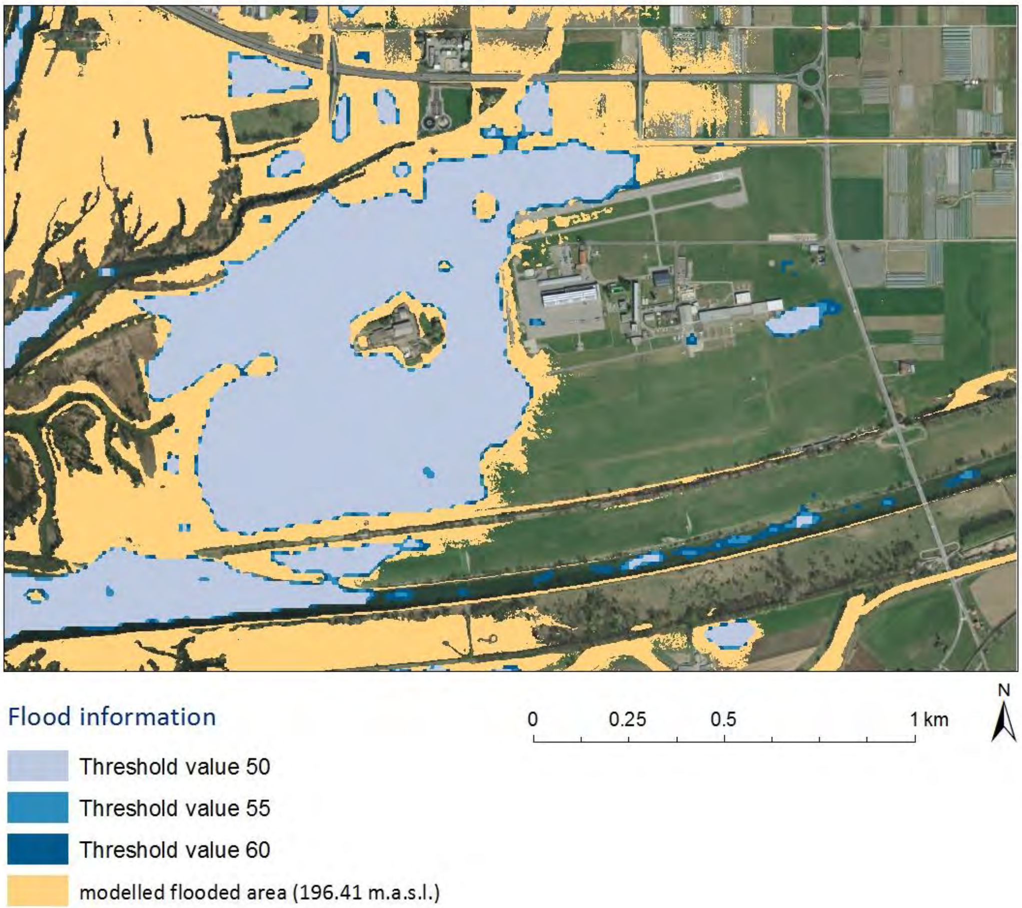


Figure 10: Comparison of flood thresholds on the Sentinel-1 image of the Magadino plain.

3.2.3.3. Refinement by slope mask

Another method to reduce the uncertainty within the speckled radar image was to combine the water mask with local slope information (Long et al. 2014). Especially in mountainous areas, this method was successfully applied (Song et al. 2007b). The flood event of 16 November had its highest impact in the Magadino plains in rather flat terrain. In mountainous regions, an elevation model can be used for refining the satellite derived flood area. Therefore, the local slope information was derived from a digital elevation model (swissALTI3D) with a resolution of 2m. The dataset was provided by the Federal Office of Topography Swisstopo. Song et al. (2007), compared water detection and local slope information. The probability of water detection is relatively high at a low slope value of 0-3°. The same values were also used by Long et al. (2014). A binary slope mask was therefore generated with values smaller than or equal to 3°. The resulting areas were converted into vector format to facilitate subsequent spatial analysis. A contiguous polygon of the Magadino plain was then derived. Finally, the satellite classified flood mask was clipped to the contiguous slope polygon of the Magadino plain.

3.2.4. Map production

Several maps were created with the software ArcGIS 10.2. Extracted flood information was combined with different base layers (Swiss national map (PK25) or Swissimage). More spatial information such as place names or road network was added. Owing to a wide selection of geodata at the RSL, it was possible to combine the flood information with up-to-date Swiss national maps and vector layers. The following datasets were used:

- Swissimage – base map from aerial imagery
- PK25 National map – base map 1:25’000
- swissALTI3D – slope detection for flood mask refinement
- swissnames – labeling places within the Swissimage base map
- swisstlm3d – land cover for spatial analysis

3.2.5. Validation

For the validation process, a threefold feedback was pursued. First, a comparison of aerial borne oblique aerial imagery of the same day as the satellite image acquisition. Coarse misclassifications could be detected this way. Multiple aerial images were found and compared as portrayed in Chapter 4.2. Second, the cantonal emergency management of Ticino would be contacted for expert validation. Specialists, who dealt with the event, would be able to verify the results. Moreover, firsthand accounts could testify as to whether such products would have an added value in their rescue efforts. Unfortunately, no answer was received and this step had to be skipped. Third, the prototype was demonstrated in the course of the focus group meeting. Face-to-face feedback was thereby received by persons who would actually work with such maps.

3.3. Focus Group

A focus group is a qualitative research method (Morgan 1998). A group of people gather to discuss a certain topic guided by a moderator. What the participants say during the focus group is the data for further focus group analysis. The method was successfully applied for finding new solutions in dynamic cartography (Monmonier & Gluck 1994) or for assessing user needs regarding a new software (Bernasocchi et al. 2012). This master's study follows a four-step application of focus groups developed by Morgan (1998). The four stages are characterized by problem identification, planning, implementation and assessment.

3.3.1. Problem identification

One conclusion drawn after the Charter Call 100 in Switzerland was that the link between the NPOC and the end-user was not established well enough (Buehler & Kellenberger 2007). In addition, a recently published report of the Center for Security Studies stated that the next important step in Swiss crisis mapping would be to bring all stakeholders together (Roth et al. 2013). By discussing their particular capabilities and needs, the stakeholders would be able to develop customized and beneficial products.

The application of a method such as a focus group has several advantages. First, the results of the questionnaire could be presented and through that the findings could be communicated to the persons in charge. Second, it was a way of validating the map prototype. By discussing the map in a group, direct feedback was received from the people who would be involved in the rapid mapping process in an emergency situation. Third, by inviting experts of the Swiss emergency management, their attention was drawn to the new possibilities of remote sensing. Fourth, the currently missing link between the persons in charge along the rapid mapping processing chain could be re-established. The focus group was thus an ideal method for validation and communication.

3.3.2. Planning

To start with, the actual goals of the focus group had to be determined in detail. Since this was the last part of the master's thesis, results from the questionnaire and the prototype could be included. The following goals were set:

1. Intensify the network between decision-makers
2. Present results of questionnaire and receive critical feedback

3. Present the map prototype and receive critical feedback
4. Determine the added value of such products

The first three goals could be measured in terms of qualitative feedback data. The fourth goal, a so-called soft goal, would be difficult to measure but played an important role.

The recruitment of participants was guided by the potential participants of the rapid mapping processing chain. The cantonal emergency managers were already determined as end-users. Having a participant of this group would therefore be essential. As mentioned earlier, the canton of Bern is by far the most affected and experienced canton with flood hazards. Fortunately, the head of the cantonal central command Bern volunteered to participate. Additional map users would be the crisis coordinating offices of NEOC and FOEN. For Switzerland, the NEOC is responsible for a Charter Call activation. In case of a large scale flood event, the FO BAFU coordinates the crisis management on the federal level. Representatives of both institutions would thus be valuable and agreed to participate. Finally, the specialized operator who processes the satellite images (in Switzerland the NPOC) also had to be involved. Since the NPOC is a joint venture by the RSL at the University of Zurich and the Federal Office of Topography Swisstopo, it was desirable to invite both (see Table for a list of all participants).

name	**surname**	**institution**	**position**
Gross	Mathias	National Emergency Operations Center (NEOC)	deputy chief of reporting and situation center
Jörg	Philip	National Point of Contact for Satellite Images (NPOC)	member of scientific NPOC (RSL)
Ruf	Wolfgang	Federal Office for the Environment (FOEN)	member of FO BAFU
Wyss	Francesco	National Point of Contact for Satellite Images (NPOC)	member of operational NPOC (Swisstopo)
Zellmeyer	Stephan	Canton Bern	head of cantonal crisis command

Table 3: List of focus group participants

3.3.3. Implementation

The focus group meeting took place at the Geography Institute of the University of Zurich on 8 May 2015. The author acted as moderator himself. The meeting was roughly structured in two parts, each with little inputs at the beginning followed by question answering and a discussion. In the first part, the results of the questionnaire were presented by the author followed by a discussion on the triggering mechanism of the rapid mapping process. The author as moderator balanced the discussion between getting answers to the questions and hearing from each participant his attitude towards the disaster map prototype. In a second part, the participants were introduced to the map prototype and questions on ideal products were asked. The focus was thereby set on the usefulness of the map prototype in relation to the delivery time. Krueger (1998b) notes, that different types of questions should be asked in the course of a focus group meeting. Open-ended questions were thus formulated so that the participants could add personal concerns. At the very end, the participants could raise individual issues for an open discussion.

3.3.4. Assessment

After the meeting, a short debriefing between the author and his supervisors took place. This step is recommended for highlighting the most important points of the focus group meeting (Courage & Baxter 2004). The entire meeting was recorded for post analysis. As suggested by Morgan (1998), the analysis took place within the first couple of days after the meeting. For that, the audio-file was transliterated with the software MaxQDA (Figure 11). Contiguous coding throughout the transliteration process facilitated the post analysis (Krueger 1998a). Discussion topics were grouped and whenever an idea or phenomenon came across, a code was attached. Thereby, the transliteration was in the end visibly structured for subsequent information retrieval.

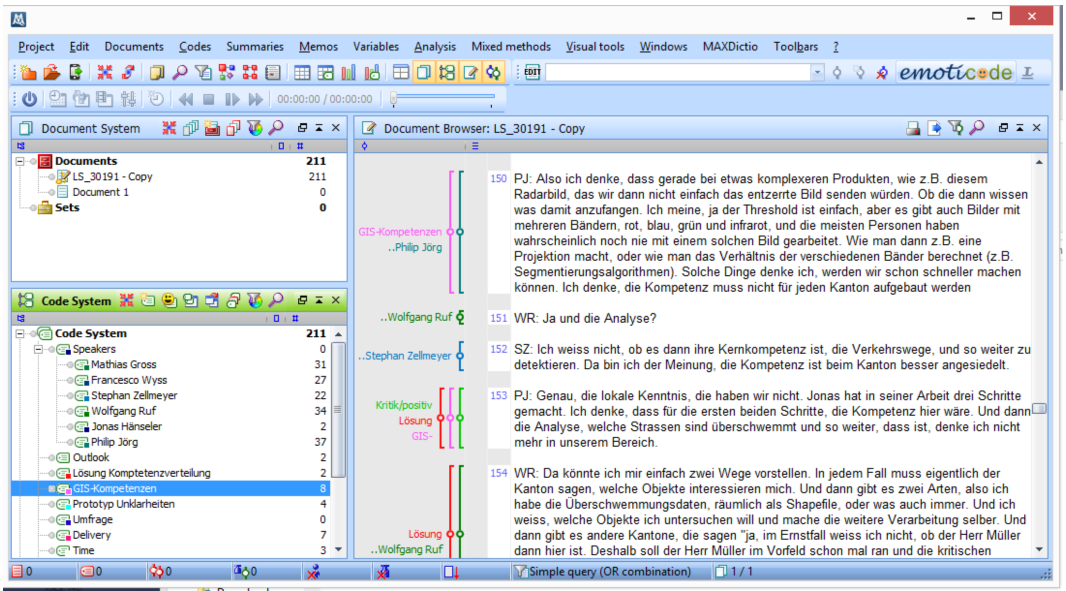


Figure 11: Example of transliteration software MaxQDA.

4. Results

4.1. Questionnaire

The following sub-chapters present the results in a descriptive manner. An in-depth analysis and discussion follows in Chapter 5.

4.1.1. Population

At least one feedback per "must-have-canton" determined in Chapter 3.1.1 was expected. Overall, a total of 46 competed questionnaires were received which was much more than anticipated (see

Table 4). Representatives from every canton responded whereby the number of emergency managers (74%) was much higher than replies from incidence documentation (26%). Because of collaborative emergency training of Switzerland and Liechtenstein, feedback from the latter was received as well. One of the smaller cantons in size didn't return a completed questionnaire but replied that due to the canton's geography and size, satellite images would not be used in an emergency situation.

Canton	EM	ID	Canton	EM	ID
Aargau	1		Nidwalden	1	
Appenzell A.	(0)	(0)	Obwalden	1	1
Appenzell I.	1		Schaffhausen	2	1
Basel-Landschaft	3	1	Schwyz		2
Basel-Stadt	1		Solothurn	1	1
Bern	1	2	**St. Gallen**	2	1
Fribourg	1	2	**Tessin**	1	
Genève	1		Thurgau	1	
Glarus	2		**Uri**	2	
Graubünden	1		**Waadt**	2	
Jura	1		**Wallis**	1	
(Lichtenstein)	1		Zug	2	
Luzern	1	1	**Zürich**	2	
Neuenburg	1				

Table 4: List of responses categorized in emergency management and incidence documentation.

Accentuated the "must-have-cantons".

4.1.2. Current types of data usage

On-ground observations by rescue services are by far the most used source in flood situations as shown in Figure 12. 44 out of 46 respondents referred to such services. Persons in charge of incidence documentation thus also mainly receive information from rescue services. The second most used information source is the media. Aerial assistance such as data from airplanes, drones and satellites are less used. Only the canton of Zurich has used satellite imagery for emergency management before. In addition, the open question on information sources showed that helicopters, hydrological and meteorological data and the federal platform for natural hazards (GIN) were frequently used as well.

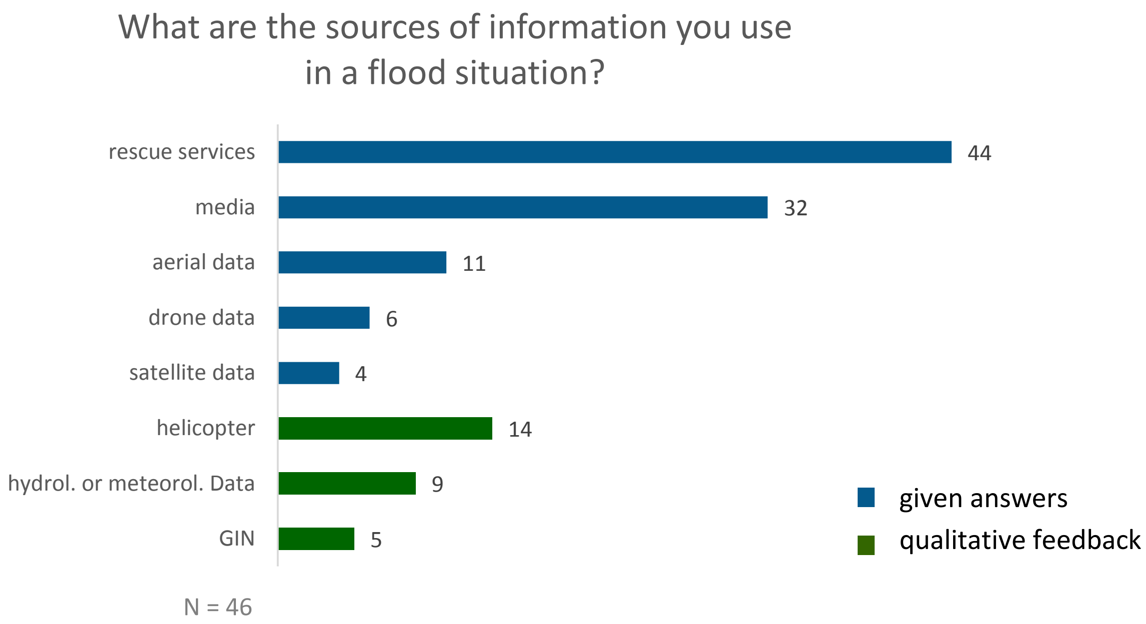


Figure 12: Information sources in a flood situation

Physical maps, photos and digital maps were mostly used as means of displaying the data. Mobile phones or tables on the other hand are hardly ever used for such purposes. Some cantons also emphasized the importance of their Emergency Management Systems (EMS) or Geographic Information Systems (GIS) systems.

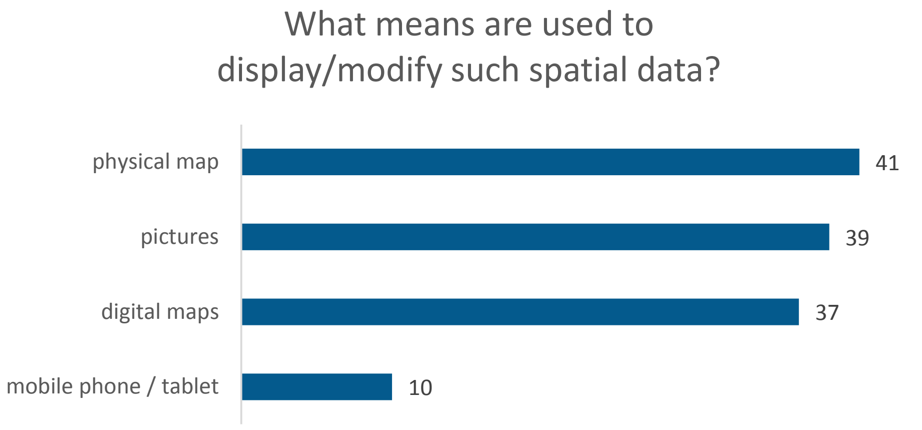


Figure 13: Means for displaying and modifying spatial data

4.1.3. User requirements

Responders had to give feedback on each of the three products (orthophoto, delineation map and grading map). Replies on the usefulness of an orthophoto were very positive (83% great need/ 17% minimal need). Besides that, no one evaluated orthophotos as “not needed” (Figure 14). Moderate needs were acknowledged for delineation maps and grading maps. 25 respondents evaluated the delineation map as “great need”. Similar approval rates were achieved by the grading map. Responders who answered with “no need” were from small cantons and responsible for emergency management. In the qualitative feedback, several respondents raised concerns on the accuracy and delivery time of the latter two satellite derived products.

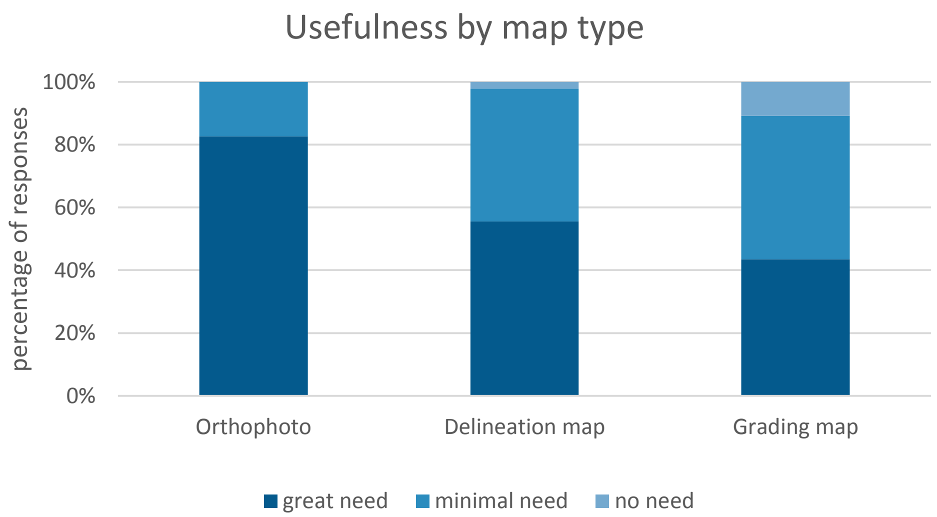


Figure 14: Usefulness by map type

4.1.3.1. Orthophoto

Out of the three product types, the orthophoto was seen as most useful. In the Scale-Availability-Matrix, the same patterns were detected (Figure 15). Roughly one third of the responders demand small scale maps (1:50'000) within half a day after the event. Large scale maps (1:5'000) are still needed after two days by 35.6% of the responders. A pattern of small scale maps shortly after the event and large scale maps after a certain amount of time can be detected.

