THREE-DIMENSIONAL (3D) MODELING FOR FLOOD COMMUNICATION

An exploratory case study using flood extent data from the Testebo River in Gävle, Sweden

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Abstract

Residents of high-risk flood areas are often unaware and unprepared for extreme flood events. In order to raise awareness and improve preventative measures, methods of communicating the potential hazards, vulnerabilities, and risks associated with flood events need to be enhanced. Geovisualizations that incorporate three-dimensional (3D) models of urban environments are being applied more frequently to improve communication of potential flood events to members of the lay-public. Recent studies suggest that the interactive and explorable environments provided by 3D geovisualization tools allow users to visualize complex geospatial data in a manner that is more easily understood than traditional 2D maps. The aim of this study was to examine the use of a 3D model for the purpose of communicating predicted flood levels in residential areas. An exploratory case study was conducted to construct and evaluate a 3D model of previously calculated data from the Testebo River in Gävle, Sweden. Methods for creating the model were developed with information obtained from in-depth literature reviews, and consultations with GIS professionals. To evaluate the communicative ability of the model, usability tests were conducted on a small sample size of participants. Through these processes, an explorable 3D model that represented the 100-year and highest probable flood scenarios in the residential areas of Varva, Strömsbro, Forsby and Stigslund was created. The results of the usability tests indicated the model was an effective visualization and provided appropriate tools for exploration. Although the study identified some limitations of the model and 3D models in general that should be considered, it also provides a valuable foundation on which to develop further studies of 3D models for flood communication purposes along the Testebo River and in other flood-prone areas.


Preface

This thesis was written as the final project towards a degree of geomatics at the University of Gävle, Sweden, and as part of a double-degree program with Thompson Rivers University in Kamloops, British Columbia, Canada. Completion of this thesis would not have been possible without those who supported me during the project period. I would like to show my appreciation to my supervisor, Nancy Joy Lim, for her guidance on this project, and for all of the excellent advice she has provided over the past year. I would also like to thank Fredrik Ekberg and other members of the Gävle Kommun for their input on 3D geovisualization and the Testebo River area, and their assistance with the 3D modeling process. Also, special thanks to Stefan Seipel, Anders Brandt, Ross Nelson, Peter Fawcett, Jenny Pettersson, and Iñaki Iraizoz. Finally, my sincerest gratitude to my family for all of the support and encouragement they have shown, and continue to provide during my studies.

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1 Introduction

1.1 Background
Residents of high-risk flood areas are often inadequately informed of their susceptibility to extreme flood events, and therefore fail to implement appropriate mitigation strategies (Grothmann & Reuswig, 2006). In order to prevent flood-caused damage and loss, efforts are being made to improve communication and increase the overall awareness of at-risk residents.

Flood maps and visualizations are emphasized by the EU Flood Directive as being essential tools to enhance communication of flood scenarios to the public (Kellens, Vanneuville, Ooms, & De Maeyer, 2009; Hagemeier-Klose & Wagner, 2009). The directive suggests that all EU member states must develop maps that indicate the extents and potential consequences of possible flood events by the end of 2015 (Hagemeier-Klose & Wagner, 2009). However, traditional flood visualizations often contain information that is complicated, and difficult for the lay-public to interpret. Basic, Cartwright and Handmer (2003) state that in order for successful communication to take place, a message must be delivered in a way that its intended recipients can relate to, and easily understand. Geographic visualization (geovisualization) is a powerful tool that could be used to increase the communication and create greater understanding of flood scenarios for the general public.

Geovisualization draws upon cartography, Geographic Information Systems (GIS), computer technology, and virtual reality, to provide an interactive geospatial environment that stimulates visual thinking and cognition (Dykes, MacEachren, & Kraak, 2005). One of the most important aspects of geovisualization is its ability to improve understanding of large amounts of complicated information by presenting it in a simple, visual manner. Within the context of flood mapping, this concept enables complicated flood terminology to be replaced with easily understood visual information (Basic et al., 2003).

Further advancements in computer-science technology, GIS, virtual reality, and data collection methods have enabled and enhanced the use of three-dimensional (3D) models with geovisualization (Wood, Kirschenbauer, Döllner, Lopes, & Bodum, 2005). The ability to model two dimensional (2D) geospatial data in 3D has become a valuable resource for many urban applications such as planning, engineering, architecture, and disaster management. Interactive 3D models allow users to orient themselves within, and explore a city, landscape, or any other geographic setting with the aid of virtual reality functions, such as zoom, pan, fly-over and walk-through. Many experts are
utilizing these interactive capabilities of 3D urban environments to help improve communication to relevant stakeholders of flood events.

The number of people living in flood-prone areas is likely to grow, and therefore so too will the need to adequately communicate the hazards, vulnerabilities, and risks associated with flood events (Kellens et al., 2009). If 3D models are a means with which to raise awareness of individual flood events, it is of interest to further investigate their ability to communicate to the lay-public.

1.2 Aims and objectives of the study

This study examines the use of a 3D model for the purpose of communicating predicted flood levels in residential areas. In order to examine the communicative ability of a 3D flood-risk visualization, it is necessary to gather insight into the characteristics of traditional flood visualizations and to explore how these visualizations are used by planners to present and communicate different flood scenarios. To determine if 3D visualizations are a viable option to increase awareness and preparedness for disaster events, this study will develop an understanding of the processes needed to present possible flood events with a 3D model. Further, to evaluate the ability of a 3D model to effectively communicate to the lay-public, it should be examined from a user-based standpoint. The objectives of this research are as follows:

1. To develop a strategy for creating a 3D model to visualize flood levels within residential areas.
2. To evaluate the ability of the created 3D model to communicate flood-risk to the general public.
3. To identify limitations of the created 3D model and indicate what overall limitations may exist when using 3D models as flood-risk communication tools.
4. To formulate recommendations for future applications of 3D geovisualization for flood-risk management and communication.

