Flood Visualization for Urban Planning

An exploratory spatiotemporal visualization of storm water runoff in 2D and 3D

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Flood Visualization for Urban Planning using GIS

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Abstract

Modelling hydrologic processes is important for understanding how the water cycle works in different environments. Cities which undergo constant changes are subject to flood hazards resulting from severe rainfall. This paper aims to simulate severe rainfall, visualize the results, incorporating both spatial and temporal dimensions, and to make future recommendations for further studies on flood visualization. Visualizing the results from a rainfall simulation using GIS provides urban planners and others the means to view the dynamics of the surface runoff. At the same time, it makes accessible advanced querying and analytical tools. A hydrological model for the study area in Gävle, Sweden was used to simulate a 100-year rainfall. Through FME, the data was reduced, time-stamped and combined to a shapefile. Both 2D software, ArcGIS, and 3D software, ArcScene, were used for creating an animated flood visualization. This study shows that although 2D tested better by a group of planners and water professionals, the 3D was still considered more intuitive. The heightened sense of realism from 3D outweighs its drawbacks, and further studies are required to test different methods of 3D visualization.
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1. Introduction

Flooding is a destructive natural hazard which could threaten the social, economic, and logistical fabrics of our society. According to a report by the European Environment Agency (EEA) the costs of flood damages in Europe, between 1998 and 2009, exceeded 52 billion Euros and 1126 people lost their lives [1]. Extreme rainfall is commonly the main cause for increased water levels in rivers and streams, which is likely to lead to flooding of the surrounding areas. The risk of flooding may vary greatly from one location to another depending on topology, geology, and nearness to water. Intense rainfall may cause flooding in cities, where there are no existing bodies of water, by overloading the storm sewer systems where the water has no other place to go due to the many impervious areas. In Europe, the EU Flood Directive [2] requires all EU member states to evaluate the risks of flooding and to draw maps presenting flood risk management for areas at risk, and EXCIMAP [3] is a reference guide for good practice on how to present flood risks and hazards in maps. The flood directive is mainly aimed at river flooding and makes no special mention of the special cases of urban flooding or the need for preparedness of handling storm water runoff. In Sweden the Swedish meteorological institute (SMHI) predicts significant increases in rainfall intensities in the near future [4] which will likely increase the occurrences of flooding in the cities due to storm water runoff.

1.1 Background

Hydrological models are ways to study the processes of the water cycle in the environment, and they can be used for flood forecasting to determine areas at risk of high water levels. River modelling is common, and in some cases required, due to their proneness of flooding and the potential risks this entails. Rivers, however, are relatively static and the flood plain varies very little for recurring floods. Cities on the other hand are like living creatures which constantly evolve, making it more difficult to predict how or when flooding will occur from severe rain. A severe rainfall is something that only happens once every so many years. A 100-year rainfall is something that has a 1% chance of occurring on any given year. The flooding caused by severe rainfalls is difficult to forecast, even with advanced hydrological models. There are many different types of models for studying urban hydrology, and the most common approach is the study of impervious cover and land-use changes [5]. There are many
variables to consider when attempting to predict flooding caused by rain in a city environment, however. Salvadore remarks that:

*Hydrological models for urban applications are considerably more complex than classical hydrological models as they try to simulate many more processes at a generally finer spatio-temporal scale. In this type of modelling approach, the number of parameters involved and data requirement significantly increase* [5].

Consequently, the results of simulating with very fine spatial and temporal resolutions can be more realistic but also generate large volumes of data. In cities it is necessary to stay true to a fine spatiotemporal resolution since the dynamics of water flow is dependent on small changes in the landscape. Visualizing these dynamics can greatly improve the understanding of where flooding may occur, but also serve as a tool for city management.

The study of risk communication for flooding is relatively new but it has shown that properly used, it can help prepare the public of flood awareness [6]. Kellens [6] states that the objectives in flood risk communications are situation dependent. When communicating the flood risks to urban planners, the objectives are to give them the tools to use the information in their work, in addition to raising awareness of flood hazards. Finding a suitable visualization method which is clear and communicative while simultaneously serves as a tool for planning and development is a challenge.

### 1.2 Aims and Objectives

This study explores methods of processing data from hydrological models for creating a dynamic flood visualization for urban planners that is both communicative and interactive. The aims are to transform the data from a simulated flood scenario to be utilized with Geographical Information Systems (GIS) for visualization. By taking advantage of GIS for visualization the data can not only be analyzed visually but it puts the advanced querying tools at the immediate disposal of the viewer. Furthermore, this study examines and compares the use of 2D and 3D flood visualizations in terms of usability. Animation will be used to account for the temporal aspect of the flood data. To gauge the effectiveness of both 3D and 2D visualizations they will be presented to a test group who provides feedback to the results.
The objectives of this study are to:

- Simulate and process data from an urban hydrological model to be visualized using GIS.
- Develop a spatiotemporal visualization of surface storm water runoff.
- Evaluate critically the usability and effectiveness of 2D and 3D GIS visualizations for flood management.
- Make future recommendations for flooding visualizations with regards to urban planning needs.