Total amount of «great need» classifications

[map scale] \ time [days]	0.5	1	2
1 : 50'000	13/45	3/45	1/45
1 : 25'000	24/45	11/45	4/45
1 : 5'000	30/45	19/45	16/45

N = 45

Percentage of «great need» classifications

[map scale] \ time [days]	0.5	1	2
1 : 50'000	28.9 %	6.7 %	2.2 %
1 : 25'000	53.3 %	24.4 %	8.9 %
1 : 5'000	66.7 %	42.2 %	35.6%

N = 45

Figure 15: Orthophoto Scale-Availability-Matrix

The user requirement over time was calculated for two groups, *emergency management* and *incidence documentation*. 33 responders were part of the first and 12 from the latter group. Equivalent to the scale-availability matrix, the demand over time drops steadily. There is a higher need of maps on a scale of 1:5'000 than for the smaller two scales. The importance of scale is well portrayed in Figure 17. Large scale maps are clearly favored for incidence documentation. The steadily high usability of 1:5'000 maps show the important demand for high resolute imagery.

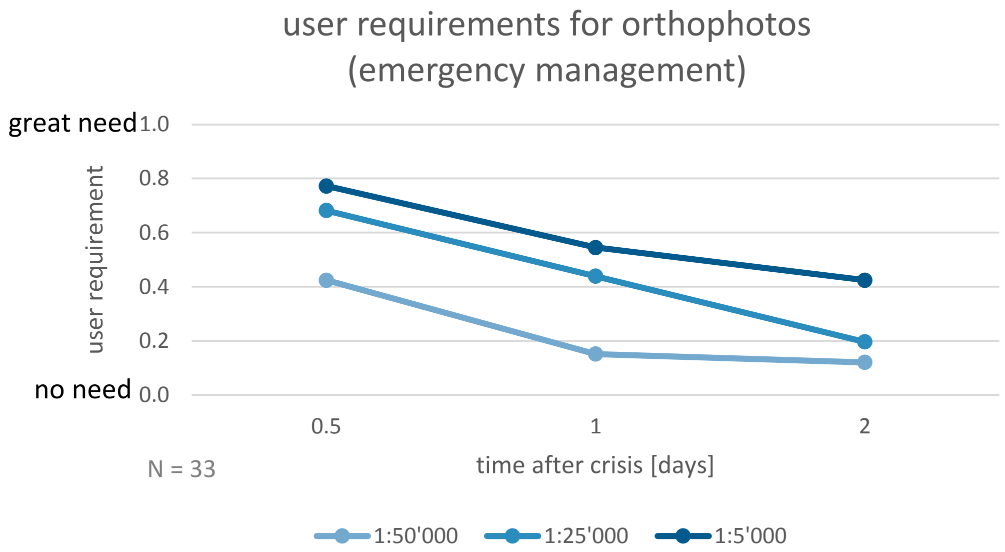


Figure 16: Emergency management user requirements over time of an Orthophoto

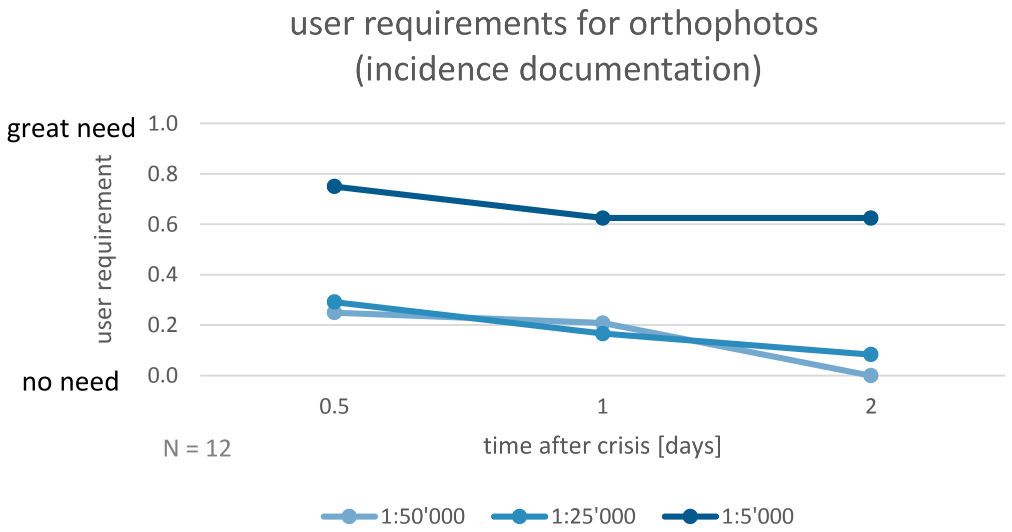


Figure 17: User requirements over time of an Orthophoto of the group incidence documentation.

Question number 6 asked for the purpose of orthophotos. Most mentioned was that such an image would provide a quick overview of the situation. Besides that, the following purposes were repeatedly cited:

- Identification of critical objects and prioritization
- Damage assessment (locate more and less damaged areas)
- Means of communication (map as internal and external communication for emergency management)

- Event documentation (Detailed orthophotos show flood extent and other processes such as mud slides)
- Evaluation of hazard map (by comparison of damaged zones on the orthophoto and the hazard map)

One respondent asked if daily updates on the situation would be possible. Another person emphasized the importance of such images to locate all the natural hazards on one map (i.e. debris flows, mud slides, etc.). Orthophotos would be helpful to locate these processes on a map. In addition an orthophoto could also be used for damage estimation in isolated areas.

4.1.3.2. Delineation map

In comparison to the orthophoto, a delineation map contains more information on flooded areas and critical objects. The demand for small scale maps is almost zero whereas medium maps are required slightly more. There is a considerable difference between user requirements of emergency management versus incidence documentation (Figure 18). For both, there is minimal demand for 1:100’00 and 1:50’000 delineation maps. The approval rate for 1:25’000 maps was moderate (between 22 and 67% “great need” classification). Persons responsible for incidence documentation clearly need high resolution data: 5 out of 12 respondents (41.7%) still have a great need for 1:25’000 delineation maps even 48 hours after the event.

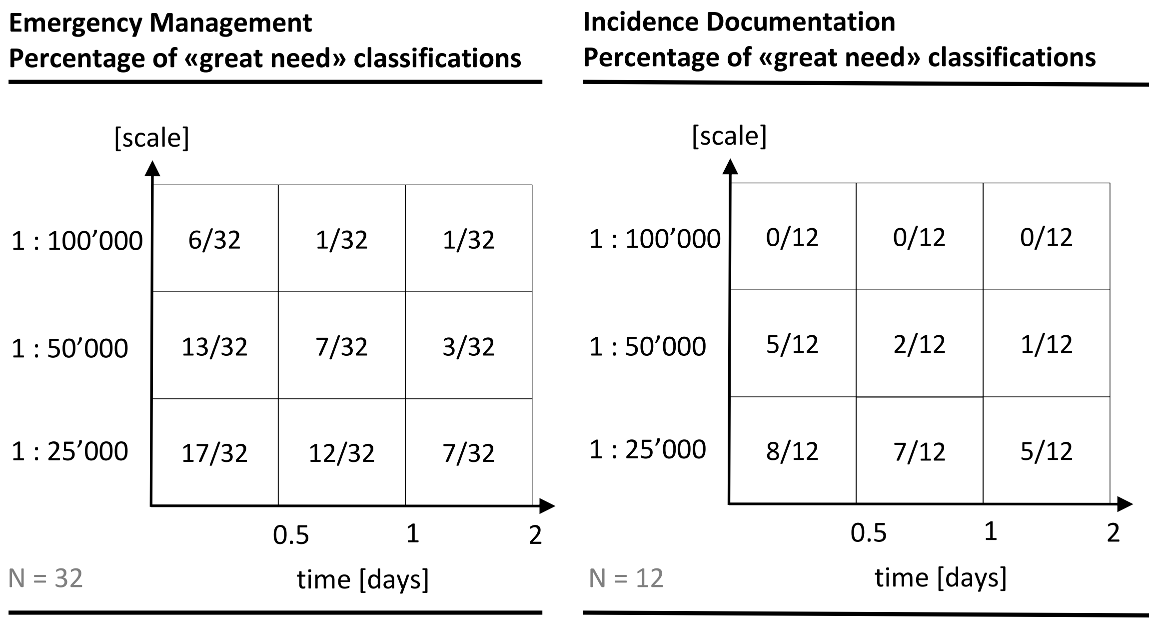


Figure 18: Delineation map Scale-Availability-Matrix

User requirement values for delineation maps were lower overall than for the precedent orthophoto. Again, a declining demand over time is shown and a higher priority of small scale products (Figure 19). In comparison, the incidence documentation has a higher requirement for 1:25’000 delineation maps. A clear preference for large scale maps is also shown here for incidence documentation (Figure 20). Respondents even asked for maps on scales of 1:10’000 or 1:5’000.

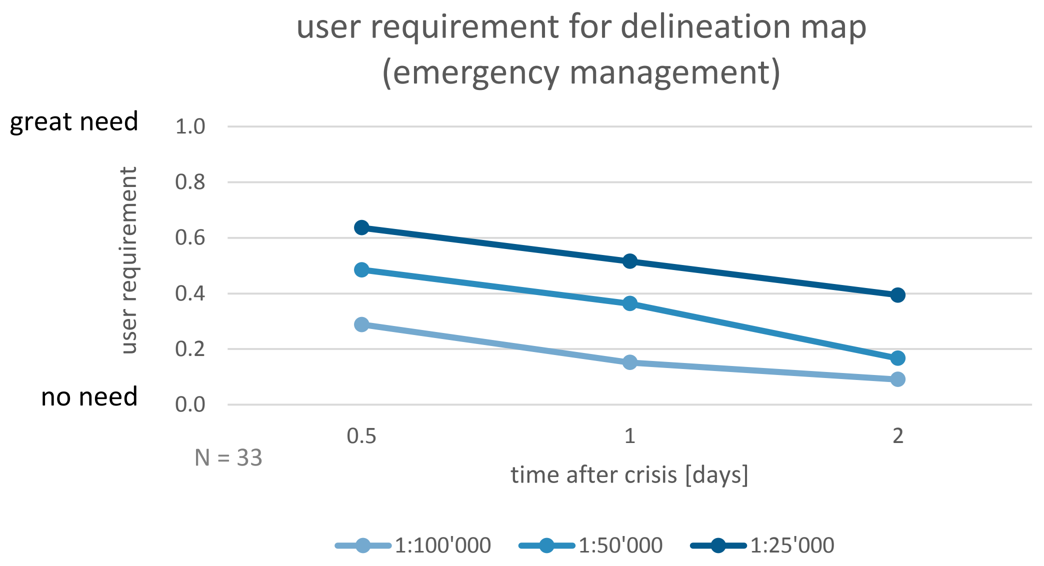


Figure 19: Delineation map user requirement over time of emergency management

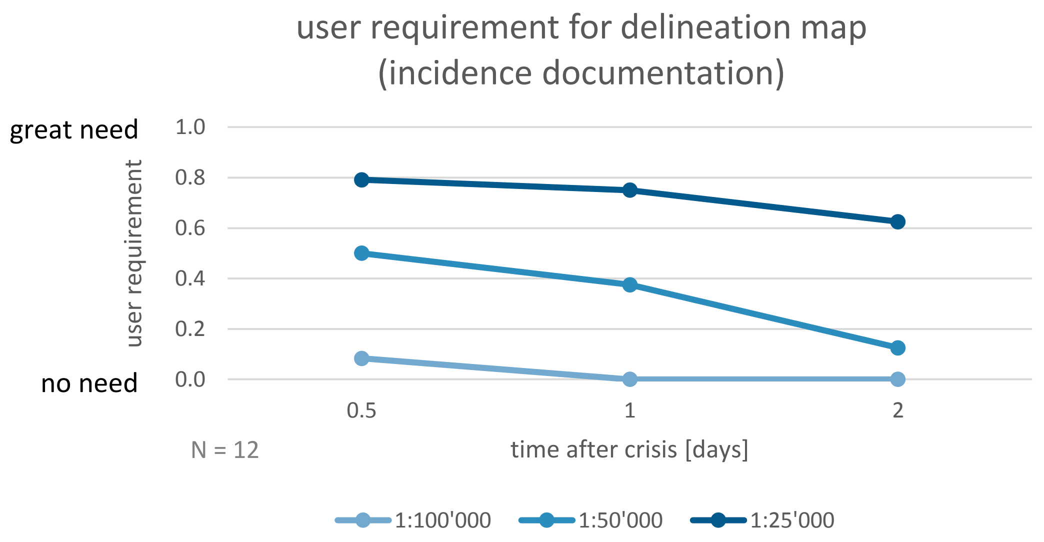


Figure 20: Delineation map user requirement over time of incidence documentation

Further questions about the purpose of delineation maps reflect the same ways of application as for orthophotos. Most often mentioned was again the provision of an overview of the flooded area.

Prioritization, damage assessments, means of communication and event documentation were mentioned again. In the qualitative feedback, several respondents raised doubts about the delivery time of satellite derived maps. The delivery of a vector file of the flooded area was a requirement often mentioned. An incorporation into their electronical emergency management systems (EMS) or GIS would greatly improve their disaster-response capabilities.

Delineation maps can include additional map elements such as location names, traffic lines, hospitals etc. Thus one question thus asked the potential users about their priorities (Figure 21). Regular water bodies and traffic lines are seen as most important elements. City names and urban areas are needed from 27 and 24 responders. Power lines and borders are not seen as essential elements on delineation maps.

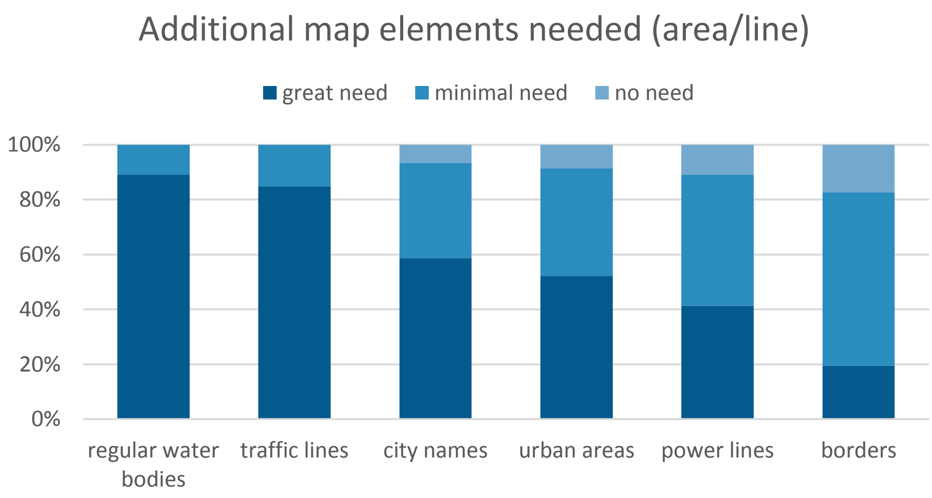


Figure 21: Additional map elements needed (area/line features)

No clear pattern could be detected for point map elements (Figure 22). Overall, only hospitals and power stations were demanded by over 50% of the responders. 8 out of 45 cantons selected all elements as "great need". None of the larger cantons in size (>1400km^2) selected "no need". Therefore, larger cantons appear to need such additional map information. There was no difference in requirement between the two group's emergency management and incidence documentation.

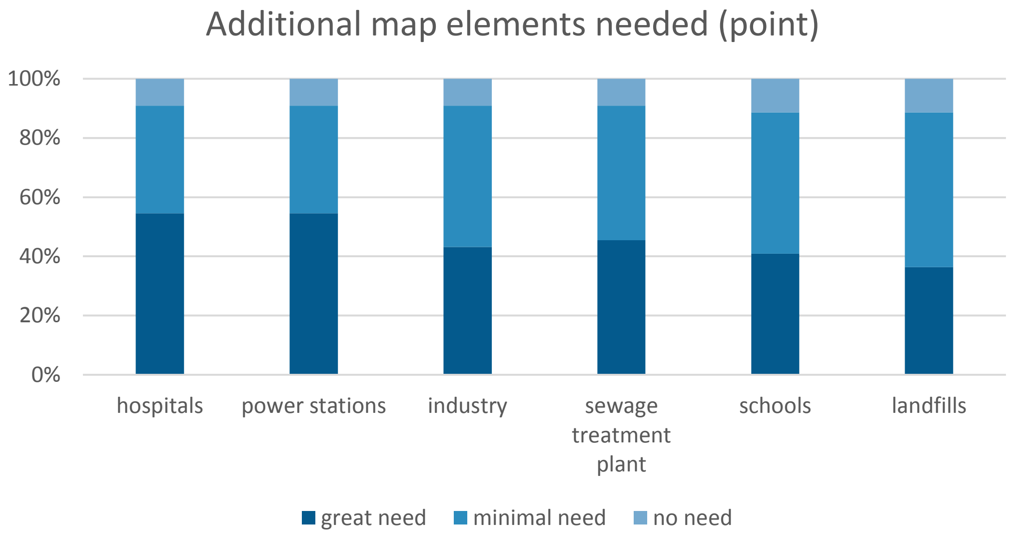


Figure 22: Additional map elements needed (point features)

4.1.3.3. Grading map

The grading map was mostly categorized as "no need". Also, there was hardly any difference in user requirement between emergency management and incidence documentation. Grading maps on a scale of 1:25'000 had a slightly higher approval rate. The highest usability was reached by incidence documentation of 1:25'000 within a delivery time of two days.