In order to achieve these objectives, a case study will be conducted using flood extent data from an area along the Testebo River in Gävle, Sweden. The research will investigate methods to create a 3D model from existing flood probability data, and explore how this model can be evaluated for its effectiveness and usefulness as a tool to communicate to the lay-public. The case study intends to produce findings that outline benefits and limitations of using 3D models to communicate flood risk along the Testebo River, and other flood-prone residential areas. The following chapter presents
an in-depth review of literature that will provide a theoretical background from which to approach the study. The Case study methods and findings will be covered in chapters three and four, and discussed in chapter five.
2 Review of previous research

This chapter presents a literature review which examines and explores the use of geovisualization for flood risk communication. In an effort to provide a background of knowledge for the study, the purpose of this review is to develop a better understanding of current techniques for communicating flood events, the use of 3D models for flood and other disaster mitigation efforts, and usability testing within the context of geovisualization.

2.1 Visualization techniques for communicating flood events

Drab and Riha (2011) state that the production of flood risk maps for multiple scenarios, has become an important step in risk based assessments, and that these are valuable decision making tools for urban and emergency planners, and relevant stakeholders. They categorize 2D flood visualizations into four main uses: flood hazard, flood danger, vulnerability, and risk. For the purpose of this research, danger, vulnerability, and risk maps are the most relevant.

Flood danger maps use an appropriate colour scheme to represent different levels of assessed danger within a flood-prone area. In order to assess danger in a particular area, it is necessary to consider criteria of past extreme flood events, alluvial flood plain morphology, the extent of alluvial loam soils, and the potential for dam breakage upstream (Drab & Riha, 2011). These considerations are used to rank each area’s flood danger on a scale from one to four. Vulnerability maps use data derived from urban planning and topological maps to classify specific objects and areas by their susceptibility to flood damage and loss. An important characteristic of these visualizations is the location of important road systems and critical facilities such as fire and police stations, schools, hospitals, and retirement homes (Drab & Riha, 2011). Stanchev, Palazov, and Stancheva (2009) emphasize that these facilities can be of significant importance during and after a flood event and that knowledge of their vulnerability to flood damage is vital to prevention and mitigation efforts.

Risk maps are used to display both danger and vulnerability in Flood Prone areas using one visual tool. These maps can be created digitally with GIS, by overlaying a vulnerability map with a flood danger map (Drab & Riha, 2011).

Kellens et al. (2009) suggest that in order for all types of flood maps to be efficient communication tools, they must be easily understandable, clearly arranged, and provided with clear and simple explanations of what is being presented. The authors emphasize the need to apply appropriate visualization techniques when presenting flood
hazard maps to the lay-public. For example, danger is commonly associated with the colour red, and therefore red should be used to indicate areas most at risk to flooding. Using a graduated colour scheme to show changes of susceptibility between areas can further improve this visual association (Kellens et al., 2009). Kellens et al. (2009) also discuss the level of detail that should be included in flood risk maps. Maps should contain enough detail that laymen can easily familiarise with what is being presented, but not so much that can lead to a false sense of accuracy or over-expectation (Kellens et al., 2009). The study concluded that if appropriate visualization techniques are applied, flood maps can be effective instruments with which to communicate possible scenarios. In addition, it emphasizes a need to increase the ease at which these maps can be interpreted. Maps for river flood scenarios have often been presented in a way that contains significant amounts of complex information that may be suitable for flood and planning experts to understand, but may cause confusion amongst the general public (Kellens et al., 2009). EXCIMAP (2007) suggests that maps created to raise public awareness should be easy to read and contain only necessary information such as the extent and depth of possible events. Other information, such as the extent of a historical flood, can also be included as it can provide a valuable reference point (EXCIMAP, 2007).

2.2 3D geovisualization and urban modeling

3D is particularly powerful for visualizing urban environments at risk (Duzgan et al., 2011). Peddemors and Bloc (2011) suggest that 3D adds a level of realism to risk visualization that increases stakeholder awareness and leads to the development of better preparation and prevention measures. Studies by Duzgan et al. (2011), Stanchev et al. (2009), and Mioc et al. (2011) have explored the use of 3D urban models in different disaster mitigation applications. In an effort to improve understanding of an earthquake vulnerability assessment, Duzgan et al. (2011) use 3D urban models to present different vulnerabilities for each building within a neighbourhood. These models improved the ability of users to determine the areas at highest risk, and provided a better understanding of where mitigation processes are needed. The studies by Stanchev et al. (2009) and Mioc et al. (2011) use similar methods to model the location of critical facilities during extreme flood events. By including realistic representations of government and emergency facilities, users can better understand the impact of a flood, and identify which buildings are safest to occupy during an event (Stachev et al., 2011; Mioc et al., 2011). These three studies utilize the ability of GIS to incorporate
urban models with geospatial information to create realistic representations of hazard scenarios that can be easily analyzed and interpreted. Furthermore, they provide insight to how 3D models and GIS strengthen the communicative abilities of geovisualization by providing an interactive geo-referenced environment in which to explore the risks associated with a given disaster (Duzgan et al., 2011; Stanchev et al., 2009; Wood et al., 2005). Their research suggests that 3D models and geovisualization provide a more effective approach to analyzing flood scenarios than traditional and contemporary 2D flood maps.

In a comparative study, Basic et al. (2003) found that the biggest advantages of 3D geovisualization tools over traditional methods is in their relevance to property owners, ability to provide safety precautions, and ability to be easily distributed via the internet. However, the study also found that 3D models are more effective tools for communication when used in combination with traditional 2D methods (Basic et al., 2003).

