COMMUNICATING FLOOD RISKS TO THE PUBLIC THROUGH VISUALIZATION IN SCIENTIFIC COMPUTING

Fatima Basic\textsuperscript{1}, William Cartwright\textsuperscript{1} and John Handmer\textsuperscript{2}
School of Mathematical and Geospatial Sciences\textsuperscript{1}
Centre for Risk and Community Safety\textsuperscript{2}
RMIT University
Melbourne, Victoria, Australia

ABSTRACT
Ever since the 17\textsuperscript{th} century humans have turned to visualization as a means of representing numerical data. As a result, graphic representations have assisted in solving countless problems and managing disastrous circumstances in areas of health, navigation, physics and mathematics to name a few. With the continual growth of the computer age, we have rediscovered the strength of visualization and have adapted the visualization process to a digital realm. Computer facilitated visualization has been named Visualization in Scientific Computing (ViSC). The main focus of this paper examines the use of ViSC for communicating flood risks to the public. The ViSC procedure used implements PHP to generate VRML from a set of coordinates stored in a text file. The representation generated provides users with a map of an ARI design event, which users are able to interact with and obtain suggested flood safety messages using Geographic Visualization (GeoVis) tools. This paper will be concluded with a summary of results obtained when more traditional means of flood risk communication (radio and fax) modes were compared to the use of digital spatial representations for flood risk communication.

INTRODUCTION
The focus of this paper is on the development and testing procedure of a prototype Flood Warning Information System (FWIS) that has been developed for improving flood warning communication to the public. The prototype is part of a research project that aims to determine whether humans respond better to flood warnings that are communicated using a graphic interface when compared to more traditional means of flood risk communication: radio and fax. Graphics are being used to challenge current modes of dissemination because they are an almost universal language that the human mind reacts to quickly. The study is motivated by the low success rate of effective message dissemination and response in Australia.

A framework has been devised which governs the development of the prototype. This framework has four individual components. One of these components is dedicated to the use of graphics for flood warning communication. The other components address issues of personalising flood warning information, disseminating flood warning information and attracting the attention of individuals so that the risks of an emergency situation occurring is explicit.

The FWIS is a combination of three Geographic Visualization (GeoVis) tools: the Flood Warning tool; the Find Property tool; and the Safety tool. As well as provide an overview of each tool, this paper will discuss the procedure adopted in developing the prototype including the chosen development environment: VRML and PHP. The combination of these two computer programming scripts was chosen because together, VRML and PHP is a development environment that satisfied set criteria outlining what was required of the development environment. Several other development environments were reviewed but did not meet the criteria.

In testing the prototype, several phases were adopted. These will be outlined in this paper along with a summary of results thus far.

FLOOD RISK COMMUNICATION IN AUSTRALIA
Awareness of the flood threat by those at risk is seen as necessary for effective response to warnings. Attempts to publicise flood risk in Australia vary greatly by state and local jurisdiction, with many attempts mired in concerns over legalities,
privacy, data uncertainties and pressure not to undermine development interests. However, it is almost certain that increased reliance is being placed on warnings. One fundamental reason for this is that warnings provide an approach to risk management that allows the risk to be taken. Development may occur in flood prone areas because warnings will (or rather should) trigger appropriate safety and damage reducing behaviour [1].

A flood warning turns a prediction or forecast into information in the form of an action statement. The purpose is to improve safety and reduce damages. They do this by communicating information to those at risk to take action to improve their safety and reduce damages: to enable “individuals and communities to respond appropriately to a threat in order to reduce the risk of death, injury, property loss and damage.” [2]. Effective warnings must be able to respond to the question asked by those at risk: “what does this mean for me and my house (or business)?” Good practice for Australia is set out in an EMA guide [3]. A central aim of this guide is to encourage those responsible to make warnings more applicable to the personal circumstances of those at risk. The emphasis is on developing shared meaning between all those involved in warnings. In practice warnings often fall well short of this ideal. A general warning will typically specify a time, precise location and river height, for example: “The Muddy River is expected to reach 10 metres on the Bridge Street gauge by 6pm today.” Apart from issues of certainty implied by such statements, to give meaning this statement must be interpreted to relate to the water spread away from the river. Crucial advice on how flood water will actually affect people, and on appropriate action, is often minimalist or missing. Warnings in Australia are generally communicated to those at risk by radio, fax, occasionally by TV crawler messages, and in some circumstances by emergency service personnel door knocking. Door knocking provides personal information but is very resource intense. Warnings are also posted on the web, but as text messages only. Although some jurisdictions put local flood histories and other detailed risk information on their web pages, the medium has yet to be used in a fully graphical interactive way to convey more personally relevant information on flood risk. Another important aspect of web usage is that some sectors of the population are increasingly relying on the web as their primary information source.