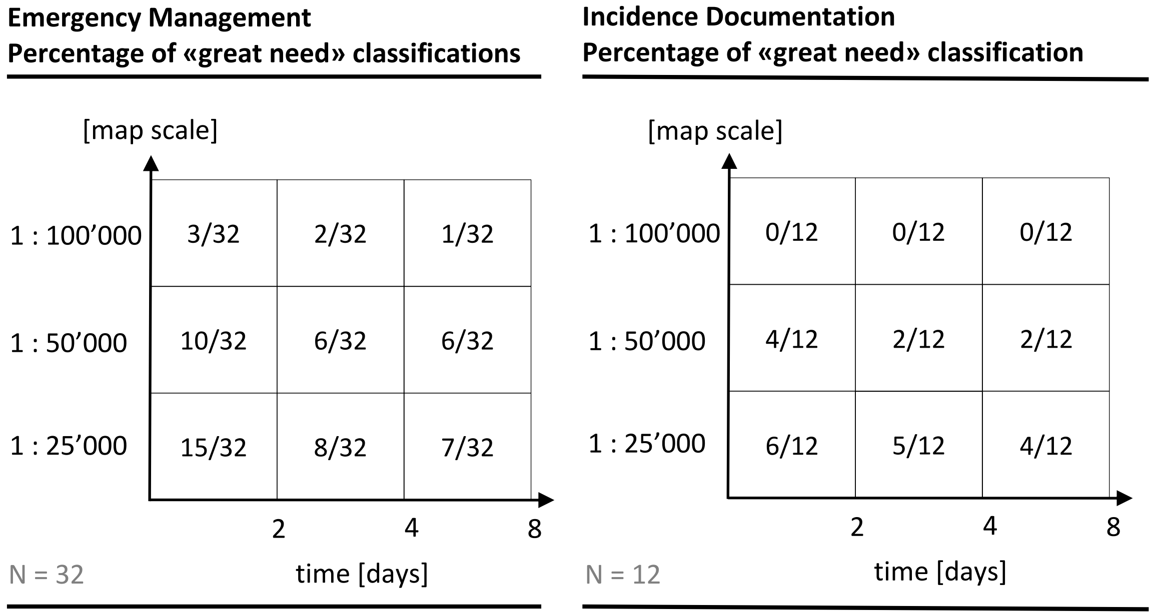


Figure 23: Grading map Scale-Availability-Matrix

The scale-availability-matrices already portrayed the low demand for grading maps. The groups were therefore combined to demonstrate the user requirements over time (Figure 24). Two days after a flood event only a 1:25’000 grading map reached a demand of slightly more than 0.5 usability. For every other point in time, the demand for grading maps was quite low.

The following question asked for the purpose of grading maps. They revealed slightly different methods of application than the first two products. Most mentioned points were:

- Incidence documentation
- Damage assessment
- Situation assessment
- Hazard map adaption

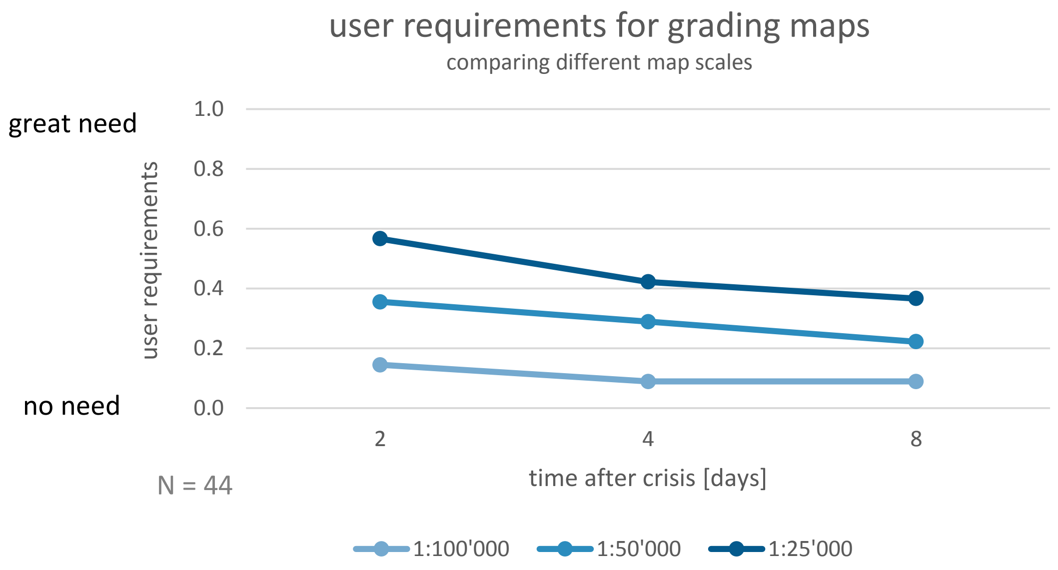


Figure 24: Grading map user requirements over time

Around 25% of respondents would incorporate such maps in reports, as means of communication, briefings or for teaching purposes. One potential user would apply grading maps for long-term prioritization of heavy equipment.

By combining the flood extent with spatial information, spatial analysis such as type of affected areas could be calculated. Affected areas, traffic lines and the exact water table at the time of image acquisition are seen as important information by more than 75% of respondents (Figure 25). The number of buildings and the affected population are less important.

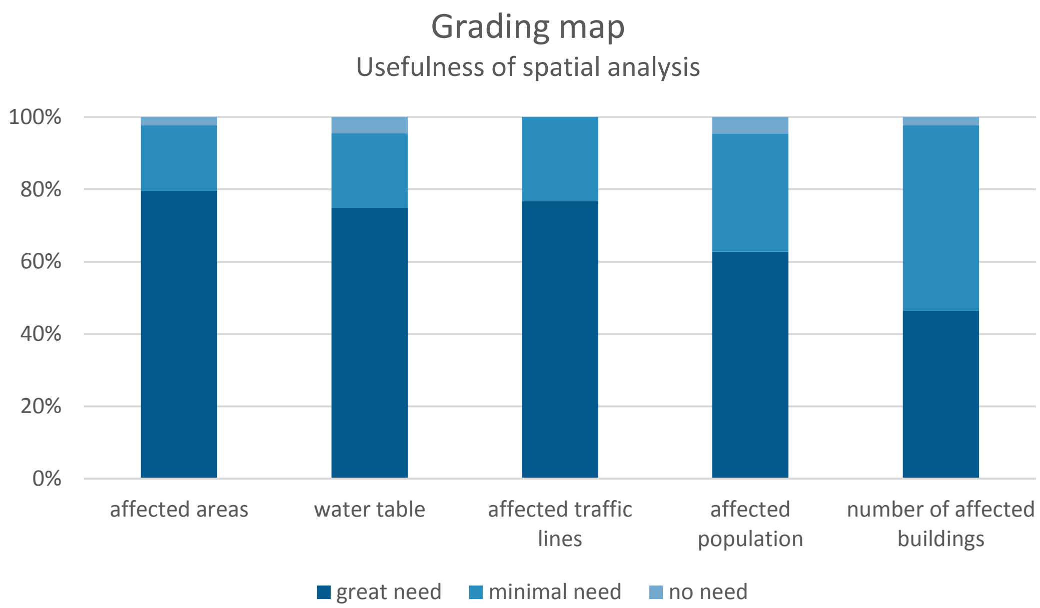
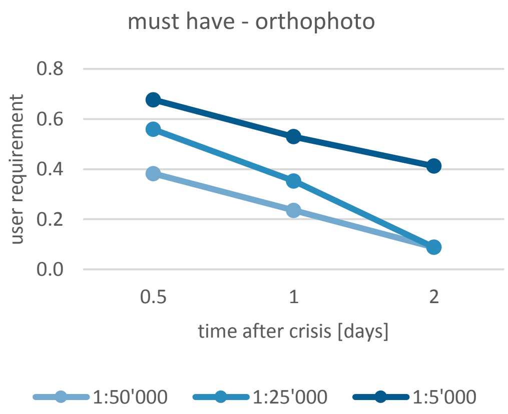
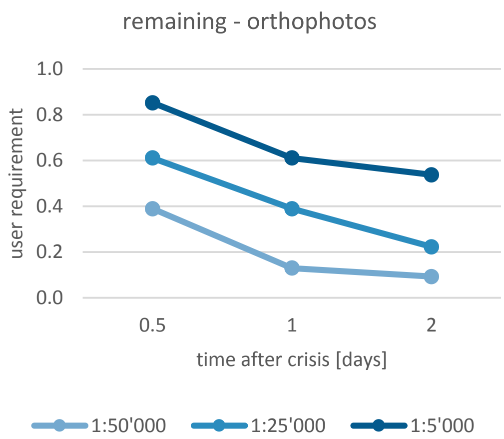
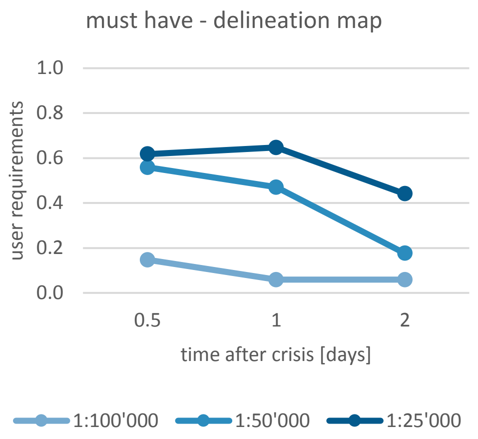
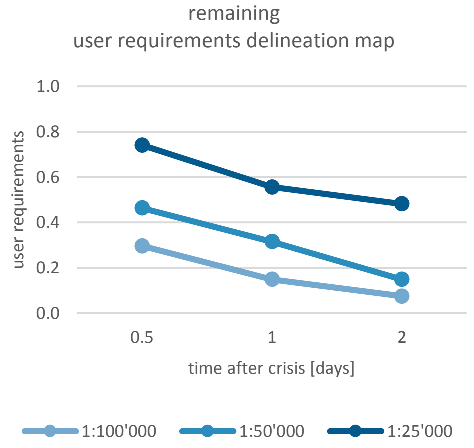
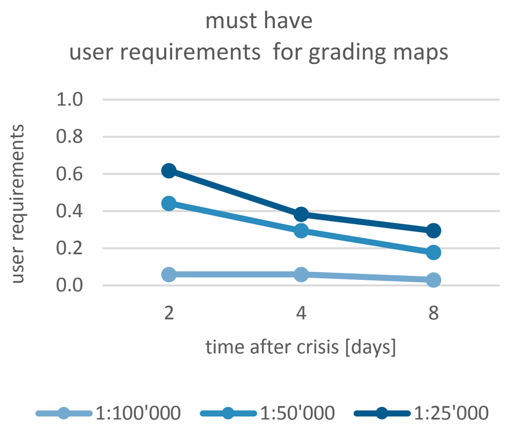
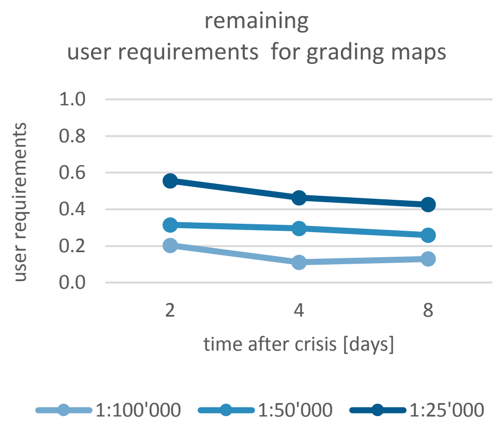


Figure 25: Usefulness of spatial analysis

An additional comparison of the *must-have-cantons* and the remaining answers was performed (Table 5). The purpose was to see if the most affected cantons had different demands. The must-have-cantons had an affinity towards large scale maps. Maps on a scale of 1:100'000 or 1:50'000 were seen as impractical. Besides that, no distinct differences could be detected between the two groups. They both shared a decreasing demand over time. For orthophotos and delineation maps, the usability fell below 50% one day post crisis. For grading maps, low acceptance was reached for both groups.

Table 5: Comparison of demands between must-have-cantons and remaining cantons

	Must-have cantons	**Remaining cantons**
Orthophoto		

	Must-have cantons	**Remaining cantons**
Delineation map		
Grading map		

4.1.4. Data delivery and data quality

The feedback on data delivery and data quality was quite clear. 57% prefer a digital delivery and 39% a digital & physical delivery. Only 4% requested only physical data. The data should be provided by download or by email. One respondent suggested that a delivery via Web Map Service (WMS) would be possible. Five cantons explicitly mentioned the use of the natural hazard platform GIN which could be used as a method of data distribution. Some cantons (BE, ZH, TI, SO) often work with EMS or GIS which could incorporate such vector layers. In case of an emergency, a breakdown of electrical power supply is likely. For such scenarios, an alternative method of production and delivery must be considered. Regarding the data quality, the following points were made:

- The delivery of the flooded area in vector format is essential so that the cantons with EMS could themselves do the spatial analysis.
- The base map should be a regular Swiss map, since these are the maps that rescue workers are familiar with (75% favored Swiss national maps over aerial or satellite images)
- Persons in charge of emergency management emphasized the importance of a quick delivery instead of a detailed, high-quality product.

4.1.5. Qualitative feedback

Less than half of the respondents took advantage of the section where they could openly formulate their remarks, desires and expectations. Nonetheless the feedback received revealed some important common points:

- Compatibility of the satellite map process and products with the cantonal infrastructure is required.
- In most cases, the flood event is on a small scale. Therefore satellite data must be very high in resolution and quickly delivered.
- Shortly after an event, small scale maps are needed to gain an overview of the situation and for prioritization. Large scale maps are needed later in time.
- The NEOC-homepage could likewise be used for data delivery.
- Desire for a specification in cases where satellite images are actually delivered. These specifications need to be communicated to the cantonal representatives so that the products will actually be used.
- A backup plan of the entire process should be considered (also at NPOC)

Besides those valuable replies, the cantonal representatives also had some desires about further development:

- Overview of satellite map process and clear assignment of responsibilities (UZH, NEOC, FOEN, Cantons)
- Specification of costs
- Daily update of situation in case of an emergency
- Assessment of the potential of satellite images for other natural hazards

4.2. Map Prototype

A total of five maps were generated (see Appendix 7.3). Each map was different either in map type, map scale or base map (Table 6). The five map prototypes portray the variety and possibilities of satellite derived flood mapping. It is also shown that spatial analysis can provide further information on the flooded areas. In answer to the demand for high resolution data, the maps were set on a scale of 1:25'000 and 1:10'000. Furthermore, the additional map elements needed (regular water bodies, traffic lines and city names) were also included.

ID	Map type	Scale	Basemap	Purpose
D1.01	Delineation map	1:25'000	Swissimage	Overview Swissimage
D1.02	Delineation map	1:25'000	PK25	Overview national map
G1.03	Grading map	1:25'000	PK25	Overall statistics
G1.04	Grading map	1:10'000	Swissimage	Tenero flood in detail statistics included
G1.05	Grading map	1:10'000	PK25	Tenero flood in detail statistics included

Table 6: List of map products and their specifications.

The resulting maps were compared with oblique aerial images for validation. Two aerial images could be found online, each taken on the same day as the flood peak and the satellite image acquisition. Figure 26 shows the results of flood classification in flat open terrain. A marginally flooded area (yellow polygon) nearby the highway was correctly detected. A meadow in between two flooded fields as well (orange rectangle). In these flat parts of the case study area, the satellite derived flood classification performed well.

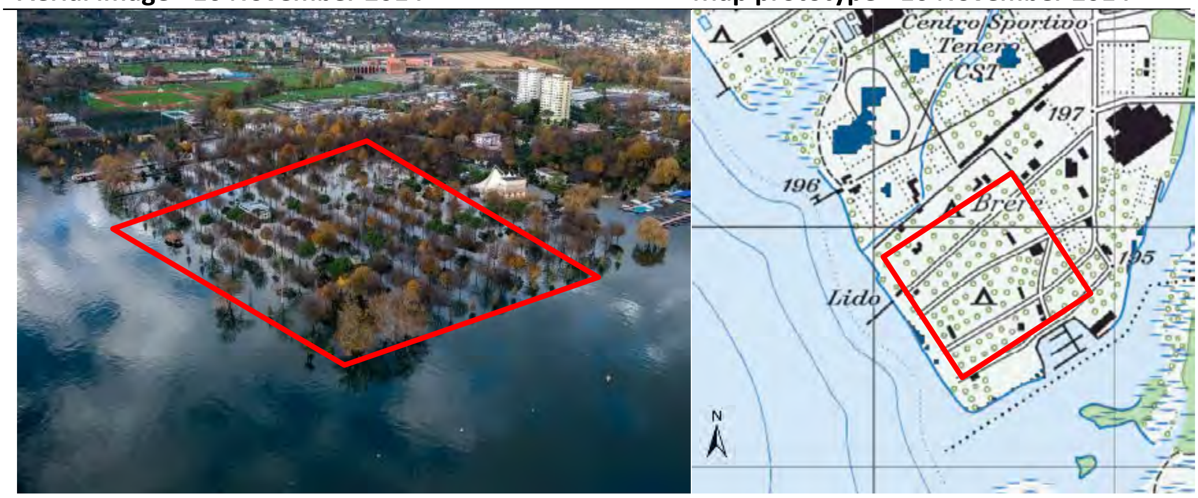
Aerial image (16 November 2014) **Map prototype (16.November 2014)**

Source: (Neue Luzerner Zeitung 2014)

Figure 26: Accuracy assessment by aerial imagery in flat terrain

The camp site of Lido Tenero was entirely flooded on 16 November. However, the area was not classified as flooded in the satellite image Figure 27. Experimenting with the threshold level did not result in better classification since other areas were then misclassified instead.

Aerial image - 16 November 2014 **Map prototype - 16 November 2014**



Source: Neue Zürcher Zeitung 2014

flooded area

Figure 27: Accuracy assessment by aerial imagery in forested regions

Further improvement was achieved by modeling the maximum water table with a DEM. Areas lying below the flood peak of 196.41 m.a.s.l. were first extracted. Next, the water bodies were subtracted so that the resulting layer contained only land areas below the maximum flood level. The close-up of Lido Tenero with the modelled area shows a better classification of the flooded area within the forested campground. Particularly for adjacent parts of the lake, the satellite derived flood area performed relatively poorly. In flat terrain, the satellite performed better than the DEM. This was due to the marginal inclination in the flat terrain. The applied DEM (SwissALTI3D) has a vertical uncertainty of +/- 1 meter (Swisstopo 2014). As a result, elevation values in flat terrain may have uncertainties in these dimensions. The delineation map D1.02 shows the full extent of the modelled flooded area and can be found in the attachment.

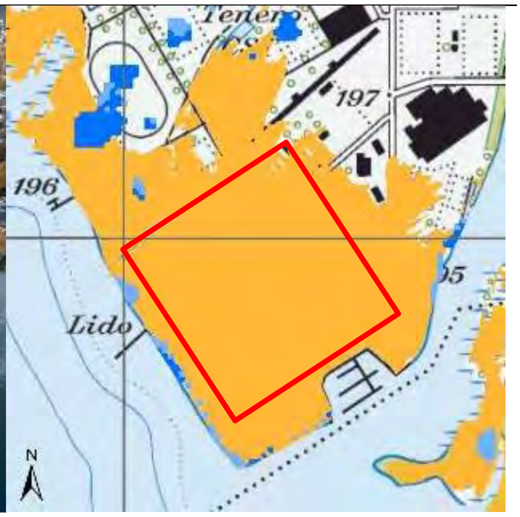
Aerial image - 16 November 2014	**Modelled flooded area – Lido Tenero**
	
Source: Neue Zürcher Zeitung 2014	
	flooded area from Sentienl-1 data modelled flooded area from DEM

Table 7: Improved accuracy by modelling the flooded area with a DEM.

4.2.1. Delineation maps

The first map (D1.01) provides an overview on the scale of 1:25’000 of the entire flooded area around Locarno and the Magadino plain (Figure 28). An extract of Swissimage was chosen as a base map. The purpose of the map was to display the development of the flood situation between 15 and 16 November 2014 on one map. By choosing a lighter and a darker blue for the flooded areas, the differences were clearly marked. Location names allow the determination of city parts on the aerial image. The discreet grid was augmented for geographic referencing. A short summary of the situation provides supplementary information on the event. Additional map elements, such as inset map, scale bar, north arrow, data sources, and information on the data producer were also added.

The second map (D1.02) is another overview on the same scale. In comparison to the first prototype, a regular 1:25’000 Swiss national map was set as a base layer. Proportions of the map were also changed to portray a different method of arranging the map elements. As a supplement, the modelled flood area is highlighted in orange. The difference between the satellite image and the potentially flooded area was clearly visualized by these means. This map also shows, that in case of a lake flood event, the integration of a high accuracy DEM can contribute to improving the results of satellite imagery.