A case study will be conducted where a long return period rainfall is simulated using a distributed hydrological model. The results will be processed for use in a GIS application as a visualization tool using map animation. Creating a useful way to visualize urban flooding from surface storm water runoff will aid the work of urban planners and decision makers which in turn can help minimize the impact from severe rainfall and lower the social and cost of future flooding. This research will contribute to the study of flood visualization and how GIS applications can be utilized for spatiotemporal visualization in 2D and 3D.
2. Review of Previous Research

This section examines previously conducted research in the areas of flood visualization, 2D and 3D geovisualization and spatiotemporal geovisualization. The purpose of this review is to place this study in the context of previously conducted research.

2.1 Flood Visualization

Pappenberger et al [7] did a study in 2012 on the best practices for visualizing flood forecast information by turning to experts on forecasting and flooding from multiple nations to get their perspective on flood visualization. The results provided an array of important attributes that are important but the conclusion reveals that no general solution exists for flood visualization [7]. The amount of information that can be collected from a flood forecasting simulation is so great that one must make selections of what to include in the visualization based on its purpose [6]. This means that some information will be lost as a consequence, in the visualization. What information should be communicated plays an important role in creating a flood visualization, according to Pappenberger et al [7]. The type of data can also matter: if it is related to the discharge of a river, it can be sufficient with tabular data and charts to communicate the necessary information. For flooding however, a map showing the spatial extents and the associated depths would be more appropriate.

EXCIMAP Handbook good practices for flood mapping in Europe [3] gives advice on how to map flooding, and it states that flood hazard maps are appropriate for land use planning and land management. Flood hazard and flood risk mapping are the two main types of flood maps [8-11]. A flood risk map visualizes assets at risk, vulnerabilities and damage estimates [3, 10] and a hazard map depicts areas potentially affected by flooding. For hazard maps, Hagemeir-Klose and Wagner [11] and Kellens et al [10] agree that the color palette best suited for water is blue to avoid any confusion of what it represents. In risk maps however, Kellens et al [10] believe that a shade of red or orange can be appropriate when showing areas of high risk to economic loss or where the highest number of victims are located. For planning purposes, maps should only limit the colors of water to blue and it is beneficial if the land parcel boundaries are included so landowners can be identified in affected areas. Using GIS, which is an ideal tool for handling the fast changing landscape of spatial information and urban hydrology [5], there is a danger of wanting to include too much information in the map. Using simple basemaps, such as a topographical map or an orthophoto, is good practice since it limits what the reader is exposed to [3]. An orthophoto is
easy to relate to for any audience, and provides a good overview of the inundation area. Planners however, may be interested in having more information in addition to the basemap, such as land parcel information, sewer and storm drain data and elevation.

GIS is used by nearly all urban hydrological modelling approaches [5] and is a natural tool for working with hydrological data [12] but few use it as a visualization method. The strengths GIS provides in the form of easy data management and data layer management, not only provides an interactive analytical toolbox, but it may also greatly benefit the observational analysis [13]. Moreover, GIS provides interaction with all the layers in the map, advanced querying, and data storage options which are valuable to have when studying flood data. GIS enables the reader the ability to query water depths for an exact number when the legend can be hard to interpret. It is also possible to customize the data to meet specific needs by changing data layers to information indirectly affected by a flooding.

2.2 2D and 3D Geovisualization

Flooding are natural events which we humans see and experience in many dimensions. We can not only see the water as a surface area, but our other senses also feed us information that all contribute to our perception of a flood. It may not be possible to incorporate all sensory information in computer visualization, but some data can be visualized in 3D more readily as it provides a sense of realism to it [14]. River flood hazards have been successfully modeled and visualized in 3D. Evans et al [15] present a 3D flood visualization project that uses realistic images and increased water levels which cover the land surfaces where there is flooding. It is unclear what methods are used in their study, however, and it appears to only be a still image with no possibilities to perform further inquiries. Using 3D-GIS would make the data available for advanced querying at the same time as it maintains a level of realism. Köninger and Bartel [16] suggest 3D GIS is an integral part of land management and that the virtual city is a natural extension to city planning. Giving an object depth and similar shapes to the way we see it in reality increases our recognition of the environment it represents [17]. Achieving high level of realism can be desirable, particularly when using hydrological models which are purposed to simulate realistically flooding events. There are however, limits to the ability to effectively visualize water, and especially water movement, in 3D. Liang et al [18] found that the computational capabilities severely restrict the spatial resolution for a realistic rendering of water simulations. Serious consideration must be taken when deciding what level of detail is necessary for the visualization purposes. To solve the complexity of graphical
rendering large amounts of data, Tully et al [19] explore the use of game technology visualization techniques to create a 3D environment for spatial data. Albeit the study successfully generated basic maps in 3D, it fails to convince how this can be applied in geovisualization purposes. In addition to heavy computational requirements, realistic 3D rendering also necessitates more manual work to be put in for each new visualization.