A FRAMEWORK FOR IMPROVING FLOOD RISK COMMUNICATION IN AUSTRALIA

To approach issues in flood risk communication, a framework has been devised that offers ways of improving flood risk communication in Australia. The framework consists of four inter-related components. An overview of each of component is to follow.

Framework component 1 - Graphics: an almost universal language

This component concentrates on the use of a graphic interface to communicate flood warnings. Graphics are thought of as an almost universal language and have been used since early Mesopotamian civilizations. They are a seemingly naturally instinctive form of communication for human beings. Benefits of using graphics to communicate flood risks include:

- The ability to transcend lingual communication barriers. Graphics are said to be universally understood. This is of special importance to disciplinary areas usually clouded with technical jargon which requires a reasonable level of topical understanding before communication is a success: as is commonly the case with flood risk communication;
- The human mind reacts quickly to visual information which can be attributed to the visual system being our most dominant sense with more brain area devoted to vision compared to any other sense [4];
- The ability to store substantial amounts of information in a relatively small space; and
- A graphic can be static for a period of time long enough to give a person a chance to reassess a flood warning message. Messages distributed by mass media are very short lived and do not give the person enough time to fully comprehend the nature of the situation.

Framework component 2 - Personalise the flood warning

This component of the framework stems from the notion that the initial concern of those at risk revolves around the safety of close family and friends as well as property belonging to the risk bearer. Therefore by personalising flood warning information it is expected that people will be more attentive to warnings and safety information as the potential damage is put into perspective.

At this stage, the framework is designed for “Specific” modes of flood warning dissemination. A Specific mode of dissemination is one that is particular to householders, businesses, primary producers or other individuals, groups or organizations [3]. The other mode of dissemination is “General”, where the message is distributed mainly by the mass media such as radio or television [3].
Generally, flood warning messages include information such as the forecast flood category for a specific river at a particular point along the river, the current river height, the tendency of the river, rainfall forecast and if any towns are of particular risk. Locals who have experienced flooding and have an understanding of the nature of the flood will find General messages adequate. But those who have not experienced a flood may not know what the consequence of the information in the message is or how to react to the message, and therefore information needs to be clear and obvious to someone who is not used to receiving flood warnings [5].

Through General modes of dissemination, flood warnings are issued for an entire region or town. This can cause unnecessary panic among residents as the warning may not be relevant to the entire locality. If flood information is personalized, appropriate degrees of risk can be issued to different properties, streets within a town or parts of towns (for example, the east or lower part of a town).

Framework component 3 - “Spice it up” with aesthetically pleasing graphics
Component 3 plays on the notion that humans are incredibly visual creatures and are generally attracted to objects that are visually pleasing and engage interest. By improving the appearance of a flood warning message, it is expected that more people will pay attention to the warning.

Framework component 4 - The Internet and the World Wide Web
The Internet is the fastest growing communicating medium in the world [6]. Statistics indicate a 146.2% growth in world Internet usage between 2000 and 2005. The benefits of using the Internet for disseminating flood risk messages include:

- Information can be accessed at any time of the day from a computer with an Internet connection;
- The same information can be accessed by many people simultaneously;
- Updates are easily received by monitoring websites;
- Web pages are dynamic and therefore redundant information can be cleared easily so that it is not mistaken for up to date information; and
- Various data formats can be sent over the Internet;

THE PROTOTYPE
To address the framework a prototype has been designed and developed. The designing phase had two predominant hurdles: 1) satisfying each component in the framework individually; and 2) combining all components to form an overall Flood Warning Information System (FWIS). The FWIS utilises ViSC to dynamically generate buildings, road networks and flood extents on the map, from set of coordinates (a brief overview of ViSC will follow this section of the paper). Users are able to access the representation over the Internet and interact with the representation to obtain flood warning information and safety suggestions.