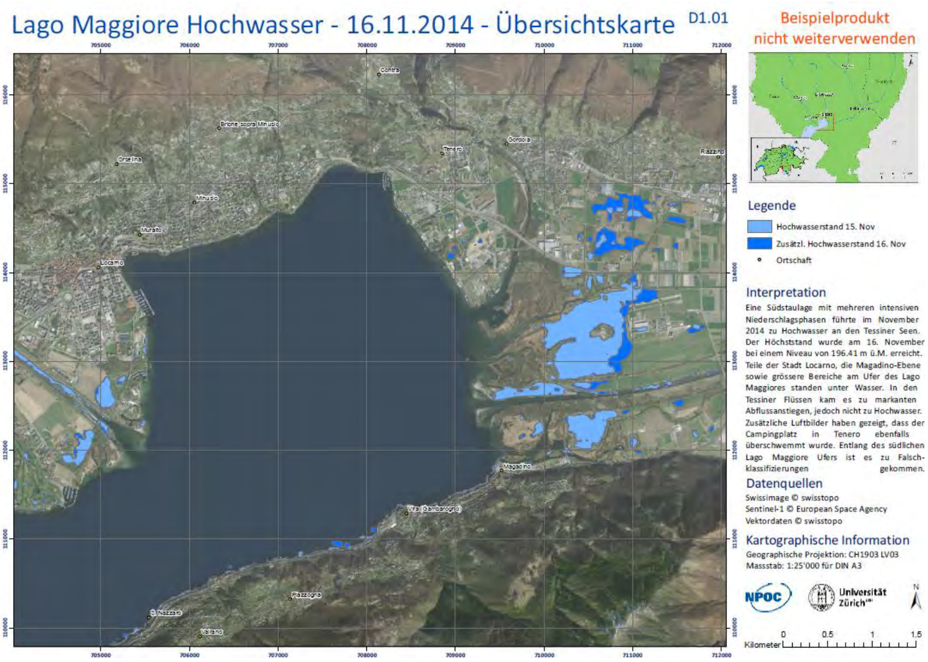


Figure 28: Delineation map prototype D1.01

4.2.2. Grading maps

The third map (G1.03) is a spatial analysis of the entirely flooded area around the northern part of Lago Maggiore. Since this satellite image was taken on 16 November, the map represents the flood extent including the inundated streets at the time of acquisition. A table on the right side provides information on the types of flooded areas.

The fourth map (G1.04) is a close-up of the most severely hit area. The base map is again from Swissimage. Streets and single buildings are well distinguishable on the map scale of 1:10’000. The train station of Tenero and the small airport of Locarno are marked with a symbol. Flooded areas are colored by type of land use. Likewise, a list and quantification of the flooded areas is shown on the right side.

The fifth map (G1.05) on a scale of 1:10’000 is a close up of the Tenero area. In comparison to the previous example, the background is a regular Swiss map PK25. Inundated areas and streets are colored and easily detectable. Difficulties in detecting floods in forested areas are again displayed on this map. The forested camp site on the Lido was not classified as flooded. This map demonstrates limitations of mapping such areas with Senintel-1 CSAR data.

4.3. Focus Group

The focus group meeting brought together responsible persons from the field of rapid mapping, federal and cantonal emergency management and incidence documentation. The meeting was unique in its constellation. The attendance of the head of crisis management of the canton Bern was important since he represented the surveyed user-group. Representatives of the FOEN and the NEOC are also possible users and were thus of interest. Expert support was provided by the two representatives from the science and operational NPOC. The network among these decision-makers was intensified by this meeting as the first goal defined. Three participants explicitly emphasized the importance of the meeting because there is need for action in Switzerland. Furthermore, the lively interaction during the meeting was proof of the interest of the participants. A first step in intensifying the network was taken, and the first goal, was thus reached.

4.3.1. Feedback on the Questionnaire

The focus group started with a short presentation by the author. Results on the current type of data use and the map elements based on the questionnaire answers were presented. A discussion emerged on the additional map elements needed. The results for the additional point map elements needed did not reveal a distinct demand for a certain element. The representative of the NEOC thus asked if a canton always needed all the map elements, or whether the demands varied. 8 out of 45 cantons selected all elements as “great need”. No clear pattern could, however, be detected. Another question was raised on the link between size of a canton and its demand of additional map elements needed. The representative of FOEN assumed that smaller cantons know the location of every single critical object. Larger cantons, however, were expected to need this information in addition. His assumption was later confirmed by taking the size of the canton into account. None of the larger cantons in size (>1400km^2) saw these map elements as not needed. Besides that, there was confusion about the exact definition of an orthophoto. The representative of NPOC (Swisstopo) claimed that radar images are also orthorectified and can also be called orthophotos. In his opinion, the questionnaire should not have asked about orthophotos. The representative of NPOC (RSL) argued that radar images can be orthorectified, but due to their peculiarity, they are difficult to interpret for laypersons. It would therefore not make sense to deliver a raw radar image. The discussion between the two experts showed that there is a wide variability of remote sensing products with different advantages and limitations. Similar user surveys in the future should therefore clearly define each remote sensing product.

The second part of the presentation dealt with the user need with relation to time. This part did not provoke a lot of feedback. It was asked if there was a difference between emergency management and incident documentation in terms of requesting a vectored layer of the flooded area. Such a differentiation did not take place. However, more than half of the respondents asked for a digital dataset and another one-third asked for a digital and a physical delivery. Thus the high demand for digital data delivery was obvious. Besides that, no further comments were made on the questionnaire.

4.3.2. Map Prototype

Printouts of all five map prototypes were distributed among the attendees and a detailed description of the performed rapid mapping process was given. The goal of this part was to retrieve feedback on the map prototype. The discussion started with questions on the production and drifted towards potentials and limitations of remote sensing. Therefore, not a lot of feedback was received on the map prototype. Nonetheless this discussion was essential for participants who were less experienced with remote sensing products.

The chosen flood scenario shows a rise in lake level which is relatively predictable and authorities are mostly prepared for such scenarios. It is therefore doubtful that radar satellites are used for such purposes in Switzerland. Yet there are flash floods that are relatively unpredictable. The representative of the FOEN thus asked if radar flood detections are also possible for such event types. He wondered if there were any limitations in terms of terrain steepness. The representative of NPOC (RSL) brought up two possibilities from the point of view of remote sensing. First, change detection of pre- and post-disaster images to delineate the flooded areas. Second, a DEM comparison to detect mass movement between two points in time. He also pointed out that the detection of objects is always dependent on the spatial resolution of the acquiring sensor. The discussion was

> *„I see preparedness and inter-connectedness as the two most important issues at the moment. Besides that, Swisstopo still needs to know more about user requirements"*
>
> *- Francesco Wyss (NPOC)*

characteristic for the focus group since experts from the natural hazard field are usually not familiar with the possibilities of remote sensing. Remote sensing experts, on the other hand, are not always fully aware of the user demand. Such discussions were important for a mutual understanding among the participants.

4.3.3. Processing chain

Often mentioned by the users was the need to define cases in which satellite imagery would be provided. It was therefore suggested to determine a trigger point for activating the rapid mapping process at the NPOC or even a Charter Call. The explanation of the current activation process, however, relies on a pro-active approach of the cantonal authorities according to the representative of the FOEN. He is also part of the FO BAFU and receives such demands from the cantons in case of natural hazards. It was obvious that certain cantonal authorities were not aware of the current activation procedures. Furthermore, not all cantons are aware of the possibilities and potential of remote sensing according to the head of the cantonal crisis management in Bern.

A second dilemma in the mobilization phase is the time of activation by a canton. The head of the Bernese cantonal crisis management explained that an activation would provoke a dilemma. Most floods in the canton of Bern do not need satellite support. In case of a large scale event, the well-rehearsed crisis staff would thus probably activate the rapid mapping process too late.

These two obstacles in mobilization demanded a solution. The NEOC confirmed the lack of knowledge of the cantonal authorities and suggested a sensitization of the cantonal authorities about remote sensing. Other participants of the focus group agreed. They emphasized that an awareness building of remote sensing data would increase the use of satellite imagery for emergency situations. The FOEN representative underlined that the questionnaire and this master thesis would be a first and important step in the right direction. Moreover, the focus group drew the attention of the persons in charge to the possibilities of remote sensing.

The representative of NPOC (Swisstopo) was curious about the stages of analysis and map production. The questionnaire's results affirmed that end-users of emergency management require information as soon as possible. He therefore asked how much time was taken up for the analysis and map production phase. The experience of the author suggested that the analysis phase would take roughly one hour if the specialist is familiar with image analysis software. The map production on the other hand took several hours in the present case. Much time was lost for the inset map design, the spatial analysis and the implementation of all additional map elements. Hence, these prototypes were built from scratch. Valuable time could be gained by setting up a layout in advance. The person in charge of the NPOC (RSL) emphasized the possibilities of the software ArcGIS for such purposes and suggested that a predefined layout would be an important step towards an efficient rapid mapping processing chain at the RSL.

4.3.4. Added value of rapid mapping products

In order to determine the added value, knowledge of the status quo is needed. The questionnaire revealed a wide difference in means of dealing with emergency situations. Because of the variety of assets, the added value can be guaranteed only if different types of products are delivered. The head of the cantonal crisis management in Bern questioned the utility of a final map product. Such maps might be nice to look at and provide an overview on the situation. But this is what the emergency management already regularly establishes. Added value might be delivering the inundation map in vector format. The cantons could then incorporate such a layer into their GIS databases and create map products and spatial analysis themselves. The FOEN on the other hand doubts that every canton would have a GIS infrastructure and trained staff available at the right time. The head of cantonal crisis management repeatedly raised doubts about the application of a map on a fixed scale. However, a scalable map might be valuable for emergency management if delivered quickly enough. Therefore, it was proposed to deliver both the map product and the vector layer, and the cantons could use whichever was better suited to the case.

> *“The final map product is a nice-looking image of the situation but I still doubt its usefulness for emergency management”*
>
> *- Stephan Zellmeyer (head of cantonal crisis management Bern)*

Since the Charter has been activated numerous times now, the head of cantonal crisis management proposed to ask emergency managers who have used rapid mapping products in the field to share their experience. Focus group participants were interested in the kind of decisions, which have been taken because of such maps. The NEOC already asked the DLR ZKI the same question and received the answer that the maps did not show anything new to local emergency management. However, it was interesting to have an image of the entire situation. The added value varies depending on the hierarchy level of the emergency manager. While rescue workers out in the field do not particularly benefit from rapid mapping products, a national crisis staff sees added value in capturing the entire situation on one map.

For further specifications on the type of deliveries that would add value, certain map products were discussed. The evaluation of the questionnaire revealed moderate demand of orthophotos and delineation maps and no demand for grading maps. It was therefore proposed to develop 1:25'000 delineation maps from the beginning of the flood. A delivery would include the map and additionally a vector file of the inundated areas. Approval varied between cantonal and federal institutions. The NEOC and the FOEN both only have limited GIS knowledge and would prefer the delivery of a finished map. Furthermore, during large scale flood events, it is usually difficult for them to collect the information from every canton on one single map. However they were skeptical about a pre-definition of the map scale. They would rather adapt the map scale case by case, in relation to the actual flood extent.

Persons responsible for incidence documentation would definitely benefit from a satellite derived flood layer. These findings of the questionnaire were confirmed in the focus group. On the national level, both the NEOC and the FOEN confirmed the usability during a crisis, but also in the aftermath for detailed documentation. The head of the cantonal emergency management in Bern questions whether or not satellite rapid mapping for emergency management is really an added value. This leaves the following results of the focus group in terms of added value of a satellite derived map:

	local/regional	**national**
Emergency management	0	+
Incidence documentation	+	+

Table 8: Usefulness of rapid mapping products according to the focus group meeting.

(0 = no added value, + = added value)

4.3.5. Open questions

The time for open questions at the end of the meeting was used to determine further steps that need to be taken. The representative of NPOC (RSL) again emphasized the potential of remote sensing and the capacity of knowhow available at the University of Zurich and the Swisstopo. He claimed that a rapid mapping processing chain needs to be established. It was added that the interconnectedness and preparedness in this field is still insufficient. A collaborative exercise in the future was proposed to tackle these issues and also to test the usability for emergency management. In addition, the NEOC suggested the development of a booklet with different hazard scenarios and potential remote sensing products. The booklet could be used as a basis for sensitizing cantons about the possibilities of remote sensing. In addition, the representative of the FOEN volunteered to coordinate further collaboration in this field.

4.3.6. Debriefing

A short debriefing took place after the focus group between the two supervisors (representatives of FOEN and NPOC (RSL)) and the author. They emphasized the importance of the focus group as a first step in intensifying the network among the participants. In particular the presence of the representative of the NEOC was appreciated since the collaboration needs to be strengthened as well. In addition, the critical view of the head of cantonal crisis management in Bern was addressed. Clear usability of satellite images for the emergency management was expected. The focus group thus showed that at the cantonal level much more sensitization work on the potential of remote sensing has to be done.

5. Discussion

First and foremost, the application of different methods proved to be efficient for obtaining a holistic view of the potential of satellite rapid mapping for flood events in Switzerland. The questionnaire provided valuable information about the user perspective on the cantonal level. The map prototype development made clear that the assets for an effective rapid mapping process are given. The focus group was used to discuss the added value of satellite imagery from different perspectives and was a step forward toward a collaborative satellite rapid mapping processing chain in the future. In the foregoing chapters, this three-way division was strictly pursued. In this chapter, the results of the three approaches are now interconnected to present a complete view and to find answers to the research questions.

5.1. User requirements for rapid mapping products

The questionnaire turned out to be the ideal method to reach the targeted audience. Also the distribution by officials of the FOEN and the NEOC proved to be effective. 46 responses were received which was far more than expected. All the must-have-cantons returned at least one completed questionnaire. The responses were characterized by (1) little end-user knowledge on remote sensing, (2) the emphasis of different affectedness of cantons, and (3) different financial and technical means of response.

Throughout the responses, several comments indicated a lack of knowledge of today's potential of remote sensing capabilities. There were comments such as "analysis of the event of 2005 revealed that the processing time of satellite imagery is far too long". This indicates that cantonal representatives are not quite aware enough of today's high spatial and temporal resolution of satellite imagery. These findings were also confirmed by participants of the focus group meeting.

In addition, cantons are not equally affected by flood events. This was reflected by the interest of certain cantonal authorities. One small canton answered: "Owing to the size of our canton we have yet not used satellite imagery and don't see a method of application in the future". In contrast, a different canton claimed: "Satellite images on a large scale could provide a valuable overview of the situation if timely delivered". Owing to the wide spatial coverage, the questionnaires portray these differences well.

Questionnaire respondents most often use rescue workers and the media as sources of information in flood situations. Only three cantons have used satellite imagery before and usually for incidence documentation. By these means it cannot be expected that the cantons have any competence in remote sensing. The situation looks different in terms of GIS competency. Some cantons referred to their EMS. Yet, the participants of the focus group raised doubts on the preparedness of GIS experts in case of a flood event. For immediate emergency management, their availability is thus doubtful. As a result, different technical means exist among the cantons.

5.1.1. Content

Different assets made it difficult to determine one single preference in terms of data content. Nonetheless, the following discussion highlights the most important aspects according to the questionnaire. User requirements on potential deliveries for future rapid mapping products are hereby specified in terms of demanded spatial information, product types, data resolution and base maps.

5.1.1.1. Spatial information

Most important spatial information were the delineation of affected areas, affected traffic lines, affected population, and the level of the current water table. In addition, the deposition of debris and driftwood was repeatedly required. Supporting data on regular water bodies, traffic lines and city names were preferred by a majority of the respondents (also see Chapter 4.1.3.2). Forthcoming rapid mapping products should contain such spatial information. However, no clear pattern could be detected for point elements such as hospitals, power stations, schools etc. Larger cantons in size requested all of the listed elements. Point map elements are strongly dependent on the individual map application. It is therefore recommended to leave out point elements in a future rapid mapping process.

During the focus group meeting, the head of cantonal crisis management Bern emphasized that cantonal emergency managers are familiar with their region. Each canton holds a list of critical infrastructure worth protecting in case of a flood event. The cantons should therefore be able to customize their own maps. This could be done by the delivery of a delineated flood vector layer. Subsequently, cantonal crisis staffs could themselves combine sensitive spatial information for their particular purposes.

5.1.1.2. Product types

Out of the three map types presented, a distinct trend in user demand could be detected. Depending on their use, a different level of detail is required. Particularly those responsible for emergency management esteem that fast delivery is more important than level of detail. Therefore the demand decreases tremendously over time. The higher preference for orthophotos compared to delineation maps is somewhat surprising. On delineation maps, the flooded areas are easier to distinguish. In addition, the required affected areas, traffic lines and population would be highlighted on this map. Simple image analysis could quickly classify the flooded areas and thus add important information. Therefore, a delineation map was expected to be more valuable than an orthophoto. Yet, respondents prefer a quick production and the earliest possible delivery. ¨

The grading map reached lowest approval rates and is therefore classified as not suitable for mapping flood situations. The level of detail is too high and persons in charge prefer to do the spatial analysis themselves. This was also confirmed in the focus group meeting. An additional product would thus be the above mentioned vector layer (i.e. shapefile) of the inundated areas. The incorporation of such a file into the cantonal EMS or in GIS systems was requested by both immediate emergency management and subsequent incidence documentation.

Concerning the issue of debris- and driftwood deposition: this depends on the volume and location of the deposited material. Optical satellite imagery has already been applied for large scale driftwood detection (Doong et al. 2011). An option for quantifying erosion processes would be the comparison of pre- and post DEM’s (Dumitru et al. 2014). However, high resolution DEM’s would be needed, as discussed in the focus group meeting, to detect such elevation changes. Alternatives would be the application of airborne LiDAR DEM’s (Lallias-Tacon et al. 2014).

5.1.1.3. Data resolution

The requirements on data resolution strongly depend on the spatial flood extent. Yet, the questionnaire reveals two trends. First, there is a change in scale requirement over time (see Figure 30). Shortly after an event, medium scale data are needed for an overall situation assessment. Only a few hours later, high resolution data of the damage hot-spots are demanded. Two cantons even asked for a resolution of 1:10’000 or 1:5’000. Second, the small scale maps of 1:100’000 or 1:50’000 are not useful for cantonal authorities. In case of a large scale flood event with several cantons involved, small scale maps would be applied at the central command of FO BAFU or the NEOC. Both institutions expressed their interest in such products in the course of the focus group meeting. It was also claimed that the scale of future remote sensing products strongly depends on the spatial extent of an event. A pre-defined map scale is therefore unnecessary. Nonetheless, the trend of increasing level of detail over time could be confirmed.

5.1.1.4. Base map

A strong preference for Swiss national maps as base maps resulted from the questionnaire. On one hand, rescue workers and crisis staff members are familiar with such maps. On the other hand, the national maps already contain information on elevation, traffic routes and place names compared to satellite images. Besides that, satellite images taken ahead of the event should not be used as base maps. They might deceive the map reader because they do not portray current conditions. Feedback on the map prototype has shown that this issue has to be taken into account, particularly in working with radar images. Flood information derived from radar sensors have to be combined with a base map. Suitable are topographic maps, such as the regular Swiss national maps, in order to avoid misinterpretation. The choice of the base map for radar derived flood information remains challenging. Ultimately the questionnaire underlined that Swiss national maps are most useful for such purposes.