Despite increasing the sense of realism, 3D can also be problematic for some visualization purposes, especially in an urban environment. Objects can shield the view of important information, requiring the user to change the viewing angles to acquire the same information that can be seen right away in 2D from above. The benefits however, can be to visually observe the map information from multiple viewpoints with a higher level of realism. Brooks and Whalley [14] propose a hybrid visualization technique where 3D map layers can be lifted up above the surface for a flat 2D view better suited for analysis. Although an interesting method to tackle 2D and 3D geovisualization, it is not a viable solution as a tool for visualizing and managing flood data. It lacks the ability to query features and no considerations have been made for temporal data. However, making use of both 2D and 3D in GIS visualization is not a bad thought. It can be easy to get caught up in the advances of 3D technology and assume it is superior for its ability to present the world more realistically. Sometimes the best way to analyze a map is to view it from directly above in simple 2D. The effect of this can sometimes be achieved in a 3D environment [20] but the usefulness of this depends on the visualization software and the data presented. Studies comparing 2D and 3D geovisualization [21-23] find little or no evidence that 3D is superior to 2D as an effective visualization method. There are varying levels of 3D, however, where strong 3D is the complete immersion into a Virtual Reality (VR) 3D environment. Weak 3D on the other hand is the projection of a 3D model onto a 2D screen. Seipel [23] found strong 3D unsuitable for solving spatial tasks whereas weak 3D is more appropriate for visualizing maps. It seems that there is no general solution for which dimensionality is more appropriate in geovisualization, in the same way that there is no general correct way to visualize flood data. The information conveyed and audience will dictate the most suitable form of visualization. In the case of presenting data for city planners and decision makers, assumptions are that 3D is the ideal solution [16, 22]. For visualizing a new development in its urban context, a realistically rendered 3D model would be very useful to planners [22]. It is less obvious whether it is as suitable when presenting data which changes over time. This study will thus explore both 2D and weak 3D as means for flood visualization.
2.3 Spatiotemporal Geovisualization

Rain storms are not time independent occurrences. It starts to rain and then some time later it eventually stops. During the rainfall there can be varying levels of intensities too. Therefore, it is necessary to include the time association when dealing with rain and rain related data, such as the surface runoff from a storm. For analytical purposes it is useful to have a complete picture of the series of events that take place in both space and time. There have been many studies in the use of spatiotemporal geovisualization, but none have provided a better overview of its applications than Andrienko et al [24]. In their analytical review of exploratory spatiotemporal visualizations, they list querying and animation as the cornerstones for working with spatiotemporal data [24]. Computer software allows a user to extract data from the map and to visualize its changes over time. Many different techniques can be applied to accomplish this, and what method is used will depend on the type of data that will be visualized and how the when, what, and where are linked to the objective of the map [24]. For the purpose of this study, to visualize the accumulation of storm water runoff on the ground surface, animation will aid visualization by presenting the user with a “time window” [24] which shows the location movement over time and over what routes. This implies that the when is given, and it will reveal the where and the what from the map. Static maps with a timestamp is one solution to this data arrangement but it would require many maps to visualize the results from a hydrological model with a fine spatial resolution. “Space-time-cubes” are yet another form of visualizing data changes over time. They use the x-, and y-axis to display spatial information and the z-axis for the temporal domain. They are suitable for tracking movement over time, but it works best if there is a single object to track [24]. Kjellin et al [21] confirms this behavior of a “space-time-cube” in a set of experiments comparing different spatiotemporal visualization techniques by tracking objects moving in time. Visualizing a surface changing in time would not be feasible in a “space-time-cube” since the data would obscure the spatial domain and it would be difficult to interpret, if not impossible. Although there is no general solution for spatiotemporal visualization either, there are methods that can be better than others for solving certain tasks [21]. For the purposes of this study, animation seems to be the clear choice to visualize flooding in space and time.
3. Methods and Data

In this chapter the method of data collection, data processing and data visualization is discussed as a part of the framework for the research strategy. The strategy was carried out to meet the objectives of the research, i.e. to process large volumes of data from hydrological simulations; develop a visualization strategy in 2D and 3D; evaluate if 3D is more effective for storm water flood communication; and, make future recommendations for flooding visualizations in urban planning purposes. The method encompasses three general parts: hydrological simulation and preprocessing of data, visualization in GIS applications, and user testing by specific user group. ArcMap 10.3.1 and ArcScene 10.3.1 were chosen as the software to be used for the flood visualization for their proven GIS capabilities and widespread use. Shapefiles are one of the most common GIS vector data formats and would be used for the simulation data to be visualized.

3.1 Study Area

An area in central Gävle, a city with a population of about 71000 inhabitants [25] in central Sweden, was selected to be used as a case-study for this project. The selection was made so that the area would encompass different types of land uses and areas of interest for planners. The site, seen in figure 1, covers approximately ½ km² of residential areas, industrial lots and busy roads. Certain sections of the study area lie significantly below sea-level and are known

![Figure 1: Orthophoto covering the study area](image)
to collect much water in heavy rainfall. This means that there are many pumps required to remove water from these low-lying areas which must be included in the simulation. All sewage pipes lead to the canals that lie within the study area, or to the river nearby.

3.2 Data Preprocessing

The flood visualization in this study is based on data collected from a hydrological model which has simulated rainfall on the study area in order to present what happens to the surface runoff during the storm.