2.3 Usability tests for evaluating geovisualization tools

Usability tests are methods of evaluating how easily end-users are able to navigate and interpret a computer-based application (Zhang & Adipat, 2005). In a geovisualization context, usability tests are conducted to determine if visualization tools are able to meet user-desired performance levels. (Koua, MacEachren & Kraak, 2006).

Koua et al. (2006) present an approach for performing usability tests on a series of maps and geographic visualizations. In the study, a target group of likely user-types tested various visualization tools to perform a series of tasks and operations. The usability of the presented tools is evaluated based on three criteria: effectiveness of user performance, usefulness, and user reactions. Effectiveness refers to the user’s ability to successfully operate functions and perform tasks, usefulness describes the appropriateness of a visualization for use in a desired task, and user reaction refers to the subjective views of the user towards the visualization (Koua et al., 2006).

Zhang and Adipat (2005) outline a similar methodology for usability testing, but emphasize the need to select between laboratory and field testing methods. In laboratory tests, participants conduct the usability tasks in a controlled setting, whereas participants of field tests conduct tasks in uncontrolled, real-world environments (Zhang & Adipat, 2005). Neither laboratory nor field testing is considered superior to the other; the appropriate usability testing methodology is dependent on the objectives and parameters of the study (Zhang & Adipat, 2005).
Woronuk (2008) used Zhang and Adipat’s (2005) methodology to test the efficiency, effectiveness, and user satisfaction of a 3D model for Fire Incident command. The tests not only evaluated the usability of the model in question, but also helped indicate the deficiencies and limitations of the model.

For the purpose of this research, usability tests, that follow Koua et al.’s (2006) framework, and Woronuk’s (2008) methods of determining user reaction, are suitable for qualitatively evaluating the 3D model.
3 Methods

This chapter outlines the research strategy and the processes conducted to investigate how 3D models can be used to visualize and communicate the extent of possible flood events in residential areas. The strategy was developed to achieve the four, previously outlined, goals of this research.

To build on knowledge gained from the literature review, the research strategy for this project was an exploratory case study. The case study involved consultations with planning and GIS professionals, the development of a 3D model, and simple usability tests to evaluate the model. A common characteristic of exploratory case studies is to provide informative results that highlight possible areas for future research (Biggam, 2011). Therefore, one of the intended results of the study was to identify limitations that should be considered when using 3D models to communicated predicted flood events.

3.1 Study Area

The Testebo River runs approximately 85 km from Ämot in Ockelbo municipality, Sweden to the city of Gävle (Lim, 2009). The study site used in this project covers a 1 km² area in Gävle municipality, near to its outlet into the Baltic Sea. More specifically, the site covers the residential areas of Varva, Strömsbro, Forsby and Stigslund. The areas exist within the limits of the Gävle Kommun, and many houses lie within or in close proximity to the extents of the 100-yr, and highest probable flood events (Lim, 2009) (figure 1).
3.2 Personal Consultations

Interviews, in the form of personal consultations, were conducted to help supplement knowledge gained from reviewed literature and to develop a better understanding of how 3D can be used to visualize flood data in the Testebo River area. Personal consultations were conducted with two staff of the Gävle Kommun and one staff from the University of Gävle.

Information obtained through these sessions is described in the results chapter of this paper. In addition, much of the knowledge gained was applied in the development and evaluation of the 3D model created in this study, and in the analysis of this research’s findings.

The first consultation was conducted on 24 April 2012 with an urban planner involved in working with flood issues in Gävle municipality, including the Testebo River. The one hour meeting took place at the Gävle Kommun and followed a relatively
informal question and answer format. The interviewee was asked to provide insight into how communication of flood events could be improved with visualization techniques and whether or not 3D models could be used to enhance the public’s ability to interpret flood data.

A second consultation took place on 26 April 2012 with Fredrik Ekberg, a GIS professional at the Gävle Kommun. The interviewee was asked to provide insight into how 3D is currently being used with flood data along the Testebo River, and to how 3D models can be beneficial for flood mitigation purposes. Questions asked during this consultation also concerned the 3D modeling process. Problems and concerns with the production of the 3D model were discussed and ways in which these issues could be overcome were developed during the session. The primary issue addressed was creating a 3D layer that represented both the extent and elevation of the different flood events, and how this could be included in the Sketchup environment.

A third personal consultation was conducted with Stefan Seipel, a professor in the Department of Industrial Development, IT, and Land Management at the University of Gävle. This meeting took place on 8 May 2012. The primary goal of this discussion was to gain an understanding of what limitations may exist with using 3D for geovisualization. Questions were asked about how and when problems are created when using 3D models to communicate geospatial information to members of the lay-public.

### 3.3 3D flood modeling

The 3D model created in this project represented the 100-year and highest probable flood events calculated by Lim (2009). The purpose for creating the model was two-fold: to explore how existing 2D flood extent data can be presented in an exploratory 3D environment, and to evaluate the possible use of 3D models as tools for communicating this risk to members of the lay-public. The model was created as an example, and therefore houses and other buildings were not entirely represented in their real world shapes and colours. However, the location of buildings on terrain, and the extent and depth of the flood events is representative of real world data and calculations.