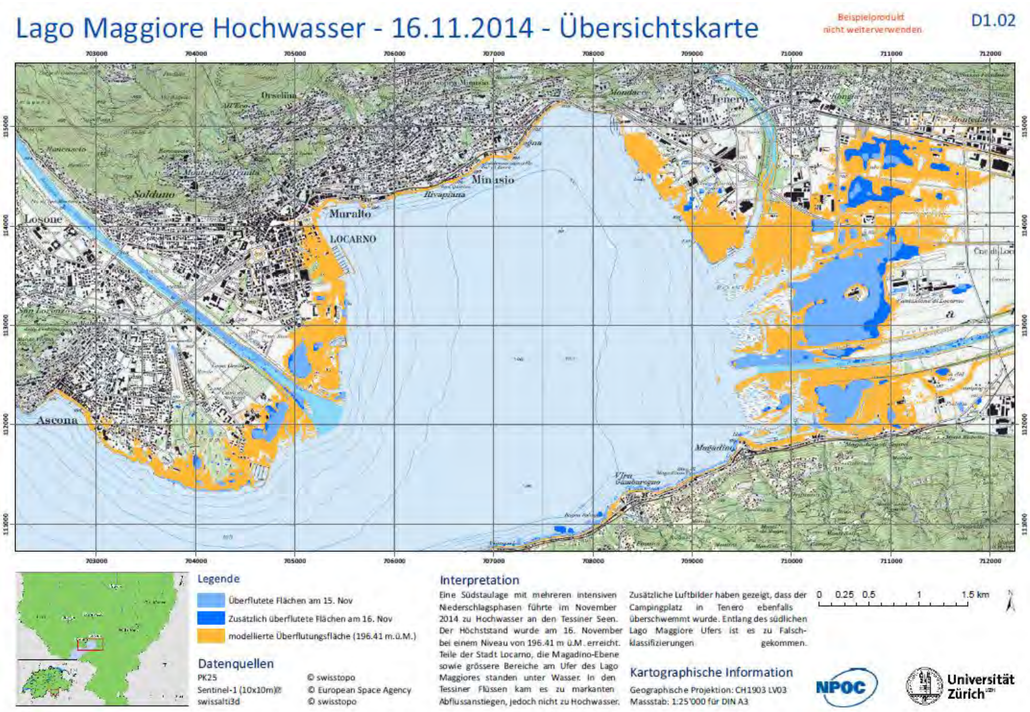


Figure 29: Example of delineation map prototype with a Swiss national map as a base map.

5.1.2. Delivery

Producers of rapid mapping products are ultimately interested in what deliveries are needed and when. Figure 30 depicts the requirements of the most demanded map types over time. Orthophotos and delineation maps on a scale of 1:25'000 are needed up to 24 hours after the event peaked. Grading maps also reached an approval rate of slightly over 50%. Yet a delivery is not recommended due to the strong criticism that has been confirmed by the focus group meeting. The often cited demand of a vector layer for individual spatial analysis would make the delivery of grading maps on any scale useless.

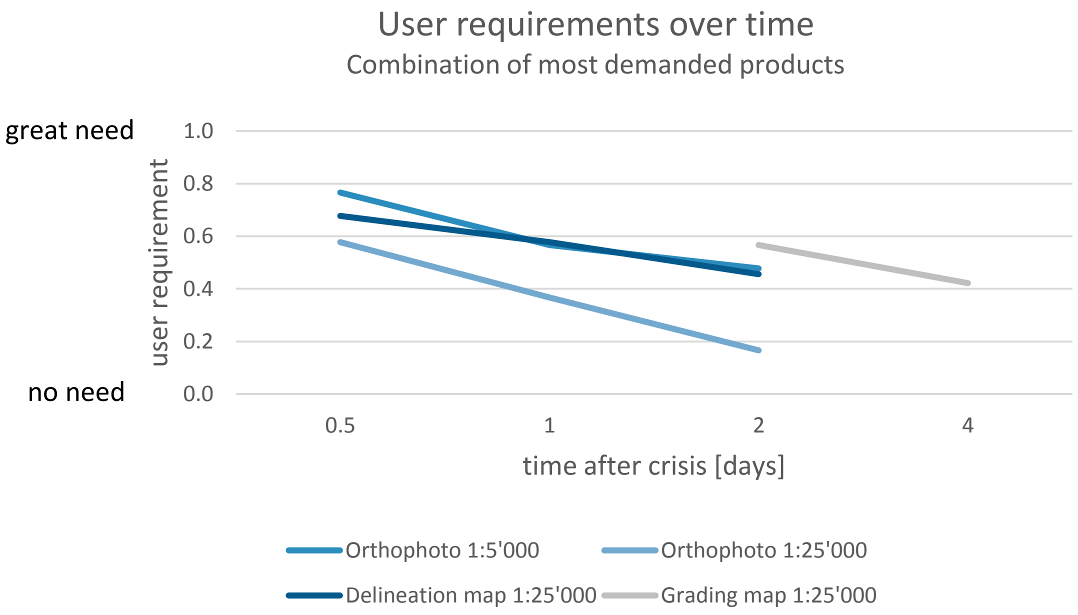


Figure 30: Comparison of user requirements of most demanded RS-products

The actual delivery needs to be fast and reliable. Several types of data delivery have been proposed:

- FTP / Download
- Email
- WMS service
- GIN (joint information platform for natural hazards)
- NEOC homepage

It has to be taken into account that upload and download rates might be quite slow in case of emergencies. A lack of internet connectivity or power outages are also possible scenarios. Therefore, alternative types of delivery should be planned.

An additional challenging demand of several cantons was the compatibility of satellite derived products with their current processes. This requirement will be difficult to meet due to myriads of emergency management processes within the cantons - Some of them work with EMS, some do not; sporadic GIS knowledge is available in some crisis staffs, some work mostly with physical maps. – The participants of the focus group even claimed that barely any crisis staff would be capable of integrating spatial data into their GIS systems right away. Unfortunately, the survey contained few questions on the methods of data implementation. With the results obtained, it is not possible to determine how many cantons actually apply EMS or GIS. Some cantons pointed out that their GIS section would be responsible for post event spatial analysis. The variety of applications makes it difficult to do justice to every single user requirement. As a result, several types of data delivery should be pursued.

5.1.3. Emergency management vs. Incidence documentation

One important task in the evaluation of the questionnaire was to determine user specific differences between emergency management and incidence documentation. Responders had to specify their position in everyday life and in an emergency situation. In addition, one question pointedly asked if they preferred to receive spatial data as soon as possible in coarse spatial resolution or as accurate as possible within a couple of days. Unambiguous assignment to one of the two classes should have been possible. This goal could not entirely be met because of two reasons: (1) some responders are responsible for both emergency management and incidence documentation. (2) Quick access to spatial flood data is often favored over high accuracy of the data. Nevertheless, the questionnaire answers were classified based on the answers to this question. Persons in charge of both favor fast delivery and were thus classified as emergency management. Their response would be representative of their position as emergency managers.

Both groups show a higher demand for large scale date. The usability of 1:100’000 and 1:50’000 is marginal for every type of product. The spatial responsibility of the cantonal crisis staffs is limited and thus calls for spatially high resolution data. Both, orthophoto and delineation maps are seen as greatly needed by a majority of respondents whereas approval rates for grading maps was marginal (Figure 31). Responders who answered with “no need” are from small cantons and responsible for emergency management. Hence, they have either no need for medium to small scale satellite maps or require the maps earlier than the specified delivery time. The demand of product types is therefore identical for both groups.

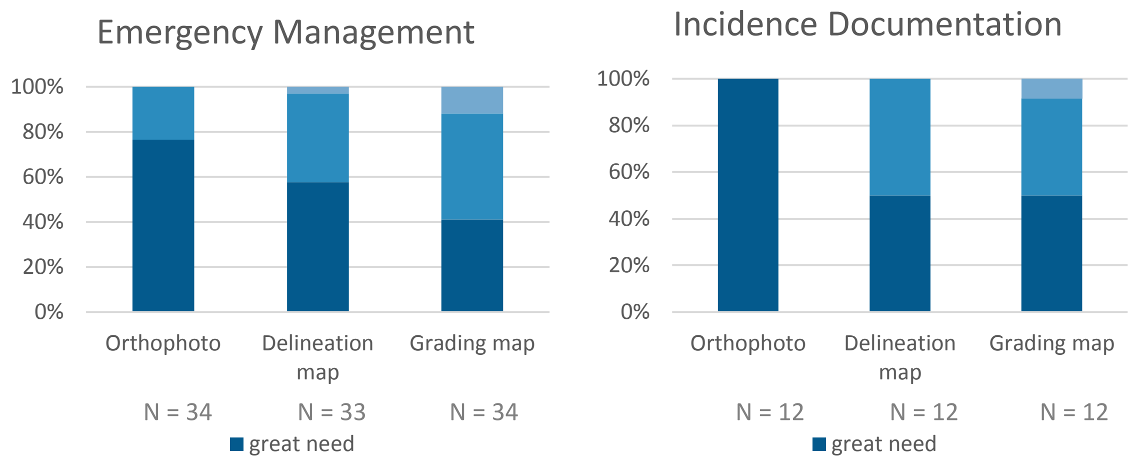


Figure 31: Comparison of user requirements between EM and ID

In terms of content, no difference could be detected in the demand of map elements. Inundated areas, water table and affected traffic lines are the most commonly needed spatial information. Besides that, both groups show no clear preference for additional map elements. The availability of a vector layer is required by both parts as well. Persons in charge of incidence documentation prefer to conduct spatial analysis themselves and thus need such a layer.

Considerable differences could be detected in the temporal requirements (see chapters 4.1.3.1 and 4.1.3.2). Quick availability of data is essential for emergency management. The results show that a majority does not need data any later than 24 hours after the event. Incidence management, however, still sees a great need for orthophotos and delineation maps, even 48 hours later. These differences were expected ahead of the questionnaire distribution and could now be confirmed.

In the end, it remains questionable whether or not rapid mapping can meet the needs of both groups. The delivery time of rapid mapping products relies on a multitude of factors. Late activation, unfavorable satellite constellations and many other obstacles can result in a delayed delivery. At the current moment, it can thus not be guaranteed to meet the requested delivery time of one day for emergency management (timelines as a limiting factor is further discussed in chapter 5.3). Yet incident management could profit from satellite derived products. There is a demand for a clear overview of the situation. In-depth analysis could thus be supported by satellite rapid mapping products. In addition, the frequent revisit time of satellites could provide a daily update of the situation. This would also be valuable for investigating events that last over several days.

5.2. Rapid mapping processing chain

Exploration in the starting phase of this master's thesis has shown that a smooth processing chain has yet to be installed. Every single stage of the rapid mapping process was applied step-by-step in the course of the map prototype creation. Mobilization, data acquisition, pre-processing, analysis and map production ultimately led to the production of five different map prototypes. Means of production such as hardware, software and expert knowledge are sufficiently accessible at the RSL. The availability of these resources is the foundation for the entire processing chain. Yet, a successful rapid mapping process must be as fast as possible, which is where improvements could be made. Potential and limitations of rapid mapping are outlined in the following two chapters.

5.2.1. Potential

Results of the questionnaire have shown that very high resolution data is required for adequate emergency management in Switzerland. Large scale maps are prerequisite for a precise delineation of flooded areas and detailed spatial analysis. The tremendous boost in space technology combined with a better availability of remote sensing data has brought remarkable improvement for applying remote sensing for disaster management. Now available optical very-high-resolution satellite imagery provides EO data on a spatial resolution of down to 31 cm (Digital Globe 2014). Radar very-high-resolution satellite data is available down to 1m (by satellite TerraSAR-X) (Baghdadi et al. 2009). In Switzerland in particular, where floods usually occur as river floods on a relatively limited scale, a high spatial resolution is requested and can now be provided.

Satellite data has become operational. Robust processing chains of satellite data providers facilitate data acquisition (Martinis et al. 2014). Particularly in case of a flood event, weather conditions often prohibit appropriate aerial image acquisition. Radar satellites are capable of acquiring all-weather day-and-night images which guarantee available images in a short amount of time and at higher spatial resolution than ever before (Malenovský et al. 2012). Announcements of upcoming missions, and with that a growing number of satellites, even reduces the interval of image acquisition. Recent publications of Skybox Imaging even capture several images per day of the same area (Skybox Imaging 2015). These innovations help improving the applicability of remote sensing for disaster management. It can thus be assumed, that the temporal availability of satellite data will increase in the following years and thus become beneficial for emergency management in Switzerland.

The development of the map prototypes have demonstrated the challenges within the rapid mapping processing chain. The abundance of geodata at the NPOC facilitates analysis. Numerous datasets can be combined with derived flood information for in-depth spatial analysis. The usually expensive datasets are available on almost every scale and level of detail for all of Switzerland. Spatial analysis across cantonal borders can be executed in a straightforward way. The designed prototype took advantage of several datasets. They were easily implemented in the map-making process. The combination of remote sensing data and reference datasets improves the value of such rapid mapping products. Furthermore, the scientific and operational NPOC are experts in the field of remote sensing and image analysis. Their experience in the field enables rapid production and saves valuable time in case of a fast and accurate product delivery.

Participants of the focus group came to the conclusion that an ideal way of testing the possibilities of rapid mapping would be a collaborative case study. In case of a future flood event, existing structures and remote sensing applications should be run through the entire emergency procedure. Emergency management and incidence documentation on cantonal and federal levels could then themselves decide if the products received would be beneficial for their particular purposes.

5.2.2. Limitations

The questionnaire evaluation has shown that persons in charge of emergency management require rapid mapping products within 24 hours after the event. If such a goal is to be reached, a multitude of factors have to coincide. The following paragraphs each highlight one critical aspect that was found while writing this master's thesis.

1. A critical point in today's processing chain is mobilization. The process is initiated by the request of a canton. Either the NEOC or the FOEN then contacts the NPOC. The FOEN but particularly the Cantons, act as the triggering authority. The conducted survey revealed an unawareness of satellite imagery potential within cantonal authorities. "Data and information products must be available and known." as Köhler (2005) asserted in a user study on geo-information. The focus group meeting confirmed that this is exactly the point where awareness building has to take place in the future. Once cantonal crisis staffs are aware of the potential of remote sensing, an increase in use is expected. Participants of the focus group see a next promising step in developing a booklet on the potential of remote sensing. The content should demonstrate different hazards for Switzerland and the related

remote sensing products. In this way, a sensitization of the cantonal crisis staffs could take place.

2. A limiting factor was exposed in the pre-processing stage. Once satellite data is received by the specialized operator, pre-processing and image analysis convert raw data into reliable information. Numerous services already execute the pre-processing stage and deliver orthorectified products (i.e. Apollo Mapping or Airubs Defence and Space). If this is not the case, the data has to be pre-processed by the NPOC. For this part, however, it took three weeks to design the map prototype. In case of a flood event, the Sentinel-1 pre-processing should thus be optimized or different satellite data must be considered.
3. The analysis stage revealed several issues in working with radar images. Polarization, incidence angle and wavelength either have a positive or negative effect on water detection of radar images. Steep incidence angles are for example better suited for flood mapping in forested regions (Voormansik et al. 2014). In addition, measuring in the L-band gives better results in such areas (Albertz 2009). Sentinel-1 applies the C-band (Malenovský et al. 2012) and is thus not best for measuring inundated forested areas. These limitations were confirmed by the prototype.
4. A time consuming factor was the map production process. Much time can be lost by the map layout and by adding all the regular map elements. The development of templates for different scenarios would cut down map production time tremendously. A predefined map layout could be arranged in ArcGIS which then only needs to be slightly adapted depending on the affected area.
5. A crucial point throughout the entire processing chain is the assignment of responsibilities. At the current moment, a loose organization exists and persons in charge do not know each other. A step forward would be the establishment of a link between the involved institutions, as already suggested by Bühler et al. in 2007. The focus group meeting can be seen as an initial step for better interdisciplinary collaboration in the future. In addition, the installment of a business continuity management would provide a 24/7 service which would again cut back the production time and increase preparedness. It is evident that the responsibilities and a clear structure of the entire rapid mapping process have to be defined by all participants.

The above-listed limitations within the rapid mapping processing chain are mostly a result of missing structures and process definitions. Yet these obstacles can be easily eliminated if a detailed process management is put in place.

5.3. Added value of satellite derived flood data

The large differences within the cantonal requirements make it impossible to determine an overall added value. Yet the previous Chapter 5.1 made it clear that rapid mapping products are able to fulfill essential requirements of emergency management and incidence documentation. Persons in charge confirmed the application of remote sensing products for the following purposes:

- Situation overview (spatial flood extent)
- Identification of critical objects
- Prioritization (deployment of personnel and equipment, traffic management etc.)
- Damage assessment (locate more and less damaged areas)
    - Identification of debris and driftwood deposition due to the flood event.
- Means of communication (map as internal and external communication for emergency management)
- Event documentation (Detailed maps delineate exact flood extent and processes over time)
- Evaluation of hazard map (adaption of existing natural hazard maps if necessary)

Besides that, skeptical voices question the added value in comparison to today's resources. The above-mentioned purposes are already handled by the cantonal crisis staff in case of a flood event today. In addition, the applicability is limited by the two factors: time and cost.

1. Timeliness: Timely delivery can be seen as the most important issue in rapid mapping. The answers of the cantonal representatives have shown that the temporal availability of different products is particularly relevant for cantonal emergency management. They only benefit from satellite derived flood map products if they are delivered within 24 hours after the event. The instant tasking service of Airbus Defense and Space (Airbus Defense and Space 2015) declares a delivery within 7 hours at best and 48 hours at worst, depending on the satellite's position. It can certainly not be guaranteed that a product be delivered within 24 hours. In addition, the development of the map prototype revealed certain time delays within today's processing chain that could delay delivery even more.
2. Cost: The question of the cost of satellite imagery was repeatedly raised in the qualitative part of the questionnaire. In case of a Charter Call activation, satellite data is available at no cost. The NPOC is responsible for data delivery and technical support in case of an emergency. These services are also free of charge. Cantonal and federal authorities could thus obtain satellite derived products for free in case of a Charter Call activation. Regional

flood events might not provoke a Charter activation. In such cases, Swisstopo would determine appropriate means of image acquisition. Aerial images or even drone data for local floods might be reasonable alternatives. Also pictures taken from a helicopter are a cost-efficient and fast acquisition method. An inquiry of Apollo Mapping (K. Nelson, personal communication, 29 May, 2015), a satellite data reseller, led to the following results: The cheapest option for satellite tasking starts at $23 per square kilometer (whereby the minimum order size is 100 square kilometer). Such requests might however take a few weeks. Priority tasking, with a delivery between 24 to 48 hours, starts at $43 per square kilometer. By taking the minimum order size of 100 square kilometer into account, this option starts at $4300. Therefore, user feedback is needed to obtain specifications on the cost maximum.

The added value for cantonal authorities is thus bound to certain restrictions. However, the delivery of a vector file would open new possibilities in comparison to today's means. The cantonal authorities are experts in their regions. An incorporation of such files into their EMS or GIS would enable customized map production. If timely delivered, emergency management and incidence documentation would benefit from such a product.

5.3.1. Perspectives on the federal level

Although not particularly surveyed in this master's thesis, the FOEN and the NEOC raised interest in rapid mapping products. In the course of the focus group meeting, both representatives explained the difficulty of getting an overview of the entire situation in case of a large scale flood event. In such moments, cantonal crisis staffs are already used to their full capacity, which makes it difficult to gather precise information on the federal level. A "view from the top" might provide quicker information for the FOEN and the NEOC. The question of added value of satellite imagery therefore also varies between cantonal and federal authorities. Periodic evaluation procedures are already undertaken by the German operational rapid mapping service of DLR ZKI (A. Twele, ZKI, personal communication, 27 May, 2015). Their feedback consequently underlines the added value of their service since its beginning.