3.2.1 Hydrological Model

The hydrological model used was a commercial software suite provided by DHI. Mike Urban 2016, which is a GIS based software, coupled with the simulation engines Mike Flood and Mike 21 made up the model in which the data would be generated. The model was fully distributed which means no catchments were used and the rain was applied to the entire surface. The surface runoff thereafter follows the topography and either collects in sinks or flows into the sewage system through any storm drain it may reach. Important for any hydrological model is an accurate elevation model. LiDAR data for Gävle, collected by Lantmäteriet and provided by Gästrike Vatten, was used to create a digital terrain model (DSM) with a spatial resolution of 2 m. This is the smallest recommended resolution for the models created in Mike Urban, according to personal consultations with DHI consultants. Initially only the ground surface elevation was kept and all other elevations were removed and a new surface was interpolated in its place using the nearest neighbor technique. Next the building footprints of all existing buildings in the region were read from a municipal database. For all the buildings in the study area, a new constant height of 5 m was given to them. The reasons for doing this were that the LiDAR data available was 6 years old, and the urban landscape changes quickly over time. Second, the elevation of buildings is not important for the hydrological model itself, but with the resulting flat roofs it was possible to account for the water channeled to the storm sewage system through roof drain pipes. For such buildings, fictitious drains were placed on the roof, and where there were such drains, the roof of the building was lowered by 2 m in the DSM while leaving the walls at the original height. This

1 Consultation took place on February 15, 2016.
created a collection area, forcing all the water landing on the roof to the well which then leads it to the sewer system. Bridges and tunnels were removed from the DTM to avoid damming from occurring. This was achieved by clipping away the bridging feature from the LiDAR data and then a new surface was created by interpolation from surrounding points.

The storm water sewer system was copied into the model from Gästrike Vatten’s databases, keeping true to current data on pipe dimensions, materials and placement depths in the ground. Parts of the model area covered pipes which were not in the study area, which were therefore excluded in the model. Five water pumps were included, and although pumps’ make and model were not known, based on data provided by Gästrike Vatten, a standard pump curve was used for all pumps. They were set to start pumping when the water level reached a specified level in the well, and stop pumping when the level had come back down to another specified level\(^2\). The maximum pumping rate was 70 liters per second.

A 100 year return period rainfall, Chicago-style storm, with a six-hour duration, was used for the simulation. A Chicago-style storm means that it does not rain equally much during the entire storm, but it peaks a few hours into the storm. Ground infiltration on permeable surfaces was taken into consideration by reducing the rain intensity by the infiltration amount for various surfaces, until a saturation level was reached, upon which the normal intensity was applied. Five different surface categories were used: green areas > 70%, green areas 50% - 70%, railroads, asphalt, and roof tops, where roof tops had no infiltration and green areas > 70% had the most infiltration rates. The surface categories were based on available data at Gästrike Vatten, and consultation with water engineers. Figure 2 shows the five different rain intensities and how they vary greatly during the peak of the rain storm. Nearer the end of the storm most surfaces are saturated and the differences in applied rainfall varies hardly at all. The total, unreduced rainfall amount was 111 mm in six hours. All rainfall related data was adapted for Swedish conditions, and was provided by water engineers at Gästrike Vatten. The simulation was given a time and date which in this case was 25 November, 2015, from midnight to 6:00 in the morning.

\(^2\) The water levels varied with each pump, based on the depths of the well
The surface runoff data from the simulation was stored in a time series file which could be converted to shapefiles using the Mike2GIS tool in the Mike Zero toolbox. Shapefiles, showing the surface water depth for each time-step in the simulation as polygons and points were created, for a total of 202 shapefiles\(^3\). The polygon layers represented each grid cell from the DTM in the model and contained the attributes for the surface level and water depth of that particular cell and the point layer represented the center point in each cell, with the same attributes.

### 3.2.2 Data Transformation

Before the data was ready to be visualized it was processed using FME Desktop 2014 which is a data transformation tool for all sorts of spatial data. For the animation to be possible in the ESRI products, a time attribute had to be affixed to all the data. This was achieved by reading the data files, which were numbered from 0 - 100. And based on the time of simulation in the model, each time step was associated with a timestamp. The timestamp was given the format `yyyymmddhhmmss` in order to be used in ArcMap and ArcScene where this was an accepted

\(^3\) The results had 101 time-steps, approximately 18 minutes per time-step, whereas the simulation had a much finer temporal resolution, 0.3 minutes per time-step.
format for reading time to be animated. Instead of reading the content of each file and adding the attribute immediately, the time attribute was saved in a comma separated value (CSV) file. In the next step, the data of each time-step shapefile\(^4\) was individually read and the points with a water depth less than 8 cm were discarded. The coordinates for the remaining points were extracted as attributes and the time was added to the attribute table for each point. To create surfaces for the water represented at each point, a buffer half the size of the resolution used in the model was applied, creating 2 m x 2 m polygons. A dissolve was applied to all the polygons, creating larger polygons showing the extent of the flooding on the surface. The attributes of the dissolved polygons were stored in a list, from which the depths of each polygon could be accessed. For each list, the maximum, minimum, and mean depths were calculated and included as attributes for the polygon surface. A vertex was created to mark the spot where the water was the deepest within each polygon with the attribute of the deepest point. Another filter was applied which discarded all water surfaces smaller than 5 m\(^2\). All data was written to new shapefiles containing polygons and points.

For the final step, all new shapefiles were read and the polygons were rounded using a line generalizer. Figure 3 shows the results of the smoothing operation, and how the water gets a more natural look. The combined data from all files were written to a polygon shapefile, and a point shapefile. A clipping was applied after the file had been completed in order to remove data from areas outside the study area and areas already covered with water. In total 4 workspaces were used and the entire data process in FME can be seen in figure 4 below.