#### 3.3.1 Data and Materials

Topographic data in the form of LiDAR and bathymetric points, ESRI shape files of buildings and flood classes, and poly-lines representing cross sections of flood depth were provided by the University of Gävle, and an orthophoto of the area was provided by SWECO (figures 2, 3, and 4). The data was derived in a previous study by Lim (2009), which used GIS analysis to predict the different possible flood outcomes in the Testebo River.
Figure 2. Building Polygon Data (Lim, 2009)

Figure 3. Flood Polygon Data (Lim, 2009)
The main software utilized were ESRI’s ArcGIS 10, SAFE’s FME 2011 and Google Sketchup 8. ESRI’s ArcGIS packages were used to delineate the study area, preprocess the topographic data, and to prepare building and flood shape file layers for the modeling process. FME 2011, was used to convert the terrain, building, and flood extent shape files into CAD files that could be opened in Google Sketchup 8. The modeling process was completed in Google Sketchup - a 3D modeling software that is available in free and professional versions. This platform was used to create an interactive 3D model showing residential areas during different possible flood-scenarios and as the primary environment in which the model was presented and tested.

3.3.2 Data preprocessing
The available data of the Testebo River area covered a much larger extent than desired for this project. The study area was derived in ArcMap 10 by examining the buildings polygon layer within different flood classes and determining the most suitable area to create the 3D model. After the extent was decided, the topographic and shape file data
were exported to new feature classes. This provided a smaller and easier to manage dataset for the project.

3.3.3 Creating 3D buildings and terrain

The bathymetric and LiDAR datasets were each converted into digital elevation model (DEM) layers using the *Topo to Raster* tool in ArcToolbox. The first DEM represented the ground surface of the study area, and the latter represented points at elevations above the surface (i.e. building roofs, tree-tops, etc.). The height of each building was extracted based on the difference in value between the two DEMs and added as an attribute to the building polygon layer. Once these heights were applied, buildings could be extruded into 3D with FME, and imported to the Google Sketchup environment.

FME software was used to create a 3D CAD file of the study area’s terrain and buildings. FME is a desktop software developed by SAFE that allows for easy conversion, transformation, and integration of and between various spatial data formats (Safe Software, n.d.). The software provides a series of data transformers and allows for the specification of a workflow along which data can be read and manipulated to make usable within different software platforms.

Using FME, the elevation data and buildings were converted to 3D and buildings were extruded to the attribute values associated with their respective heights. To ensure the buildings were located on the terrain model, the raster values of the terrain file were extracted to the buildings’ foundations and the features were merged together. Building and terrain CAD files that fit the extent of study site were created from this process. The FME workflow for buildings and terrain can be seen in figure 5.

![FME workflow](image)

**Figure 5.** FME workflow for extruding buildings and terrain
3.3.4 Creating 3D flood layers

In order to visualize the study area during the 100-year and highest probable flood scenarios, the 2D flood polygon extents needed to be converted into 3D CAD files. FME 2011 was also used for this process. Poly line shape files that represented cross sections of flood elevations were extruded into 3D and were draped with each of the 100-year and highest probable flood polygons. FME’s SurfaceModeler was used to create a TIN model of each flood scenario that could be imported to Google Sketchup and added to the 3D model of buildings and terrain. The FME workflow for creating the flood TIN models can be seen in figure 6.

![FME workflow](image)

**Figure 6.** FME work flow for creating 3D file of 100-year flood

3.3.5 Modeling in Google Sketchup

Google Sketchup 8 was used as the primary environment to create and present the 3D model. Other 3D software environments such as City GML and ESRI’s ArcScene also provide exploratory environments which could have been used in this project. However, because the model was being created as a tool to communicate to end-users with little experience using 3D or GIS software, Google Sketchup was chosen for its relatively small learning curve. Users are able to easily explore 3D models with Google Sketchup’s zoom, pan, orbit, walk, and look around functions. The software also provided an easy to manage layer system that could be turned on or off to visualize buildings before and during different flood events.

After the buildings, terrain, and flood extents were written as CAD files they were imported into Google Sketchup 8 to begin the modeling process (figures 7 and 8).
The first step of modeling involved correcting errors that were encountered during the import process. Some buildings were either not extruded or were extruded from incorrect elevations leaving 2D polygons floating above the terrain surface. To correct this, these buildings were extruded with Sketchup’s push/pull tool to heights determined manually by analyzing the 2D building polygon layer with the DEM values in ArcMap. A second problem, which commonly occurs when importing CAD files into Sketchup, was that several buildings’ ‘faces’ were misaligned and their exterior walls were facing inwards. Reversing these faces was a necessary step to allow textures to be properly applied.

Figure 7. Imported file of 3D buildings and terrain

Figure 8. Imported file of 3D highest probable flood extent. (Top View)
After all errors were corrected, and it was ensured that the building and flood features aligned properly with the terrain, textures and components were applied to the model. Roofs were added to all buildings within or in close proximity to the flood extents and were textured with materials provided in the Google 3D Warehouse. Using textures and components provided by the software allowed for the model to have a realistic appearance while maintaining a manageable file size. After roofs were created, the buildings were given textures, windows and doors. Due to time constraints, houses that were considered safe from both flood events were not given roofs or components. Colours used to texture the building were chosen with consideration to EXCIMAP’s *Handbook on good practices for flood mapping in Europe*. The handbook suggests that people associate certain colour schemes with danger and flooding and a graduated use of a colour can be used to demonstrate different degrees of that danger (EXCIMAP, 2007). To comply with this practice, and maintain an adequate representation of Swedish houses, houses within or in close proximity to the 100-year flood event were textured in red. Houses outside of the 100-year flood, but within the extent of the highest probably flood were given a slightly lighter shade of red as they were concerned less susceptible to flooding. Houses outside the extent of both flood events were considered safe and were textured in a very light pink colour. Finally, trees and other landscape components were added to enhance the level of realism presented in the model.

### 3.4 Usability Testing

The method for evaluating the communicative ability of the 3D model was developed from the literature review, and from knowledge obtained through the personal consultation process. Koua *et al.*’s (2006) proposed criteria of effectiveness, usefulness, and user reaction were considered during the performed usability tests.