5.4. Recommendations

The user study of this master's thesis shows differentiated demand for satellite rapid mapping for flood events. Cantonal and federal incidence documentation would benefit from delineation maps and orthophotos. The NEOC and the FO BAFU expressed demands for satellite derived flood maps. However, potential products are only of added value if they are delivered timely and with high accuracy. Therefore, an efficient processing chain needs to be established. The following points should thereby be considered:

1. User requirements vary from one cantonal authority to another. The delivery of **orthophotos**, **delineation maps** and **vectored flood layers** would thus satisfy the diverse demands. Further specification on the precise deliveries need to be executed.
2. An optimization of pre-processing and map production would tremendously cut back production time within the rapid mapping processing chain.
3. Cantons should be sensitized on the potential of remote sensing. This could be done by the development of a short and informative remote sensing/rapid mapping brochure.

Hopefully the focus group meeting, conducted within the framework of this master's thesis, initiated restructuring of the processes. A collaborative case study could be the next step for fostering the application of remote sensing data. Finally, the responsibility for further actions should be assigned to one single institution. This would guarantee an efficient and timely development of rapid mapping for disaster management in Switzerland.

6. Conclusion

This master's thesis has summarized the current state of the art of satellite rapid mapping in Switzerland and demonstrated its potential and limitations for large scale flood events. In the face of recent developments in remote sensing an assessment of the current situation has been necessary. The application of quantitative and qualitative methods have led to a holistic view of the process of satellite rapid mapping.

The questionnaire assessed the cantonal user requirements and thus provided answers to the first research question. Cantonal authorities were divided into emergency management and incidence documentation. Affected areas, water tables, affected traffic lines and affected populations are important information for both sectors. In addition, respondents of both groups work only partially with EMS or GIS. It was found that emergency management needs data delivery within 24 hours after the event whereas the spatial resolution is less important. Incidence documentation requires high resolution data of the precise flood extent whereas delivery time is secondary. Incidence documentation in particular requires digital products for further editing. Furthermore, a clear demand for satellite derived flood maps was underlined by the crisis staffs of the FOEN and the NEOC. The user study within the cantonal authorities could be adopted for further requirement assessments of different disaster types.

Satellite rapid mapping products can meet these requirements. Spatial resolution in the sub-meter area offers precise delineation of the flood extent. Orthophotos and delineation maps on a scale of maximum 1:25'000 were confirmed as suitable products. In addition, the delivery of a vector file of the inundated areas would enable cantonal authorities to include the relevant spatial information in their systems. By these means, they would be empowered to develop customized maps and perform spatial analysis independently. Potential products are proposed and thus answer the second research question.

The development of a map prototype revealed challenges within the rapid mapping processing chain. The mobilization phase could be improved by awareness-building within the cantonal crisis staffs. According to the replies of the questionnaire, persons in charge within the cantonal authorities are not quite familiar enough with today's potential of remote sensing. A sensitization of the cantonal authorities could be achieved by the development of a booklet that summarizes the potential and limitations of remote sensing for disaster management. In addition, procedures within the pre-processing phase should be revised. More time could be gained in facilitating the map production by developing templates for certain scenarios. Along the entire process, clear responsibilities have to be assigned by the institutions involved. Overall, a profound revision of the processing chain should be carried out to guarantee preparedness in case of an emergency.

Ultimately, the last research question asked for the added value of satellite derived data. A variety of purposes demonstrates the wide range of applications. However, the added value of satellite remote sensing is limited by time and cost. Rapid image acquisition and fast delivery increase the application for emergency management. There are different means in terms of crisis response among cantonal authorities. Particularly on the federal level, an overview in case of a large scale flood event would provide valuable information. Continuous innovations in remote sensing create new potential for flood disaster management. This master's thesis exposed a need for further action in the field of satellite rapid mapping and laid the foundations for further implementations of this promising technology for disaster management in Switzerland.

7. Appendix

7.1. Questionnaire (German Version)

Universität Zürich[UZH]

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Umwelt BAFU
Office fédéral de l'environnement OFEV
Ufficio federale dell'ambiente UFAM
Uffizi federal d'ambient UFAM

Fragebogen

Bedürfnisabklärung von Fernerkundungsprodukten

Szenario: Hochwasser

Die Möglichkeiten der Fernerkundung entwickelten sich in den letzten Jahren rasant, sodass Fernerkundungsprodukte vermehrt in Krisensituationen verwendet werden. Oft ist jedoch unklar was für Nutzergruppen es potentiell gibt und welche Bedürfnisse bzw. Ansprüche diese Nutzer haben. Dieser Fragebogen richtet sich an Personen, die im Falle eines Hochwassers für die *Lagebeurteilung* oder die *Ereignisdokumentation* zuständig sind.

Der Fragebogen ist in drei Teile gegliedert. Im ersten Teil werden Fragen zur aktuellen Nutzung von Lagedaten gestellt. Der zweite Teil beinhaltet Produktbeispiele basierend auf Fernerkundungsdaten und geht auf Nutzerbedürfnisse ein. Im dritten Teil stehen die Datenüberlieferung und die Datenqualität im Fokus.

Die Beantwortung des Fragebogens wird ca. 20 Minuten dauern. Selbstverständlich werden Ihre Angaben vertraulich behandelt. Wir möchten Sie bitten den Fragebogen bis am 10. März 2015 als ausgefülltes PDF oder per Post zurück zu senden.

Vielen Dank für Ihre wertvolle Mitarbeit.

Bei Unklarheiten stehe ich Ihnen gerne zur Verfügung:

Jonas Hänseler
Hochwachtstrasse 43
8400 Winterthur
Mail: jonas.haenseler@uzh.ch
Tel: 076 594 59 35

Angaben zur Person

Vorname:

Name:

Email:

Tel:

Kanton:

Position (Alltag):

Position (Krisensituation):

Art der Nutzung

1. Welche Informationsquellen nutzen Sie in einer Hochwassersituation?

- ◻ Rettungskräfte
- ◻ Drohnengestützte Daten
- ◻ Flugzeuggestützte Daten
- ◻ Satellitengestützte Daten
- ◻ Medien
- ◻

2. Welche Mittel verwenden Sie für die räumliche Darstellung/Bearbeitung dieser Informationen?

- ◻ Physische Karte (z.B. Landeskarte 1:25'000)
- ◻ Digitale Karte (z.B. in einem GIS)
- ◻ Mobiltelefon/Tablet
- ◻ Fotos
- ◻

3. Was trifft *eher* auf Sie zu?

- ◻ Der Detaillierungsgrad meiner Daten muss nicht sehr hoch sein (Überschwemmte Fläche reicht aus). Ich benötige die Daten aber möglichst rasch.
- ◻ Der Detaillierungsgrad soll hoch sein (Gebäude, Einzelbäume etc. sollen erkennbar sein). Die Lieferzeit ist dagegen sekundär.

Beispielprodukte

In diesem Kapitel werden Ihnen vier mögliche Produkte der Fernerkundung vorgestellt. Bewerten Sie diese nach dem Nutzen, den die Produkte für Ihre Tätigkeit bringen könnten. Markieren Sie jeweils *eine* Antwort nach den folgenden drei Kategorien:

0	Kein Nutzen	Erbringt neben den heutigen Mitteln keinen Mehrwert
+	Minimaler Nutzen	Könnte genutzt werden, gleichwertige Alternativen sind aber verfügbar
++	Grosser Nutzen	Würde für die Lagebeurteilung und/oder Ereignisdokumentation erhebliche Vorteile erbringen

Orthophoto

Quelle: Swisstopo, 2015

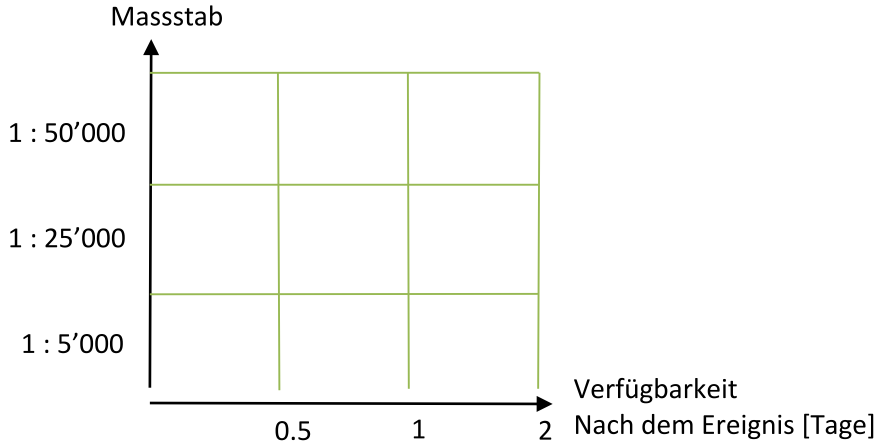
Das Orthophoto zeigt ein verzerrungsfreies Abbild der Erdoberfläche und wird aus Luft- oder Satellitenbildern abgeleitet. Ein Vorteil ist die relativ rasche Produktion und die hohe räumliche Auflösung, die eine Erkennung von z.B. Verkehrswegen und Gebäuden ermöglicht. Bei Schlechtwetter ist die Bildqualität aufgrund von Wolken und geringerem Kontrast der Objekte stark reduziert oder die Aufnahme gar unmöglich.

Massstab:	1:5‘000 bis 1:50‘000
Datenquellen:	Luftbild (Flugzeug) Optische Satelliten
Räuml. Aufl.:	0.5m - 5m/Pixel
Datentyp:	Raster

4. Wie hoch ist oder wäre der Nutzen eines Orthophotos für Sie?

- □ Kein Nutzen (0)
- □ Minimaler Nutzen (+)
- □ Grosser Nutzen (++)

5. Wann benötigen Sie ein Orthophoto und in welchem Massstab? Füllen Sie diese Matrix entsprechend Ihren Nutzerbedürfnissen aus. (Beispiel: Falls eine 1:50‘000 Karte innerhalb eines Tages einen sehr grossen Nutzen erbringt, füllen Sie ++ ein). Ein Massstabsvergleich ist im Anhang zu finden.



6. Für welchen Zweck würden Sie ein Orthophoto einsetzen?

Übersichtskarte

→ Karte in besserer Auflösung im Anhang

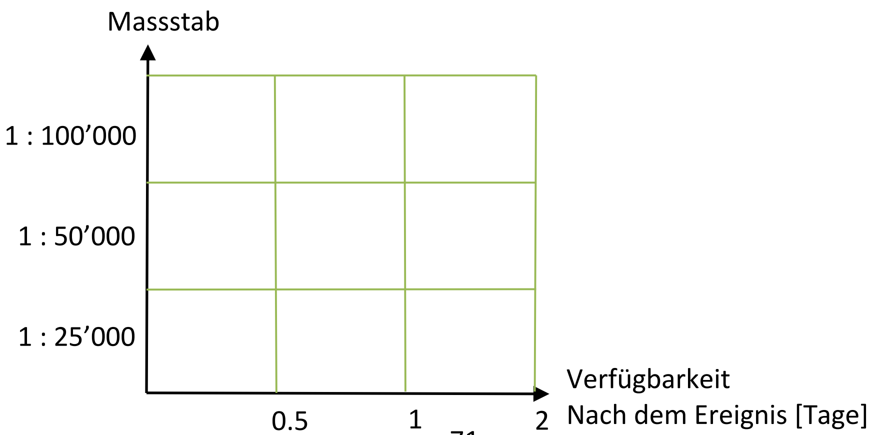
Eine Übersichtskarte zeigt das gesamte Ausmass der Hochwassersituation. Die überfluteten Gebiete werden von Satellitenbildern abgeleitet und auf eine Hintergrundkarte gelegt (Radarsatelliten liefern auch bei Bewölkung ein zuverlässiges Bild). Als Hintergrund-Karte kann eine Landeskarte oder ein älteres, wolkenfreies Orthophoto verwendet werden. Sowohl die überfluteten Gebiete, als auch der reguläre Gewässerverlauf werden farblich hervorgehoben. Zusätzliche Informationen, wie Ortsnamen oder Grenzen, können ebenfalls hinzugefügt werden. Im Zentrum steht jedoch die Darstellung der Gesamtsituation des Krisengebietes.

Massstab: 1:25‘000 bis 1:200‘000
Datenquellen: Luftbild
Optische Satelliten
RADAR Satelliten
Räuml. Aufl. : 5m - 30m/Pixel
Datentyp: Raster (Hintergrundbild)
Vektor (Überschwemmungsfläche, Flusslauf etc. als GIS-Layer verfügbar)

7. Wie hoch wäre der Nutzen einer Übersichtskarte für Sie?

- □ Kein Nutzen (0)
- □ Minimaler Nutzen (+)
- □ Grosser Nutzen (++)

8. Übersichtskarten benötigen eine gewisse Produktionszeit und können in unterschiedlichen Massstäben produziert werden. Ein höherer Detaillierungsgrad führt normalerweise zu einer längeren Produktionsdauer. Füllen Sie diese Matrix entsprechend Ihren Nutzerbedürfnissen aus. (Beispiel: Falls eine 1:100‘000 Karte innerhalb eines Tages einen sehr grossen Nutzen erbringt, füllen Sie ++ ein). Ein Massstabsvergleich ist im Anhang zu finden.



9. Für welchen Zweck würden Sie eine Übersichtskarte einsetzen?

10. Welche Hintergrundkarte würden Sie bevorzugen?

- ◻ Schweizer Landeskarte
- ◻ Satellitenbild
- ◻

11. Welche der folgenden Informationen benötigen Sie ebenfalls auf einer Übersichtskarte?

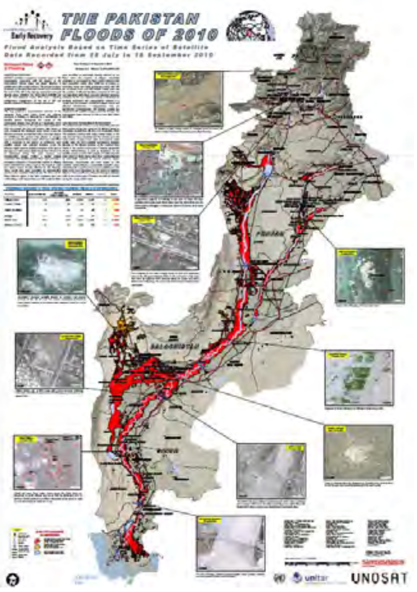
	0 (Kein Nutzen)	+ (minimaler Nutzen)	++ (grosser Nutzen)
Name von Ortschaften	◻	◻	◻
Grenzen	◻	◻	◻
Regulärer Gewässerverlauf	◻	◻	◻
Verkehrswege	◻	◻	◻
Hochspannungsleitungen	◻	◻	◻
Ausbreitung von urbanen Gebieten	◻	◻	◻

12. Wie wichtig ist die Kennzeichnung von:

	0 (Kein Nutzen)	+ (minimaler Nutzen)	++ (grosser Nutzen)
Schulen	◻	◻	◻
Spitälern	◻	◻	◻
Kraftwerken	◻	◻	◻
Industriegebiete	◻	◻	◻
Abfalldeponien	◻	◻	◻
Kläranlagen	◻	◻	◻

13. Gibt es dringend benötigte Informationen, die nicht erwähnt wurden? Wenn ja, welche und was wäre deren Nutzen?

Analysekarte



Eine Analysekarte zeigt den detaillierten Verlauf eines Ereignisses. Die überfluteten Gebiete werden mit zusätzlichen räumlichen Daten kombiniert (z.B. Bevölkerungsdichte, Gebäudedaten, Areal-statistik etc.). Dies ermöglicht detaillierte Analysen der betroffenen Gebiete. Die Analysekarte enthält im Vergleich zur Übersichtskarte mehr Informationen zu den überschwemmten Gebieten oder sogar hochaufgelöste Bilder der besonders stark betroffenen Orte.

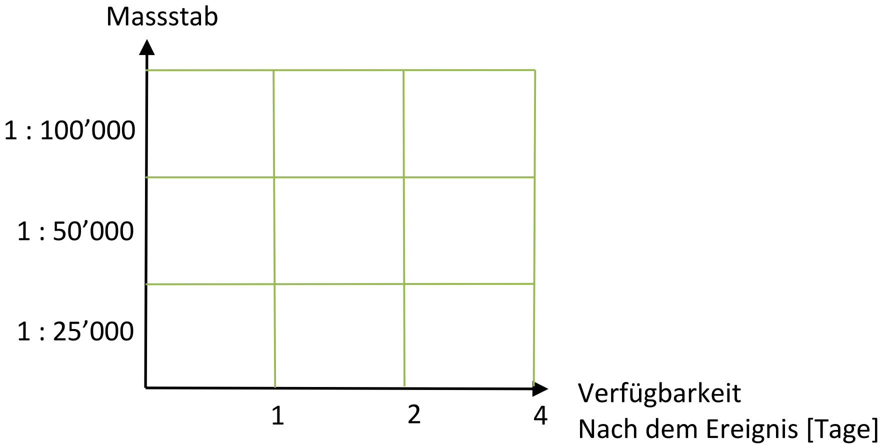
Massstab: 1:25‘000 bis 1:150‘000
Datenquellen: Luftbild
Optische Satelliten
RADAR Satelliten
Räuml. Aufl.: 0.5m - 30m/Pixel
Datentyp: Raster (Hintergrundbild)
Vektor (Überschwemmungsfläche, Flusslauf etc. als GIS-Layer verfügbar)

[→ Karte in besserer Auflösung im Anhang]

14. Wie hoch ist der Nutzen einer Analysekarte für Sie?

- □ Kein Nutzen (0)
- □ Minimaler Nutzen (+)
- □ Grosser Nutzen (++)

15. Analysekarten benötigen eine gewisse Produktionszeit und können in unterschiedlichen Massstäben produziert werden. Ein höherer Detaillierungsgrad führt normalerweise zu einer längeren Produktionsdauer. Füllen Sie diese Matrix entsprechend Ihren Nutzungsbedürfnissen aus. (Beispiel: Falls eine 1:100‘000 Karte innerhalb zwei Tagen einen sehr grossen Nutzen erbringt, füllen Sie ++ ein). Ein Massstabsvergleich ist im Anhang zu finden.