In order to address the framework, the following will be included in the prototype design:

- Use a map showing the location at risk of inundation at a scale that clearly shows the road networks and property boundaries and show the forecast flood water extents. This addresses Framework component 1 - Graphics: an almost universal language
- By using a map showing property boundaries, information can be property specific, hence addressing Framework component 2 - Personalise the flood warning.
- As a way of grabbing a person’s attention, the map will be in 3D and will have a “Geographical Dirtiness” level of 2a [7]. The map will also be equipped with basic interactive features to give the user control over the amount of information they would like to view at any one time. This addresses Framework component 3 - “Spice it up” with aesthetically pleasing graphics
- The map is designed to be accessed over the Internet, therefore addressing Framework component 4 - The Internet and the World Wide Web.

The FWIS is a combination of three GeoVis tools (Figure 1). Initially there were ten GeoVis tools designed for communicating flood warning information to the public, but due to restrictions in time and resources only three of these have been developed. They are the:

1. Flood Warning tool;
2. Safety Information tool; and
3. Find Property tool.
The FWIS allows the user to obtain property specific flood risk information by using a 3D map. This map shows the flood extents for a particular Average Reoccurrence Interval (ARI) design event (for example a 1 in 20 year flood or a 1 in 100 year flood). Since the FWIS is deployed over the Internet, river heights that are collected by the Bureau of Meteorology (BoM) and displayed on their website can be used to link the appropriate map to the current river height reading using the Flood Warning Information System.

A map of the study area was made with VRML. PHP was used to generate VRML from a set of coordinates in a text file.

The Find Property tool allows users to locate properties on the map by business name or street address.

The Safety Information tool: By clicking a property on the map, users can view flood information and safety suggestions particular to that property.

---

Figure 1. The Flood Warning Information System. Users are able to change viewpoints to a street and individual property level using the Find Property tool (a larger scale viewpoint is shown in the lower image).
programming scripts. Therefore, the FWIS provides users with a flood warning service that they can access when ever necessary and is automatically and continuously updated.

Users are allowed basic interaction with the map using the computer mouse. This interaction includes clicking on properties to obtain relevant information and using a menu to select business names or addresses in order to re-position the map so that the selected property is in the main view. The level of interaction has been kept at a basic level as a way of maintaining simplicity.

**VISUALIZATION IN SCIENTIFIC COMPUTING**

Visualization in Scientific Computing (ViSC) is a stream of visualization that restricts scientific visualization to the computer and tools constructed to work on a computer (Figure 2). The computer became a powerful tool for facilitating visualization during the 1980s. As the accessibility and speed of computer systems improved, ViSC was noticed for its ability to process large datasets in a fraction of the time taken using pencil and paper, and generate visual representations of those datasets. Exploration and analysis of datasets also became a lot more efficient through the use of computers as generated visual representations that were dynamic, enabled representations to regenerate when changes were made to data. This, opposed to re-drawing every possible scenario, as with pencil and paper, saved a lot of time and energy, providing the user had a sound knowledge of the computer software being used.

Early applications of ViSC were in chemical crystallography [8]. In 1971, inventor Bill Wright developed “GRIP”: a computer generated molecular model with accompanying electron density maps. Wright’s invention demonstrated the power of computer facilitated visualization to extend human insight into the previously unseen. Today, ViSC is used in a broad range of disciplines for various purposes from photorealistic terrain modelling (Figure 3) to anatomical reconstruction (Figure 4) to environmental modelling (Figure 5). An example of particular interest is the Sentinel Fire Mapping website is an internet-based mapping tool designed to provide timely fire location data to emergency service managers across Australia (Figure 6). In a similar way to the FWIS, the Sentinel Fire Mapping website allows users to identify fire locations that pose a potential risk to communities and property. The major difference between the Sentinel Fire Mapping system and the FWIS is that the FWIS is aimed at the public and provides information at a much larger scale.
DEVELOPING THE PROTOTYPE FWIS

The first step in developing the prototype FWIS was to decide upon a suitable development environment. Several possibilities were found and evaluated against the criteria listed in Figure 7. Almost all criteria were devised around the framework components. The preference to use open source technologies was made so to minimise costs to those who wish to implement the system. The ability to link contents in a database to map objects is a requirement affiliated with the template design.

Criteria for prototype development environment

<table>
<thead>
<tr>
<th>3D base map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output format must be displayed in 3D;</td>
</tr>
<tr>
<td>Output format must be viewed over the WWW;</td>
</tr>
<tr>
<td>Map objects must allow interaction;</td>
</tr>
<tr>
<td>The graphics must be aesthetically pleasing;</td>
</tr>
<tr>
<td>The size of the output file needs to be minimal to avoid tedious download</td>
</tr>
</tbody>
</table>
rates when using a modem with no less than a 33 KB per second download capacity;

- Preferably open source.