Usability tests were conducted at the University of Gävle Library on 16 and 21 May, 2012. The test audience was a small participant group of 8 people - 4 females and 4 males between the ages of 20 and 30 - that were selected by convenience. Chosen participants had little or no experience with reading flood maps, or using interactive 3D software. It is important to note that this group does not represent any larger population. The test group consisted of possible user-types to which communicating flood risk may be necessary. Therefore, the findings of the usability tests provide only evidence and insight into the use and limitations of 3D models for communicating flood risk.

The tests were started by familiarizing each participant with Google Sketchup. Time was given for the user to explore an unrelated 3D model and become comfortable
with the interactive functions of the software. When the short-training period was complete, participants were asked to explore the 3D model of flood events, and answer questions regarding their interpretation of the visualization.

Effectiveness was qualitatively measured based on the level of difficulty experienced by each user to identify, locate, and compare various features of the model. Each participant explored the model, and completed simple tasks such as locating houses within different flood levels and identifying which areas of the study site were in greater relative danger during each flood scenario. The ease at which participants could function the model to get an overall understanding of the study area, visualize the location of houses, determine which houses were in the 100-year flood, determine which houses were in the highest probably flood, and visualize the inundation level at each house was observed by the test supervisor and indicated by each participant in the form of a questionnaire. Participants were asked to rank the difficult of performing each of the above operations as being one of easy, medium, or hard (see appendix). For comparison purposes, the same questions were asked in regards to the 2D map.

Usefulness and user reaction referred to each user’s perception of the appropriateness and functionality of the model, and their overall reaction towards it. Following Worunuk’s (2008) methods, these criteria were measured by each participant filling out a short questionnaire after they had explored the 3D model (see appendix). Answers were given by each on a scale of 1-5, with 5 being yes, strongly agree and 1 being no, strongly disagree. Additional opinions of the model were expressed by each user in the form of short sentence responses.

The tests were not conducted to obtain an absolute decision for whether or not 3D models are necessary flood communication tools, but to help identify limitations of the model and to indicate what limitations may be present when using 3D urban models to visualize and communicate flood events.
4 Results

This chapter presents the findings of the case study and the results generated from personal consultations with staff from Gävle Kommun and the University of Gävle, 3D flood modeling of events, and usability tests.

4.1 Personal Consultations

4.1.1 Respondent 1: Planner (Gävle Kommun) (personal communication, 24 April, 2012)

The first interview was conducted with Respondent 1, a planner at the Gävle Kommun. Information gathered during this interview suggested that traditional 2D flood maps can be difficult and complicated for members of the lay-public to interpret. However, it was also suggested that the use of 3D data and models to improve this understanding should be advanced with caution. 3D models, although visually attractive, have the ability to cause misinterpretation among the public. Events portrayed with 3D models can be exaggerated and may cause greater than necessary expectations or concern for residents. For the Testebo River area, 3D has not been given much consideration for the purposes of communicating flood risk. Due the relatively flat terrain characteristics in the Testebo River area, 3D data may not provide any visual or analytic advantage over 2D data. For these reasons, Respondent 1 suggested that 3D modeling may not be a viable option to increase awareness of flood events in the Testebo area.

4.1.2 Fredrik Ekberg: GIS professional (Gävle Kommun) (personal communication, 26 April, 2012)

A second personal consultation was conducted with Fredrik Ekberg, a GIS professional at the Gävle Kommun. The results of this interview suggest that 3D modeling can be a very powerful tool for raising flood awareness and preparing for events. The realistic nature allows users to easily visualize and relate to the presented information, and therefore 3D models deliver an easier to interpret message that 2D information. 3D models of residential areas during flood events allow not only for visualization of houses within a particular flood extent, but also the water level rise on the house. This can help planners and professionals determine adequate response and help inform local at-risk residents. In areas, such as the Testebo River, where flood levels may not cause significant damage to houses or directly threaten lives, they can however cause various logistical problems such as disabling transport and evacuation routes. Preparation is needed to ensure adequate evacuation and emergency service is available. Realistic 3D
models can help visualize an area both before and during a flood and help analyze probable events to secure infrastructure and better emplace preparative measures. On the other hand, Ekberg did suggest that 3D can provide unnecessary amounts of detail. Therefore, 3D models should provide only relevant information and should be presented with a software environment that can be easily functioned by the user. For the purpose of modeling and communicating 100-year and highest probable flood extents to lay-users, Ekberg suggested that Google Sketchup was an adequate platform.

4.1.3 Stefan Seipel: Professor (University of Gävle) (personal communication, 8 May, 2012)
The last personal consultation was conducted at the University of Gävle with Stefan Seipel at 13:00 on Tuesday 8 May, 2012. The main point obtained in this consultation was that 3D visualizations often impress user groups with attractive and highly aesthetic features, but do not provide any actual analytical advantage over 2D visualizations. When using 2D and 3D visualizations to complete spatial tasks, the realistic nature of 3D visualizations often causes users to feel more confident in their performance, but does improve results. However, the consultation did suggest that 3D geospatial models can make an effective contribution as a pedagogical tool. If models are designed using accurate and appropriate features, they can be an informative means in which to communicate information.

4.2 3D model of Testeboån flood levels
The finished 3D model represented the 100-year and highest probable flood events, calculated by Lim (2009), in Varva, Strömsbro, Forsby and Stigslund; near Gävle, Sweden (figure 9). The model included residential buildings within the area, and an ability to visualize neighborhoods during different possible flood scenarios (figures 10 and 11). Houses within or in close proximity to the different flood events were textured in a red to light-pink colour scheme to represent their predicted susceptibility to flooding (figures 12 and 13).
Figure 9. Top View of 3D model - buildings within highest probable flood event

Figure 10. View of house during 100-year flood

Figure 11. View of house during highest probable flood
Figure 12. Houses in or within close proximity to 100-year flood.