16. Welche abgeleiteten Informationen wären für Sie von Interesse?

	0 (Kein Nutzen)	+ (minimaler Nutzen)	++ (grosser Nutzen)
Wasserstand zum Zeitpunkt der Aufnahme	☐	☐	☐
Betroffene Verkehrswege	☐	☐	☐
Betroffene Flächen (z.B. betroffene Siedlungsfläche)	☐	☐	☐
Anzahl betroffener Gebäude	☐	☐	☐
Betroffene Bevölkerung (in Anz. Bewohnern)	☐	☐	☐

17. Gibt es dringend benötigte Informationen, die nicht erwähnt wurden? Wenn ja, welche und was wäre deren Nutzen?

18. Für welchen Zweck würden Sie eine Analysekarte einsetzen?

Datenüberlieferung und Datenqualität

19. In welchem Format sollen die Produkte übermittelt werden?

- ◻ Als physische Karte und somit direkt einsetzbar.
- ◻ Als digitaler Datensatz, der weiter bearbeitet werden könnte (z.B. im GIS oder Google Maps).
- ◻

20. Falls ein Produkt für Sie hergestellt würde, welches wäre dann die ideale Lieferart?

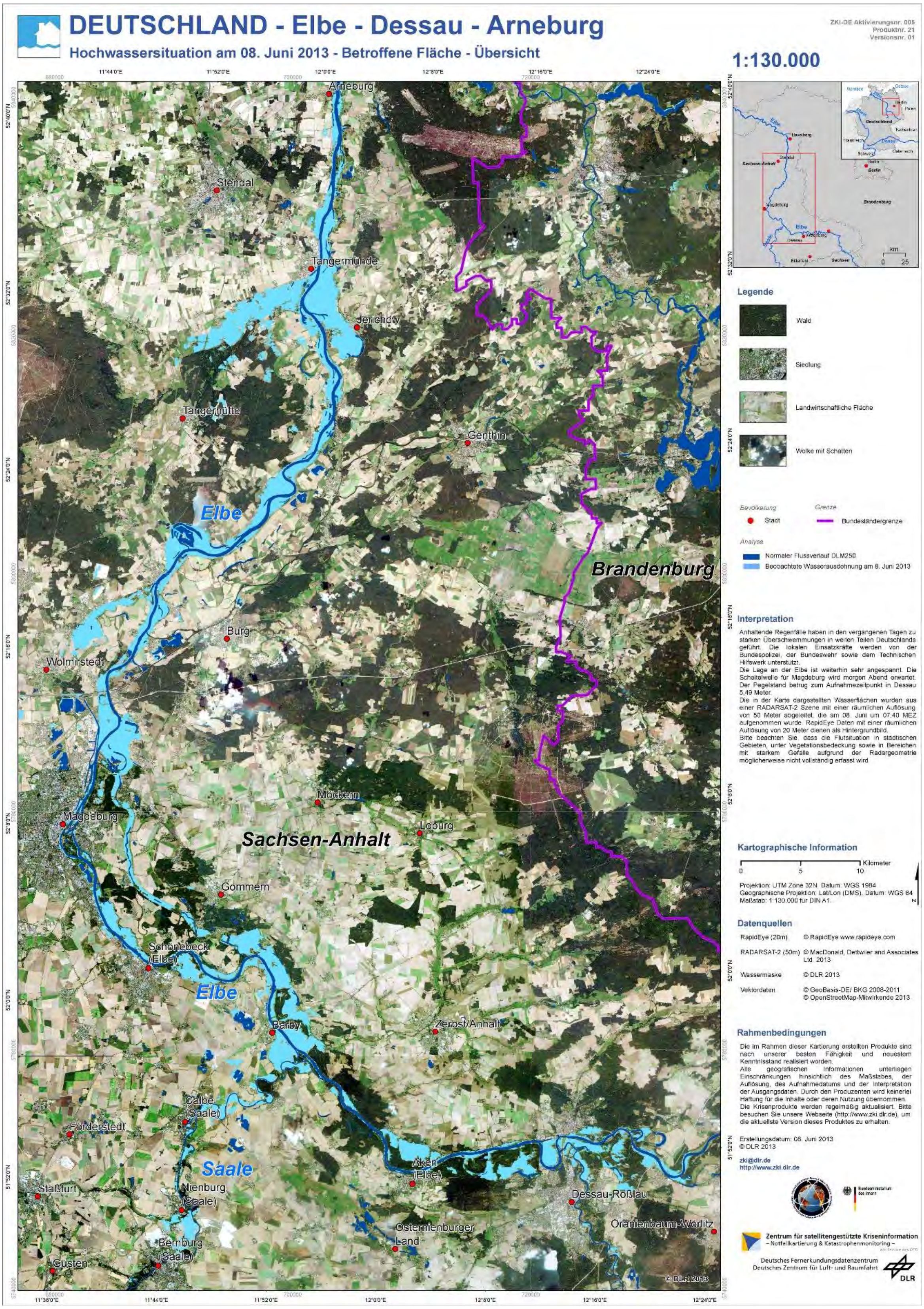
- ◻ Email
- ◻ Download (FTP, Dropbox, etc.)
- ◻ Datenträger (HD, USB, CD, etc.)
- ◻

Bemerkungen

Anhang: Massstabsvergleich

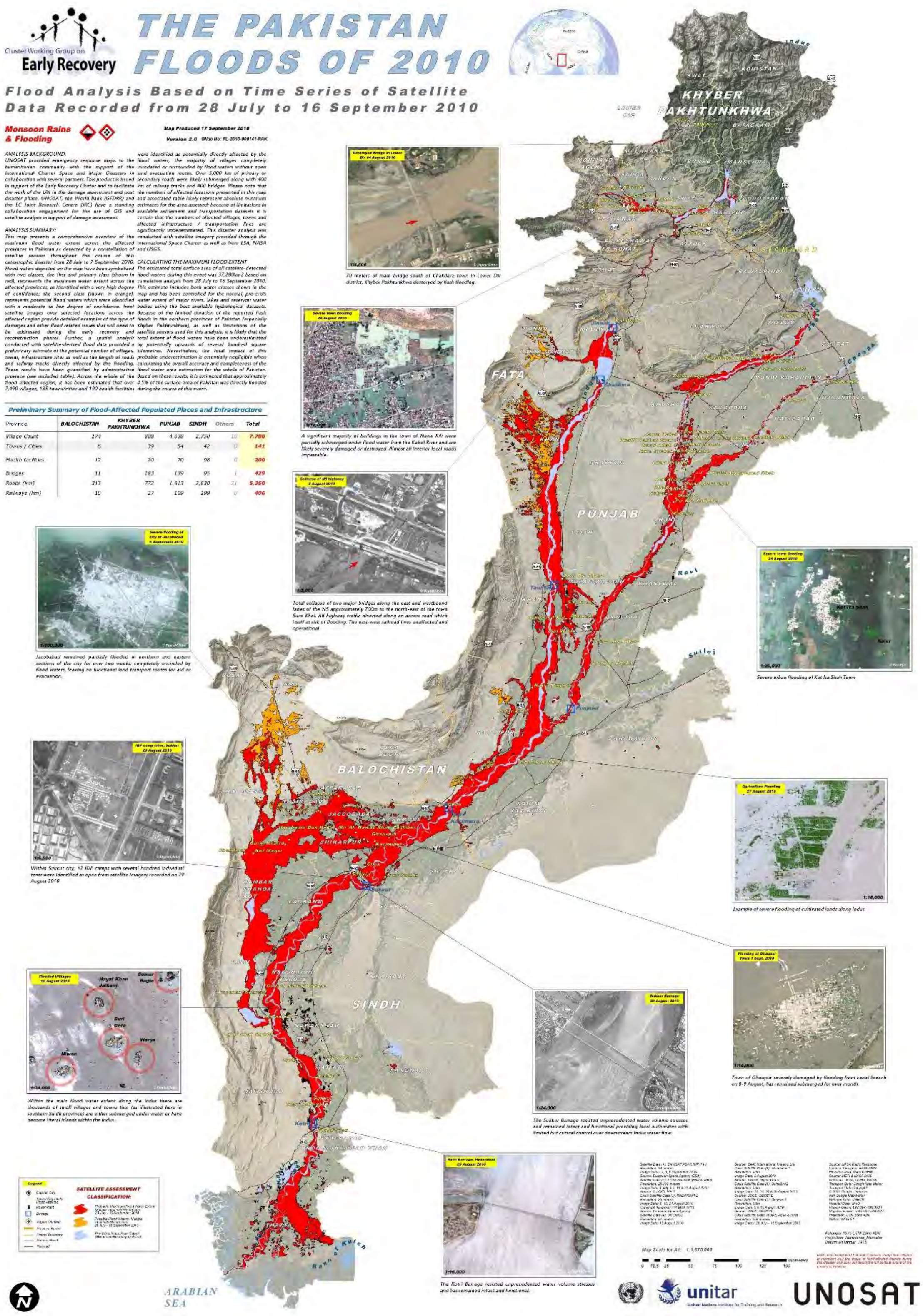
1: 5’000		• Sehr hoher Detaillierungsgrad • Fahrzeuge, Einzelbäume und kleine Bauwerke sind gut erkennbar
1: 25’000		• Hoher Detaillierungsgrad • Verkehrsnetz, kleine Flussläufe, Gebäude und Schiffe erkennbar
1: 50’000		• Mittlerer Detaillierungsgrad • Grössere Gebäudetypen, Flüsse, Brücken und Pärke erkennbar
1: 100’000		• Geringer Detaillierungsgrad • Siedlungsgebiet, grössere Flüssläufe, Waldgebiete und Seen erkennbar

Anhang: Beispielprodukt Übersichtskarte



(Quelle: DLR ZKI, 2015. http://www.zki.dlr.de/de/product/map/dlr-zki-de005-deutschland-dessau-arneburg-flut-2013-betroffene-flaeche-uebersicht-p21 Besucht am 22.01.15)

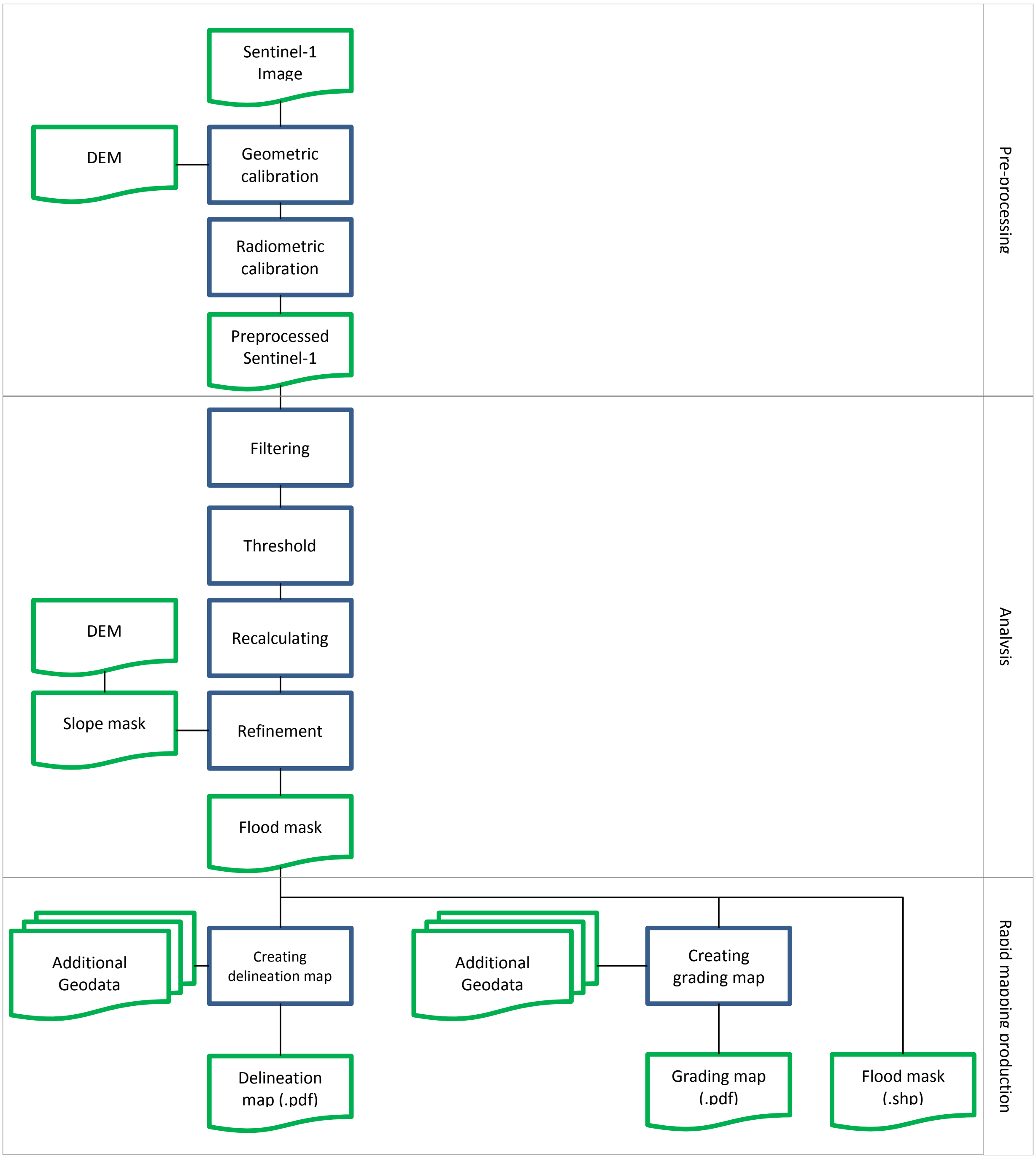
Anhang: Beispielprodukt Analysekarte



(Quelle: UNITAR UNOSAT, 2015. http://www.unitar.org/ unosat/ node/44/1506 Besucht am 26.01.15)

7.2. Processing chain

This processing chain was derived and adapted from the DLR ZKI as thoroughly explained in Chapter 2.3. It has to be considered, that this procedure is optimized for radar satellite images processed by the means of the RSL at the University of Zurich.



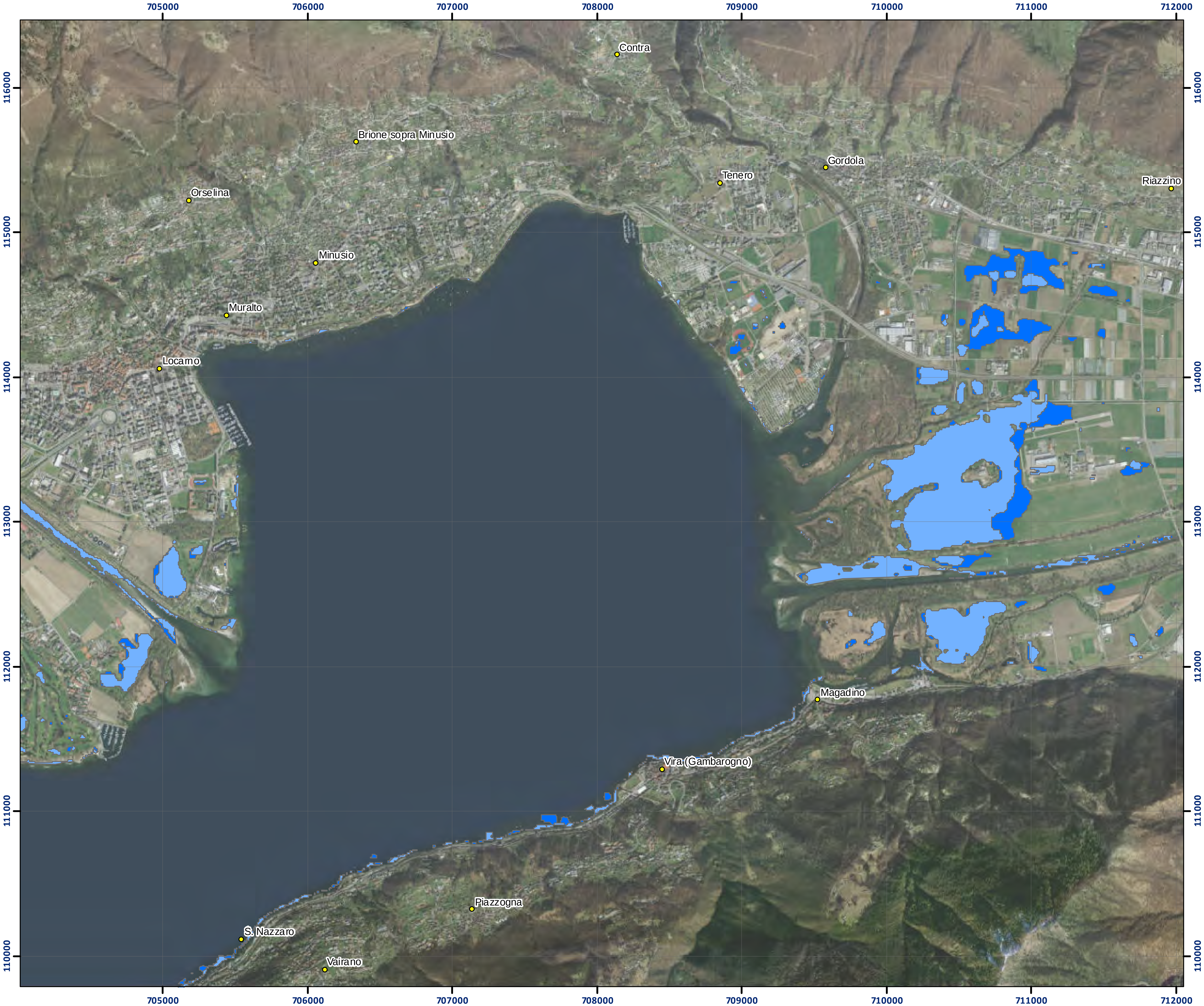
7.3. Map Prototypes

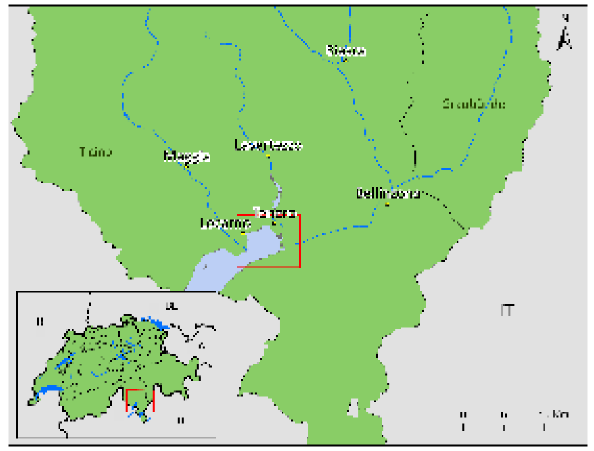
ID	Map type	Scale	Basemap	Page
D1.01	Delineation map	1:25’000	Swissimage	82
D1.02	Delineation map	1:25’000	PK25	83
G1.03	Grading map	1:25’000	PK25	84
G1.04	Grading map	1:10’000	Swissimage	85
G1.05	Grading map	1:10’000	PK25	86

Lago Maggiore Hochwasser - 16.11.2014 - Übersichtskarte

D1.01

Beispielprodukt
nicht weiterverwenden





Legende

Hochwasserstand 15. Nov

Zusätzl. Hochwasserstand 16. Nov

Ortschaft

Interpretation

Eine Südstaulage mit mehreren intensiven Niederschlagsphasen führte im November 2014 zu Hochwasser an den Tessiner Seen. Der Höchststand wurde am 16. November bei einem Niveau von 196.41 m ü.M. erreicht. Teile der Stadt Locarno, die Magadino-Ebene sowie grössere Bereiche am Ufer des Lago Maggiores standen unter Wasser. In den Tessiner Flüssen kam es zu markanten Abflussanstiegen, jedoch nicht zu Hochwasser. Zusätzliche Luftbilder haben gezeigt, dass der Campingplatz in Tenero ebenfalls überschwemmt wurde. Entlang des südlichen Lago Maggiore Ufers ist es zu Falschklassifizierungen gekommen.