![Figure 3: the image on the left shows the water as a dissolved polygon from squares. The image on the right shows the same data after the line generalizer has been applied.](image)

\(^4\) Point features only.
Figure 4: Data management process in FME. Four workspaces were used to read files, read data, filter data, create and new shapefiles. The final output were two new shapefiles. The FME workspaces can be seen in the appendices.

3.3 Visualization

The flood data polygons were added to ArcMap for the 2D visualization and the symbology was changed to follow best practice for flood representations [3, 10, 11]. A color ramp with different shades of blue was applied to represent the water using the mean water depths, where darker blue indicated deeper water and lighter blue indicated shallower water. An interval of 0.5 meters was used to classify the water depths, resulting in 7 distinct classes, from 0.08 m to 3.5 m. To prevent all polygons from each time-step to be drawn at once and to enable animations, the *time* setting was activated for the data layer. When enabled, only surfaces with the same time attribute are be drawn. An opacity of 40% was applied to the flood so that the underlying surfaces and features could be seen too. A time slider was activated in order to animate the data from the beginning to end. Figure 5 shows the time slider and its functions of playing forward or stepping forward or backward one step at the time. It also has a button for rendering speed and an option to export the animation as a video. An orthophoto of the study area was used as a basemap, on top of which land parcel

Figure 5: Time slider with the ability to play the animation, step forward and backward. The time of the current step is shown in the center display.
information was applied. The land parcel data was represented as polygons which were made hollow with a black border. Railroad tracks and roads were added in order to highlight those in the orthophoto, as well as the footprints of any buildings. The roads and railroads were given discreet colors to not stand out, whereas the buildings were given a colorful orange to be easily distinguishable against the water. The order of the layers in the map was: buildings, flood, roads, railroads, land parcels and orthophoto. All data was provided by Gästrike Vatten and was clipped to fit the study area only.

For the 3D visualization the same data and symbology was used in 2D, with the addition of a 0.5-meter digital elevation model (DEM) which was created from LiDAR data. Bridges and other overpasses were intentionally kept for this surface as it was used to provide the 3D topography of the study area as the base-heights for all data layers. The DEM was not displayed. The building footprints contained data on the height of the roof as an attribute, which was used to extrude the buildings into three dimensional objects. The flood data was also extruded by the amount of the water depth for each polygon.

### 3.4 Usability Testing

To gauge the usability of the 2D and the 3D visualizations, a survey was conducted with people who work in the field of urban planning and water management. The survey was setup to gather qualitative and quantitative data by combining Likert item questions and short answer questions. The participants were invited to Gästrike Vatten to partake in the survey on one of three group meetings on May 11, 12, and 13. For the first meeting, eight participants showed up and completed the survey, none came to the second meeting, and in the third meeting 18 participants came. Since many more showed up than had reported interest, only 11 had time to complete the survey. Of the participants who completed the survey, 11 were from Gästrike Vatten, seven from the municipal planning department, and one from the fire department. All 19 participants were volunteers and had no involvement in the study.

The survey was held in a conference room where the participants were given an introduction to the study and a briefing on how to use the software. Each participant was then asked to identify a building which was directly affected by flooded water where the maximum depth was 0.5 m or greater. The same task was repeated for both 2D and 3D, starting with the 3D visualization. Although the user was asked to find the same data in two different visualizations, the test was not about finding hidden information as much as it was using the tools to navigate and find the desired information. No times were recorded for this test since
the purpose of this study is to determine the overall usability of the visualization. Solving tasks on time in a GIS application is heavily influenced by the user’s previous knowledge of the software. Each participant answered the questions in the questionnaire, rating whether they considered the visualization to be intuitive, appropriate and useful for their work duties.
4. Results

The simulation of the 100-year return period rainfall returned a DFS2 time series file containing the surface runoff data. Processing this data was a big part in making the flood visualization possible in 2D and 3D GIS. With FME it was possible to combine 101 individual shapefiles and filter out excessive data for the visualization. The number of polygons containing surface runoff in the original data: 76,775,150 and used over 12 gigabytes of storage. After filtering and removing all water surfaces with less than 8 cm of water, the number of polygons were reduced to 8,187,098. The surface area filter did not result in a significant reduction however. After the clip and dissolve operations, 43,194 polygons remained at a size of 300 megabytes.

4.1 Visualization

The visualization in 2D gives a 90 degree viewing angle of the study area where the user is able to pan around and zoom in on individual objects for visual inspection, interactive querying, and analysis. Figure 6 shows the 2D visualization where no surface water can be seen before interacting with the time slider. Pressing the play button animates the entire simulation of the six-hour rain, each step moves 18 minutes forward, showing where the water collects and withdraws from different areas on the surface. When the playback is
finished the flood data disappears from the map until the user plays the animation again or steps back on the time slider. In figure 7 the time slider has moved further into the simulation and the surface runoff is becoming visible as it collects on the streets mainly.

For further analysis, it is possible to perform advanced analysis using attribute or spatial queries. Simple querying, such as using the identification tool or the HTML popup tool, as can be seen in figure 8, can quickly provide the user with information in the map.