Figure 13. Houses within highest probable flood
Features of the model were organized into layers that could be turned on or off to isolate and examine specific areas and aspects that are of interest to the user (figure 14). The model could be viewed from any selected camera angle and explored using Sketchup’s orbit, look-around, walk, and pan functions. Users could also adjust time, season, and weather settings to visualize the model with shadows, fog, and under various lighting conditions.

![Layers window](image)

**Figure 14.** Google Sketchup layer window.

### 4.3 Usability testing

#### 4.3.1 Effectiveness

Observations of each participant by the test supervisor suggested that users were able to easily handle the functional tools of Sketchup and could successfully utilize these tools to locate houses and features within the different flood extents. Layers were noted to be particularly useful, as participants frequently switched features on and off to make comparisons between different features and scenarios. The most noticeable errors were observed when participants would zoom-in to view houses at very close distances. Users would become slightly disoriented and need to revert to view the full extent of the model. Often in these cases, users would refer to the 2D map to re-orient themselves before proceeding to explore the 3D model.

Given the choices of *easy, medium, and hard*; all eight test participants responded that operations were *easy* to perform with the 3D model. With exception to visualizing the inundation level at each house, participants also felt that it was *easy* to perform these operations with the 2D map. Information of flood depth and inundation
levels was not provided by the 2D map and therefore all participants, expectedly, responded that visualizing inundation levels was hard.

4.3.2 Usefulness/user reaction

Usefulness and user reaction were measured with participant responses to a questionnaire. Each participant was asked questions about the usefulness of the model’s features and tools, and whether or not they helped understand the predicted flood events. Answers were provided on a scale from 1-5, with 1 being strongly disagree, and 5 being strongly agree. Questions concerning the overall opinion of users towards the model were also answered in short sentences. These responses will be used in the discussion chapter of this report to help analyze the findings of the study.

3D environment

The model was presented in the Google Sketchup software environment. Although this research was not concerned with the use of different 3D software for presenting flood scenarios, it was of interest to know users’ perceptions of Sketchup. Perception of the software can provide indication to what limitations exist within the created model. Overall, users responded that they were satisfied with the amount of training and felt comfortable with the functions provided (figure 15). It should be noted however, that some participants were less comfortable with the software and felt it was somewhat complicated to use.

![3D Environment](image)

**Figure 15.** User response to the 3D environment
Interpreting the model

To determine if the flood scenarios were clear and easy to interpret, participants were asked to indicate how well they were able to understand information presented in the 3D model and 2D map of the study area. All users strongly agreed that the 3D model allowed them to easily interpret the presented material. In general, the same was true for the 2D map. However, one user felt the 2D map was slightly more complicated and difficult to understand than the 3D model (figure 16).

Visualization of features using layers

Buildings and the extents of the 100-year, and highest probable flood extents were organized into separate layers in the 3D model. Layers help maintain an easy to manage model and allow users to select which features to explore. Users were asked if the Sketchup layers were useful and if they helped visualize the various features of the model. Overall, all users believed that use of layers was effective, and most users believed that they helped visualize the different flood scenarios (figure 17).
Textures were applied to houses and flood extents based on recommendations in EXCIMAPS’s (2007) *Handbook on good practices for flood mapping in Europe*. A red - light pink colour scheme was used to texture houses by their respective susceptibility to flood events, and a blue transparent texture was used to represent each flood. Users were asked if these colour schemes helped identify the flood features and houses’ respective risk of flooding. In general, users suggested the chosen colour schemes were useful. However, some felt the colour scheme selected for houses was not necessary, and did not help visualize the flood events (figure 18).

**Colour scheme**

Textures were applied to houses and flood extents based on recommendations in EXCIMAPS’s (2007) *Handbook on good practices for flood mapping in Europe*. A red - light pink colour scheme was used to texture houses by their respective susceptibility to flood events, and a blue transparent texture was used to represent each flood. Users were asked if these colour schemes helped identify the flood features and houses’ respective risk of flooding. In general, users suggested the chosen colour schemes were useful. However, some felt the colour scheme selected for houses was not necessary, and did not help visualize the flood events (figure 18).

**Figure 17.** User perception of their ability to visualize flood features using the layer functions

**Figure 18.** User perception of usefulness of colour-scheme
**3D and 2D comparison**

To compare the exploratory 3D model with a 2D map, users were asked if they preferred the use of the 3D model, and if they preferred to use the 3D model in combination with the 2D map. All users preferred the exploratory 3D model over the 2D map. Also, the combination of the 3D model with the 2D map was preferred by a large majority of test participants. One participant suggested that they only slightly preferred the combination of the 3D and 2D visualizations, while another responded that they were unconcerned with the combination.

![Figure 19. User comparison of 3D model and 2D map](image-url)
5 Discussion

This chapter presents a discussion and analysis of the study’s findings. The results of the 3D modeling process, and usability evaluation will be examined from within the context of previous literature and knowledge obtained through personal consultations at the Gävle Kommun and University of Gävle. Limitations of the presented model will be identified and subsequently used to outline general limitations to the use of 3D flood models.

5.1 Modeling process

The model created in this study represented the 100-year and highest probable flood extents in an exploratory 3D model of residential areas. Using FME software, laser scanned elevation data and 2D data of buildings were accurately extruded into a 3D format that could be imported into and modeled in Google Sketchup. A main difficulty was determining how the depth of each flood extent could be represented in the 3D model. The problem was overcome in a consultation with Fredrik Ekberg (personal communication, 26 April, 2012). 3D TIN models for each flood scenario were created in FME by draping flood extent polygons over 3D cross sections of flood elevations. Another issue, which could not be overcome, was an inability to include 3D representations of historical flood extents in the model. EXCIMAP (2007) outlines that historical flood extents are not essential, but are desirable parameters to include in flood maps for public awareness. Although 2D data of a 1977 flood extent was available, data representing the depth of the flood was not. Therefore, it was not possible to represent the historical flood at accurate depth in model. Overall, the modeling process outlined in this study was successful, and could be followed in future 3D flood modeling projects.