Datenquellen

Swissimage © swisstopo
Sentinel-1 © European Space Agency
Vektordaten © swisstopo

Kartographische Information

Geographische Projektion: CH1903 LV03
Massstab: 1:25'000 für DIN A3

NPOC

Universität Zürich

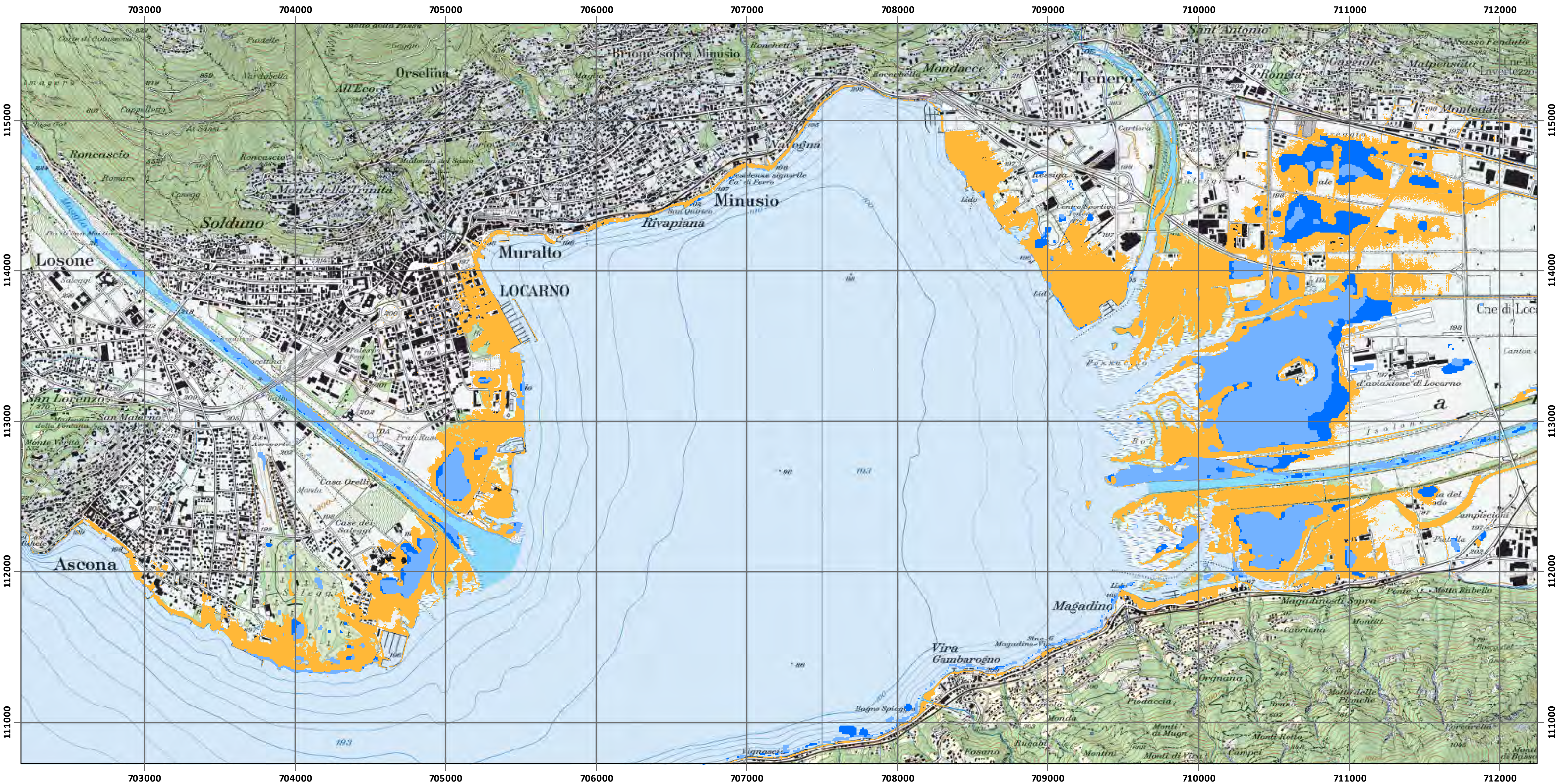
N

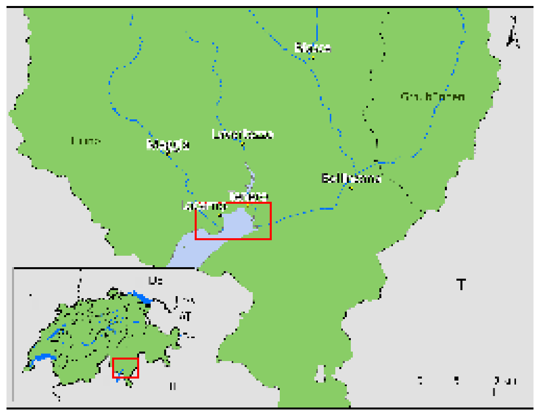
0 0.5 1 1.5
Kilometer

Lago Maggiore Hochwasser - 16.11.2014 - Übersichtskarte

Beispielprodukt
nicht weiterverwenden

D1.02





Legende

- Überflutete Flächen am 15. Nov
- Zusätzlich überflutete Flächen am 16. Nov
- modellierte Überflutungsfläche (196.41 m.ü.M.)

Datenquellen

PK25	© swisstopo
Sentinel-1 (10x10m)	© European Space Agency
swissalti3d	© swisstopo

Interpretation

Eine Südstaulage mit mehreren intensiven Niederschlagsphasen führte im November 2014 zu Hochwasser an den Tessiner Seen. Der Höchststand wurde am 16. November bei einem Niveau von 196.41 m ü.M. erreicht. Teile der Stadt Locarno, die Magadino-Ebene sowie grössere Bereiche am Ufer des Lago Maggiores standen unter Wasser. In den Tessiner Flüssen kam es zu markanten Abflussanstiegen, jedoch nicht zu Hochwasser.

Zusätzliche Luftbilder haben gezeigt, dass der Campingplatz in Tenero ebenfalls überschwemmt wurde. Entlang des südlichen Lago Maggiore Ufers ist es zu Falsch-klassifizierungen gekommen.

Kartographische Information

Geographische Projektion: CH1903 LV03
Massstab: 1:25'000 für DIN A3

0 0.25 0.5 1 1.5 km

N

NPOC

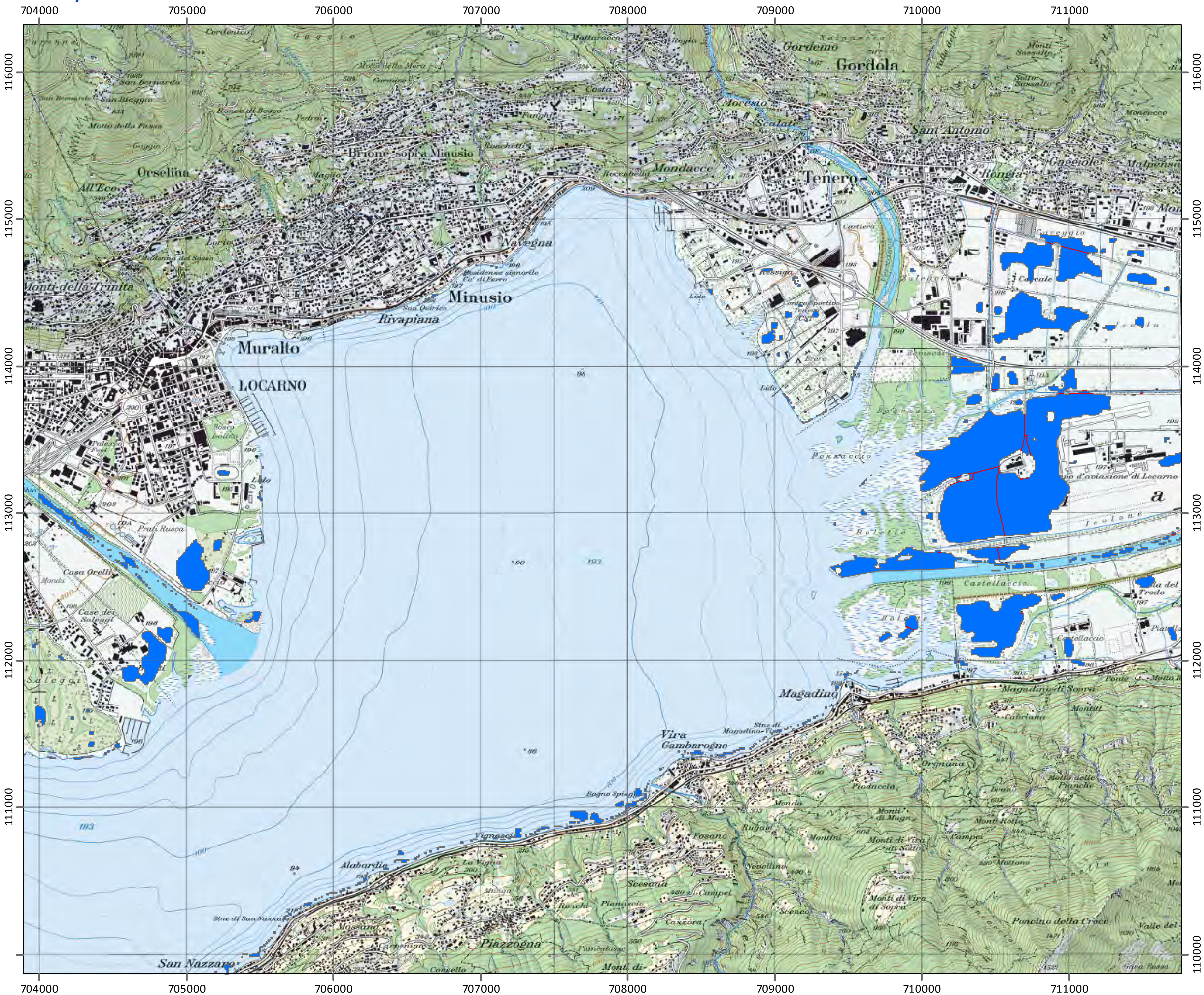
Universität Zürich[UZH]

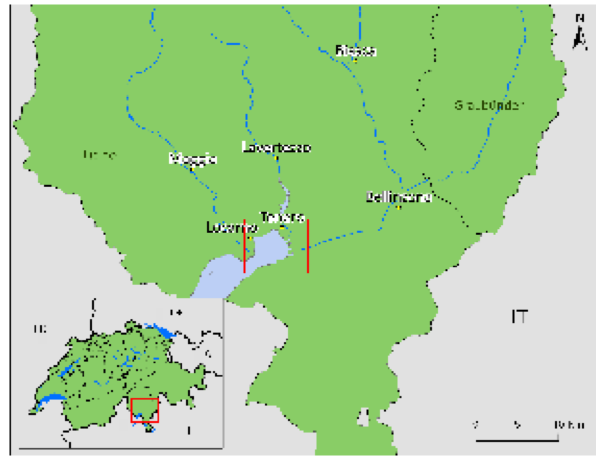
Lago Maggiore Hochwasser - 16.11.2014

Analysekarte G1.03

Beispielprodukt
nicht weiterverwenden

NPOC
Universität Zürich[UZH]





Legende

Überflutete Strassen am 16. Nov 2014

Überflutete Fläche am 16. Nov 2014

Interpretation

Eine Südstaulage mit mehreren intensiven Niederschlagsphasen führte im November 2014 zu Hochwasser an den Tessiner Seen. Teile der Stadt Locarno, die Magadino-Ebene sowie grössere Bereiche am Ufer des Lago Maggiores standen unter Wasser. Der Höchststand wurde am 16. November bei einem Niveau von 196.41 m ü.M. erreicht.

Betroffene Flächen und Strassen

Typ_Primärfläche	Fläche (m2)
Siedlung	39'314
Piste	371
Obstanlagen	5
Wald	23'207
Übrige	1'571'510
Total	1'634'406

Zusätzlich wurden ca. 2200 Meter Verkehrswege überflutet.

Datenquellen

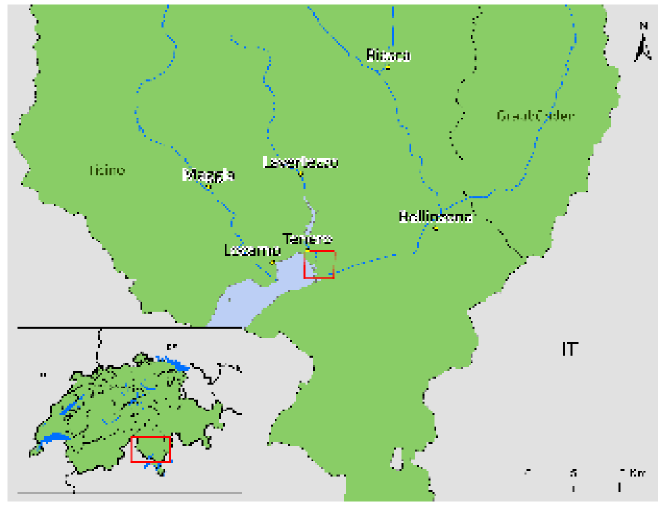
PK25	© swisstopo
Sentinel-1 (10mx10m)	© European Space Agency
swisstlm3d	© swisstopo

Kartographische Information

Geographische Projektion: CH1903 LV03
Massstab: 1:25'000 für DIN A3

Km 0 0.5 1 1.5
N

Lago Maggiore Hochwasser - 16.11.2014 - Analysekarte G1.04



Legende

- Überflutete Strassen
- Piste (Flugh.)
- Obstanlagen
- Wald
- Siedlung
- Übrige

Infrastruktur

- Bahnhof
- Flugplatz

Betroffene Flächen und Strassen

Typ	Fläche (m2)
Siedlung	15'638
Piste (Flugh.)	19'997
Obstanlagen	181
Wald	2'003
Übrige	1'016'481
Total	1'054'300

Zusätzlich wurden ca. 2200 Meter Verkehrswege überflutet.

Datenquellen

Swissimage © swisstopo
Sentinel-1 (10x10m) © European Space Agency
swisstlm3d © swisstopo

Kartographische Information

Geographische Projektion: CH1903 LV03
Massstab: 1:10'000 für DIN A3

NPOC

Universität Zürich[UZH]

0 0.3 0.6 Km

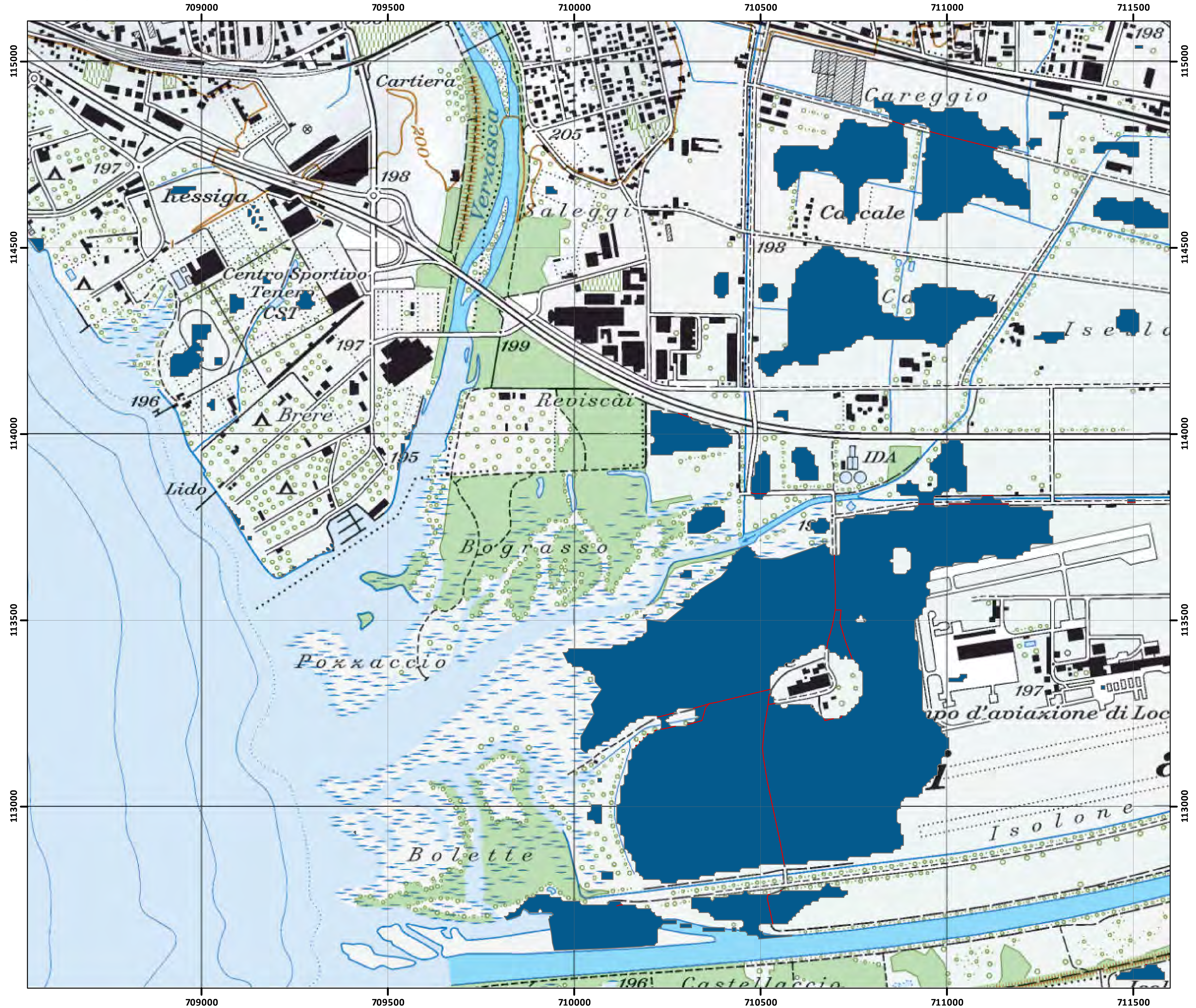
N

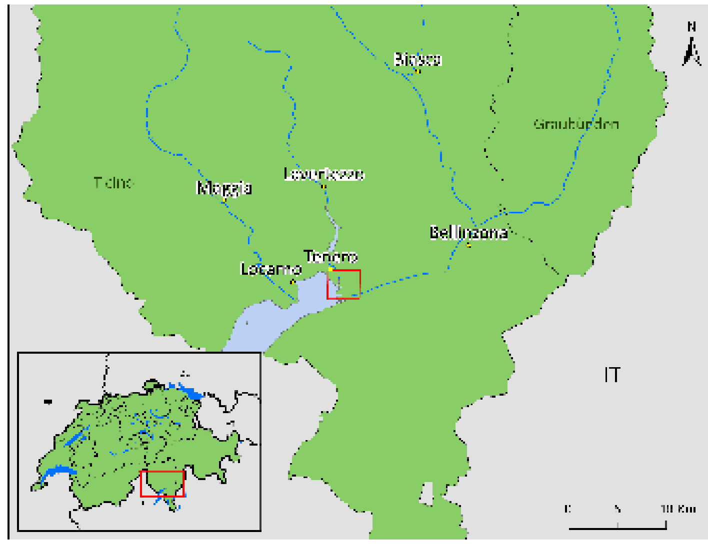
Lago Maggiore Hochwasser - 16.11.2014

Analysekarte G1.05

Beispielprodukt
nicht weiterverwenden

NPOC
Universität Zürich[UZH]





Legende

Überflutete Strassen

Überflutete Flächen am 16.Nov

Betroffene Flächen und Strassen

Typ_Primärfläche	Fläche (m2)
Siedlung	15'638
Piste (Flugpl.)	19'997
Obstanlagen	181
Wald	2'003
Übrige	1'016'481
Total	1'054'300

Zusätzlich wurden ca. 2200 Meter Verkehrswege überflutet.

Übergflutungsflächen sind von einem RADAR Satellitenbild (Sentinel-1) abgeleitet. Die Detektion von Wasser in bewaldetem und besiedeltem Gebiet ist relativ schlecht. Luftbilder haben gezeigt, dass grosse Teile des Camping-platzes Tenero am Lido und direkt anliegende Stadt-quartiere am Lago Maggiore ebenfalls grossflächig betroffen sind.

Datenquellen

Swissimage © swisstopo
Sentinel-1 (10x10m) © European Space Agency
Vektordaten © swisstopo

Kartographische Information

Geographische Projektion: CH1903 LV03
Massstab: 1:10'000 für DIN A3

0 0.125 0.25 0.5 Km

N

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9. Personal declaration

I hereby declare that the submitted thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the thesis.

Zurich, June 29, 2015

Jonas Hänseler