The 3D map, seen in figure 9, has the same colors and map layers, but an added dimension for increased sense of realism. The buildings are extruded and the topography is true to the actual heights. The flood data is also extruded to show the depths of the water levels, which can be put in perspective against buildings for instance. Figure 10 shows the flood water and a building zoomed in at 5 hours and 30 minutes into the simulation.
4.2 Usability Testing

The user survey was setup so that the participants were given a chance to sit one at a time on the computer provided for them with the visualization ready to be viewed and interacted with. After spending approximately five minutes getting used to the software and looking at the study area, making inquiries for water depths to find a building affected by at least 50 cm of water, each participant answered the questions in the questionnaire. 18 of the 19 participants agree or strongly agree that the 2D visualization was appropriate and intuitive, and only one disagrees. For the 3D, 17 agreed or strongly agreed the visualization to be intuitive and 2 disagreed. All participants agreed that the 3D visualization was appropriate
however, and 15 agreed that it was more intuitive that the 2D visualization. Although most agreed that the 2D or 3D visualization would be useful in their work, 3 did not agree and 4 were of no opinion on the matter. 12 participants agreed or strongly agreed that the colors were appropriate whereas one disagreed and 2 were of no opinion. The majority also found there to be no problems identifying features where the water levels were high and up against a building. Figure 11 shows the participants’ answers for the Likert scale questions as percentages.

![Questionnaire Summary](image)

**Figure 11: Summary showing all participants answers to the Likert questions, where n = 19**

Of the 7 planners, only 5 agreed that 3D was more intuitive than the 2D visualization, to be compared with all 11 of the water professionals. Still, 6 planners strongly agreed, and one agreed, that the 3D visualization would be useful in their work. All planners and 9 water professionals strongly agreed that the 2D map clearly showed areas affected by flooding. On the other hand, nearly half the water professionals disagreed that the 3D map was able to do the same. The planners too showed more uncertainty about the 3D ability to clarify areas of flooding where 2 had no opinion on the matter, but 4 strongly agreed and one agreed.

In the written feedback, the general consensus for the 2D visualization is that it provides a good overview, it is a familiar way to view maps and the navigation was easier. One person found the opposite to be true, however, that it was difficult to move about the map. Another thought that there was a lack of detail from the 2D visualization, whereas
another was happy with the amount of details and showed approval of the focus on a limited area. Concerning the 3D map, the participants predominantly found the navigation to be the biggest issue. It was hard to get used to the controls, but some noted that it would be a matter of getting used to only. There were no comments indicating issues with the visualization itself, but many stated that it was a relevant way to display flood data and it provided a good tool for identifying areas affected by flood. That the water could be seen against the building façade, was another benefit pointed out by a couple of participants. When asked what would improve the visualization some made no remarks but several suggested that greater color contrasts between the water levels would be beneficial. Fewer classes for quicker distinction was also mentioned, as well as something to highlight specific buildings that were affected by flooded water. One noted that ArcScene was not the optimal tool for visualization and one wanted more life-like effects as part of the visualization.
5. Discussion

The first objective of this study was to simulate a severe rainfall on an urban environment to gather surface runoff data for a flood visualization using GIS software. The use of GIS is essential for this task in order to make the data available for advanced data management, analytical tools and querying abilities, which are very useful to urban planning. GIS is a natural tool for setting up hydrological models [5] but is just as useful for studying the results of the simulations created thereof. The urban setting dramatically increases the number of parameters that go into a hydrological model, where manholes, storm drains, pipe and well dimensions, flow rates and much more, need to be considered. This increased level of complexity increases the uncertainty that comes with hydrological modelling in general. Including uncertainty studies in the visualization, as is presented by Lim et al [26] would increase the reliability of the results. Based on the simulation time and the amount of data produced from one simulation, as shown in this study, it would at present not be reasonable to conduct uncertainty modelling for urban simulations using the methods presented in this study for visualization.

The second objective, which was to develop a spatiotemporal visualization for surface runoff was achieved by processing the results from the simulation. Choosing ESRI’s ArcGIS platforms for the visualization meant giving it access to querying tools for deeper and more comprehensive analysis. Andrienko et al [24] describes querying as one of the two cornerstones in exploratory spatiotemporal visualization. Using shapefiles for making the visualization also provides planners with data for software that is already widely used, maintains familiarity in most urban planning needs. An added benefit of using GIS tools for visualization is the ability to customize the symbology and data layers for a personalized visualization.

Setting up the temporal aspect of the visualization there are many alternatives, but few that provide a more intuitive view of flood dynamics than map animation. A space-time cube only offers a three dimensional solution, and is not always very intuitive even for tracking simple objects, as shown by Kjellin et al [21]. Static maps at varying times provide snapshots that provide a glimpse of the location changes happening over time. For this kind of data however, where the temporal resolution is very fine, and the changes occur unevenly over time, the number of static maps needed would be many. Animation as a solution was the best alternative and was also achieved using the ESRI GIS platforms.
5.1 Data Processing

To accommodate the data for visualization and animation a number of processing steps had to be taken which affected the output of the data. Most noteworthy is the polygon assimilation which was necessary for delineating the flood boundaries as single bodies of water and to reduce the size of the data. As the results show, the extent of the flood water remains intact but the information of the varying depths over the shape’s area get lost since only the average water depth for the entire surface of the flood extent is used for visualization. For this reason, the water levels used in the visualization do not represent the exact water level at a specific location. Larger areas with greater surface variations will show less accurate water levels and smaller areas with little or no surface gradient will show a mostly accurate water level. Attempts to work around this problem were made by bypassing the polygon dissolve step to use symbol level rendering in ArcMap to virtually dissolve all the polygons based on water level. This turned out to be impossible due to the size of the resulting file which exceeded the shapefile format limits at 4 GB. Including the minimum and maximum depths for the whole body of water gives the user an indication of how severe the flooding is. If exact numbers are required for a specific location, it is possible to use the unprocessed shapefile for the time-step where the flood is occurring. Each flood polygon contains the time-step filename it was derived from originally as an attribute. Another solution to include the exact water levels for the whole surface is to use raster data instead of vector data. This would greatly improve the size of the data and it is a preferred method for representing continuous surfaces. The inability to animate raster data in GIS limits its uses for spatiotemporal visualization however.