5.2 Evaluation of Model

The results of the usability tests conducted in this study suggested that the 3D model provided an effective and useful environment for the tested participants to visualize the possible flood scenarios. Observations by the test supervisor and user responses suggested that the model was an effective geovisualization tool - users could easily utilize functions of the 3D environment to successfully identify, locate, and compare the building and flood features. It was also indicated that the model was well understood and presented information in an easy to interpret manner. Most users were comfortable using the 3D environment and responded that adequate training was provided. However, some observations by the test supervisor contradicted this. Although users were
observed to be successful in completing tasks and interpreting the model, many of them used only one or two of the available functions to explore it. Possible reasons for this are that efficient exploration only required use of a few functions, Sketchup training was insufficient and led to slight discomfort among users, or that subjective views of the test supervisor led to inaccurate observations.

The model created in this project was designed to provide an interactive environment that was easily interpretable for users with little or no experience with flood maps. Kemec, Zlatanova, and Duzgan (2010) state that useful 3D geovisualization tools include appropriate presentation of information and appropriate tools for interaction. Based on questionnaire responses by the users, the model presented an adequate visualization of flood events and provided tools and functions that were useful for exploring houses within different flood inundation levels. For most users, the red-light pink colour scheme was helpful for determining which areas were more susceptible to flood events than others. Users also suggested that the ability to examine individual houses in the study area was a particularly powerful element of the 3D model. This is stated by Basic et al. (2003), as being the major advantage of geovisualization tools over traditional methods. However, it should be considered that the model created in this project was an example and did not show individual properties in ‘life-like’ appearance. Therefore, to produce a model that communicates directly to the residents of the Testebo River study area, more detailed modeling should take place so users could personally identify with the effect of each flood on their property.

User feedback also identified other deficiencies of the model that should be considered if future 3D models of the Testebo River area are to be developed. Many users expressed a desire to know the quantitative depth of water at each residence. Although the depth of water at each house could be measured using Sketchup’s tape measure tool, this was a difficult operation for most users. The addition of flood depth indicators at each household should be included in future models to allow these levels to be more easily comprehended. An inability to identify and determine differences in elevation between houses was also outlined as a limitation. This is likely a result of the study site being a relatively small area of flat terrain. As respondent 1 (personal communication, 22 April, 2012) suggested, the flat terrain in the Testebo area creates difficulty in visualizing differences in elevation. Therefore, elevation levels need to be included by manually labeling each house. These limitations aside, overall user response suggested the model was well presented and provided useful tools that helped explore and interpret the study area.
In general, user perceptions and reactions towards the 2D map were also positive. With exception to visualizing the depth of flood water at each residence, users found the 2D map to be as easy to understand and as effective as the 3D model. However, all users stated that they preferred the 3D model over the 2D map. Woronuk (2008) found similar results when users were asked to complete task-based scenarios with both a 3D model and 2D map for fire incident command. Users were just as effective completing tasks using 2D, but in most cases preferred to use the 3D model (Woronuk, 2008). Reasons for these findings align with a point suggested in a consultation with Stefan Seipel; 3D geospatial data is often preferred by users and considered more reliable, not because of increased accuracy, but because it provides a more impressive visualization (personal consultation, 8 May, 2012).

The evaluation of the present model agrees with previous research by Duzgan et al. (2011), Mioc et al. (2011), Stanchev et al. (2009), and Basic et al. (2003) that state interactive 3D models are valuable tools with which to improve awareness of flood events. The findings of this study further suggest that if relevant information is presented in an explorable and easy to interpret manner, 3D is a preferred form of visualization for lay-users. However, the results do not entirely support Mioc et al.’s (2011) notion that 3D provides a better platform from which to communicate floods than traditional 2D maps. Most users preferred to explore the 3D model in combination with the 2D map. The 2D map was both observed by the test supervisor, and suggested by the test participants as being a valuable tool for providing a general overview of the study area and helping orient users within the model. Similar results have been found by Basic et al. (2003) who concluded that it is the combination of 3D geovisualization tools with traditional 2D visualizations that can be used to improve communication of flood events to the public.

The results derived from usability tests are not absolute, but are merely good indications of the usefulness of a geovisualization tool (Koua et al., 2006). In terms of the model created in this project, the findings of the usability tests indicated that 3D models are a possible means of communicating flood risks in residential areas along Testebo River. It also helped identify limitations to the model that should be considered in any future use of 3D models of flood events in the study area. However, the study is, itself, limited to the size and age range of the tested population. To produce more definite results, usability of the model should be evaluated with a larger size and greater age-range of test participants. This aside, the study also helped outline what general limitations may exist when using 3D models to communicate flood risk.
5.3 Limitations of using 3D to visualize flood levels

An important consideration to be made for all flood visualizations is the uncertainty of when a flood will occur. Brandt and Jiang (2004) outline that reoccurrence intervals, such as the 100-year and highest probable flood, are based on historical data and are subject to change with new data collections and climate trends. This has implications on 3D flood models for two reasons. First, the development of a 3D model requires large amounts of manual work and, as was the case in this model, they are often derived from previously analyzed 2D data. Therefore, producing updated 3D models can be a much more time-consuming and complicated process than updating traditional 2D maps. Secondly, as Respondent 1 (personal communication, 24 April, 2012) suggested, 3D maps are often misinterpreted as being more certain and exact representations of reality than intended. It is possible that this misinterpretation could be exaggerated by a 3D model that provides ‘out of date’ information.