Other parameters were used to limit the size of the data output used for the visualization were the limits set on water depths and area on the flood extent. 8 cm was used as the parameter as the minimum depth that should be included in the visualization which led to a 90% reduction in the number of data points to be processed. 5 cm was tested also but it yielded two million points more and the results would include many areas of negligible flooding. With a 10 cm cutoff depth the amount of points was reduced by yet another 2 million points. In addition to reducing the size of the data, the filter was meant to clean up the visualization from surface water which is not more than regular puddles that can be created in any kind of rain. 8 cm was chosen for the amount of data it removed and because it did not limit the results too much. Removing water from existing water features was done as to avoid confusion in the visualization. The model used in this study does not simulate river flow or sea level rise, so it is not accurate to show water level increase on these areas.
5.2 Visualization with GIS in 2D and 3D

Both 2D and 3D visualization was used to present the simulation data. 2D is the natural GIS environment where maps are studied from directly above and therefore needs to be tested against using flood data as well. Flooding as an event is something that is perceived in 3D however, where you can fully grasp the nature of the flood by seeing how high up water reaches on a wall or how much under water a roadway is submerged. A fully realistic water rendering would be impractical at this spatiotemporal resolution, as shown by Liang et al [18] but many studies use 3D for flood visualization at lesser degrees of realism successfully anyway [15, 20, 27].

The result presented in 2D was a simple map with limited data layers to avoid confusion and an orthophoto as a basemap. The navigation proved simple and the data was animated relatively smoothly. The 3D rendering in ArcScene had some lesser issues however. There were conflicts in the polygon rendering which resulted in discolorations or polygons showing where they should not be visible. The orthophoto which was rendered with the baseheights based on the DEM layer was slightly distorted and the resolution depreciated somewhat, but provided a realistic setting for displaying the results. The addition of the 3D buildings significantly added depth to the visualization and a higher degree of realism, despite the lack of realistic façade textures. The map animation worked well here too, but with a little slower rendering speeds. When animated, the rounded shape, and blue colors of the water, contributes to the appearance of water moving over the surface. Initially the flood extents only expand and the depths get deeper. In some areas, however, the animation reveals that the water begins to retract from the surface where it had once been accumulating. In such areas the storm drains are able to receive water again after initially becoming overloaded by the water brought on by the rainfall.

Although ArcScene was able to display the data, there were many little issues that need to be noted. Where multiple surfaces, such as polygons, were used on top of one another, there often occurred conflicts in the rendering order of the data. When navigating around the scene, it could be possible to see layers underneath the expected top-most layer. This was usually solved by navigating a little, allowing the software to re-render the data again. Visually, the 2D rendering performs much better than the 3D. The added realism of extruded ground, buildings, and the flood water, makes the 3D visualization more desired, despite the somewhat sluggish animation and overlapping polygon rendering. The 2D top-down view, however, is standard portrayal of a map, and it suggests its own intuitiveness and
appropriateness. As such, the visualization of flood water in a map is suitable in both variations.

5.3 Usability

The third objective of this study was to evaluate the usability of the presented method of flood visualization. As can be seen from the user survey, both applications, in 2D and 3D, tested well with all participants with regards to intuitiveness and appropriateness. Although the 2D visualization was much better and presenting to the participants what areas were affected by flooding, the vast majority believed that the 3D visualization would be more useful in their work. The preference of the 3D visualization can be further seen where nearly half of the participants agree that the 3D was a more intuitive visualization than the 2D, and 32% strongly agreed to the same statement. This follows the lines of Königer and Bartel [16] who believe that 3D-GIS is an integral part of urban planning for adding new depths and perspectives to urban planning. Despite certain drawbacks and a lack of realistic rendering, the 3D visualization was perceived more appropriate than the 2D visualization. This supports the findings of Herbert and Chen [22] who found similar preferences among urban planners.

The results of using both maps to find locations of deep water affecting buildings by contact show that more were able to gather data with less effort from the 2D map than the 3D map. The trend indicates that 3D seems more suitable and appropriate, but it does not improve the analytical or interactive aspects of the visualization. Participants who work in planning were less inclined to agree that the 3D was very intuitive however, but found it to be a something that could be useful in their work more so than the 2D.

5.4 Future Recommendations

As this study demonstrates, there is a need for an ability to visualize urban storm water runoff using dynamic and interactive tools. The methods used here are one way to solve this task, but there can be other approaches that could be equally or more suitable. Exploring ways to animate raster data in GIS would be one way to go. Another is to examine alternative means for data management in order to prevent a too high data loss when the results are to be presented.