Another limitation of 3D models concerns the platform on which they are presented. Exploring a 3D geovisualization tool requires users to have access to a computer and particular software environment. In many areas of the world, where flood events may pose risks, residents do not have access to computers or the internet (Kellens et al., 2009). Therefore, the use of 3D visualization tools as a means to communicate to the public, is limited to specific areas and populations. Furthermore, in areas where computer access is available, users may not possess adequate computer skills to effectively explore a 3D environment. In this study, one usability test participant suggested that the 2D map was easier to use because it did not require the need to learn the software functions. Although Patterson (1999: as cited by Basic et al., 2003) suggests that 3D models are likely to be easier understood by users without map-reading experience, it cannot be discounted that learning to interact with a 3D model is as difficult as acquiring the necessary skills to interpret a 2D map.

5.4 Recommendations

This study provides a valuable foundation on which to develop further studies of 3D models for flood communication purposes along the Testebo River and in other flood-prone areas. However, certain adjustments to the study can be recommended to enhance the results of this research. To conduct a more representative study of 3D models in the Testebo River area, a model should be created that represents the houses in the area in more realistic detail and, if the data is available, includes the extent of the 1977 flood. Moreover, the model should be evaluated using specific tasks determined
by the designers of the model and conducted on a sample population that is representative of those with invested interest in the area.

Another recommendation would be to better explain or “avoid technical and statistical terms” (Hagemeier-Klose & Wagner, 2009: 573). The ‘100-year’ and ‘highest probable flood’ can be replaced with easier terminology such as ‘medium-probability’ and ‘low-probability’ floods (Hagemeier-Klose & Wagner, 2009). This would increase the ease at which end-users can interpret flood events and therefore improve the communicative ability of the model.
6 Conclusion

This study examined the use of a 3D model for the purpose of communicating predicted flood levels in residential areas. Laser scanned elevation points and 2D flood and building data were successfully extruded into 3D and modeled in Google Sketchup. The resulting 3D geovisualization was determined to be an effective and useful tool in which end-users could explore areas along the Testebo River during the predicted 100-year and highest probable flood events. When compared with a more traditional 2D map, the 3D model was preferred because of its interactive capabilities and its usefulness for visualizing inundation levels at individual buildings. However, the 2D map still proved useful for general overview and orientation purposes. Currently, it is also a more readily accessible form of flood risk visualization. It can be suggested from this study that 3D models enhance the ability to communicate flood-risks to the public but are most effective when used in combination with traditional 2D visualizations. However, further research is needed to produce a more definite conclusion.
References


Appendix

1. User questionnaire for effectiveness of 3D model

Please circle one of EASY, MEDIUM, or HARD in terms the following operations

5. Ability to get an overall understanding of the study area
   EASY     MEDIUM     HARD

2. Ability to visualize the location of houses and buildings
   EASY     MEDIUM     HARD

3. Ability to determine which houses are within the extent of the 100-year flood
   EASY     MEDIUM     HARD

4. Ability to determine which houses are within the extent of the highest probable flood
   EASY     MEDIUM     HARD

5. Ability to visualize the inundation level at each house
   EASY     MEDIUM     HARD

6. Overall ability to use the visualization’s tools and functions
   EASY     MEDIUM     HARD
2. User questionnaire for effectiveness of 2D map

Please circle one of EASY, MEDIUM, or HARD in terms the following operations

6. Ability to get an overall understanding of the study area
   EASY MEDIUM HARD

3. Ability to visualize the location of houses and buildings
   EASY MEDIUM HARD

4. Ability to determine which houses are within the extent of the 100-year flood
   EASY MEDIUM HARD

5. Ability to determine which houses are within the extent of the highest probable flood
   EASY MEDIUM HARD

5 Ability to visualize the inundation level at each house
   EASY MEDIUM HARD

7. Overall ability to use the visualization’s tools and functions
   EASY MEDIUM HARD
3. Questionnaire for usefulness and user reaction

Please circle the number that best corresponds with your response on a scale of 1 to 5.

1: Strongly Disagree  2: Disagree  3: N/A  4: Agree  5: Strongly Agree

7. Was adequate training of the Google Sketchup environment provided?
   1  2  3  4  5

4. Were you comfortable using the Google Sketchup software?
   1  2  3  4  5

5. Using the 3D model, were you able to understand the presented flood scenarios?
   1  2  3  4  5

6. Using the 2D map, were you able to understand the presented flood scenarios?
   1  2  3  4  5

8. Were you able to easily identify the extent of the 100-year flood?
   1  2  3  4  5

6. Were you able to easily identify the extent of the highest probable flood?
   1  2  3  4  5

7. Did the use of layers help you visualize the extent of the highest probable flood?
   1  2  3  4  5

8. Did the use of the colour blue help identify the areas within the flood extents?
   1  2  3  4  5
9. Did the colour scheme (red-light pink) used to represent the houses help identify which areas were most, and least susceptible to flooding?

1  2  3  4  5

10. Do you prefer the 3D model over the 2D map?

1  2  3  4  5

11. Do you prefer to use the 3D model in combination with the 2D map?

1  2  3  4  5

Please give short responses to the following questions

1. What do you think are deficiencies of the 3D model? Including feature representation and availability of provided information?

2. What tools and functions of the 3D model did you find not to be useful?

3. What tools and functions of the 3D model did you find most useful?

4. What do you feel could improve the 3D model? Including addition of and changes to features.

5. For what, if anything, did you prefer to use the 2D map over the 3D model?

6. What are your overall feelings of using the 3D model in comparison with the 2D map?

7. Do you have any other comments or observations about the 3D model or 2D map?