When presenting the data in either 2D or 3D, the color choice of water should be carefully investigated. Using varying levels of the color blue is appropriate, but the number of variations can make it difficult to distinguish one from another. It would be useful to conduct
a study to determine how to classify the water depths in the visualization. In order to reduce
the number of classes, and thereby the number of color variations, it would be necessary to
determine which depths are of interest to the users of this data, and choose the symbology
thereafter. It may not be necessary to show exact depths above a certain level for instance.

An expanded user study should be conducted in order to gain a better
understanding of the needs for urban planners and other interested user groups so that the
visualization can be improved to better suit their needs. The usability testing in this study only
provides a cursory look at what users’ reactions are. An expanded study should include more
planners from other municipalities, more and varied testing of the applications using multiple
study areas so that the 2D and 3D tasks can be done independently of one another.

Additionally, it needs to be considered finding alternative 3D visualization
software. ArcScene demonstrated difficulties in rendering multiple surfaces on top on each
other which could potentially provide misinformation. ArcPro is another ESRI product which
could offer a better solution, but it is so far not proven to be able to handle the amount of data
used in this study.
6. Conclusions

There is a need for data from hydrological models to be made available for further analysis in an environment where it can be viewed and interacted with closely. Urban hydrological models are very complex due, in part, to the ever changing city landscape. Simulations can help provide urban planners with information that can be used as decision support when planning new developments. Although some data is lost in the translation, the availability of flood data in a GIS friendly format is not only possible, but an effective way to visualize flood scenarios. It is easy to gather information from the map and it allows further analysis with other data layers and querying tools. Both 2D and 3D are appropriate methods for visualizing flood data, even though the 3D is both considered more intuitive and useful by the user group, and it takes more time getting used to. The 3D has the most potential for improvement but is also what requires more data and computational power. So far, 3D-GIS is a desired visualization goal for flood data, but for practical use and effective visualization, the 2D should be the preferred alternative.
Acknowledgements

This study would not have been possible without the support of Gästrike Vatten, from where I have had the full support and access to the data needed to complete this task. Special thanks to Nils-Erik Dahlsten at Gästrike Vatten for his guidance in the use of FME. I would also like to thank DHI for providing me with all the licenses necessary to make the hydrological model possible. My supervisor and family who have been very supportive during this whole process deserve my full gratitude, as does my loved one, who has been by my side all the way.
References


Appendices

Appendix A

**FME Workspace to read the file names and calculate the time for each time-step. Resulting in a CSV file.**

**FME workspace which reads the CSV file, and runs a third workspace based on the time input from the user.**
FME workspace run automatically from previous workspace. Reads the data in each file according to the times selected by the user. Data points are filtered and, buffered, and attributes are created. Results are a new shapefile for each time-step, one with points and one with polygons.
FME workspace that reads the shapefiles created in previous workspace. Points and polygons are separated and polygon edges are smoothed. The result is two shapefiles containing all surface runoff data.
Appendix B

FLOOD VISUALIZATION QUESTIONNAIRE

Employer:  
Work title/duties:  

Please answer each statement below by circling the most appropriate answer as it related to visualization of urban flooding.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>No opinion</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>The 2D visualization was intuitive</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The 2D visualization was appropriate</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The 2D visualization made it clear which areas were at risk of flooding</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The 2D visualization would be a useful tool in my work</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The 3D visualization was intuitive</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The 3D visualization was appropriate</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The 3D visualization would be a useful tool in my work</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The 3D visualization made it clear which areas were at risk of flooding</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The 3D visualization was more intuitive than the 2D</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The colors were appropriate</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I had no problems gathering information from the map</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Please give a short answer for each of the following questions:

- What did you like, or not like, about the 2D presentation?

- What did you like, or not like, about the 3D presentation?

- How could the visualization of flooding be improved (anything missing/too much information, etc)?
Appendix C

ENKÄT OM VISUALISERING AV ÖVERSVÄMNING

<table>
<thead>
<tr>
<th>Påstående</th>
<th>Håller inte alls med</th>
<th>Är emot</th>
<th>Ingen åsikt</th>
<th>Är för</th>
<th>Håller med fullständigt</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D visualiseringen var intuitiv</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>2D visualiseringen var lämplig</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>2D visualiseringen klargör vilka områden som påverkas av översvämningar</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>2D visualiseringen skulle vara användbar för mitt arbete</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3D visualiseringen var intuitiv</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3D visualiseringen var lämplig</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3D visualiseringen klargör vilka områden som påverkas av översvämningar</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3D visualiseringen skulle vara användbar för mitt arbete</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3D visualiseringen var mer intuitiv än i 2D</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

| Färgsättningen var lämplig                     |                      | 1       | 2           | 3      | 4                     | 5                   |
| Jag hade inga svårigheter att få ut den eftersökta informationen från 2D kartan |                      | 1       | 2           | 3      | 4                     | 5                   |
| Jag hade inga svårigheter att få ut den eftersökta informationen från 3D kartan |                      | 1       | 2           | 3      | 4                     | 5                   |

Svara kort på följande frågor (skriv på baksidan om ni behöver mer plats):

- Vad tyckte du om/tyckte inte om med 2D presentationen?

- Vad tyckte du om/tyckte inte om med 3D presentationen?

- Vad skulle förbättra visualiseringen av översvämningar (t.ex. färger, bakgrundskarta, andra lager)?