**Basic interactive tools**

- Able to link contents in a database to map objects;
- Able to interact with objects in the 3D map by clicking onto an object and obtain information;
- Preferably open source.

The five most probable development environments were AVS/Express Professional Edition, ArcView GIS, IBM Visualization Data Explorer, Virtual Reality Modelling Language (VRML) with the HyperText Preprocessor (PHP), and World Construction Set. VRML with PHP was found to be the most suitable development environment and was therefore the chosen environment.

VRML is an open source 3D interchange format designed for viewing 3D objects over the World Wide Web (WWW). Internet based scripting languages such as JavaScript and PHP can be used with VRML to increase certain VRML functionalities. PHP has particular strength in the generation of dynamic web pages. Another of its strongest features is the ability to support a wide range of databases such as MySQL, Oracle, ODBC and Ingres. This feature compliments the ability of PHP to extract data from a database. Typically PHP is used for the generation of 2D web pages. But with its ability to produce files with many MIME types, the VRML format can be sent over the Internet with suitable PHP scripts [14]. PHP can also be used to generate VRML scenes from data stored in a database and text files.

The development process involved two steps: 1) creating the 3D map and 2) building the tools. ViSC was utilized in the making of the 3D map. The creation of the 3D map involved preparing a set of coordinates (which were stored in a text file) and read into an array using PHP. The coordinates where then used to generate a VRML scene and position objects as specified by the coordinate points. Therefore, the map generated is a product of a template created using VRML and PHP. The advantage of creating a template, opposed to a static map, is that if map objects such as buildings and roads require alterations, additions or deletions, changing coordinate values in the text file would achieve this. Therefore, any-one who would like to customize the FWIS does not require extensive knowledge of VRML and PHP scripting. As well as map object dimensions and location, the color, transparency and texture of each map object can be altered from the text file. When using VRML and PHP in the same script, either VRML can be embedded into PHP or vice-versa. When generating VRML objects, the VRML code needs to be embedded into PHP code as shown in Figure 8. The code in Figure 8

.. code-block::

    echo '   geometry Extrusion {
    echo '      spine [';
    echo '         0 0 ' . $variable_spine . ', 0 0 0' ;
    echo '         ' . $variable_crossSection . ']
    echo '    }' ;
    echo '  }#end shape' ;

Figure 8

An sample of showing how to embed VRML in PHP.

8 demonstrates how the VRML values of fields ‘spine’ and ‘crossSection’ of the Extrusion node can be substituted by variables “$variable_spine” and “$variable_crossSection”. Within the Extrusion node, the ‘spine’ and ‘crossSection’ fields are used to set the height along the Y axis and the shape in the XZ plane respectively. The values to be substituted into variable places can be accessed from within the script. A method with greater efficiency is to use a database or a text file to store values. Therefore, the script above can be re-used for each object within the VRML world (refer to [15] for a technical review on generating VRML from a database).

---

1 MIME is the acronym for Multipurpose Internet Mail Extensions and is a specification for formatting non-ASCII messages so that they can be sent over the Internet [13]
In order to describe the processes involved in building each of the tools, a description of each of the tools will precede beginning with the Flood Warning tool.

**Flood Warning tool**
The Flood Warning tool is not an interactive tool but a tool that controls which ARI design event map should be displayed for a particular river height reading. It links the BoM river height readings that are tabulated and displayed on the BoM web site to a map of a particular ARI design event. The tool associates a numeric quantity (river height) to a visual representation. The map displayed is the visual interpretation of the numeric river height. PHP was used to make the Flood Warning tool.

**The Find Property tool**
The Find Property tool is a search tool that allows users to find properties on the map. Users are able to specify the property using an index or by typing the business name or street address into a text area. Once the property is specified, the view of the map changes so that the opted property dominates the viewing space. This tool is interactive and works with the map that the Flood Warning tool displays. Although VRML browsers are equipped with navigation controls, it is felt that the standard VRML browser controls are not user friendly. Therefore they have been disabled for the FWIS.

A Java applet has been used to make the Find Property tool. Therefore an External Authoring Interface (EAI) was required so that the Java applet can communicate with the VRML browser.

**The Safety Information tool**
The purpose of the Safety Information tool is to provide users with a way to access safety information and safety suggestions that are particular to different properties on the map. Access to the safety information is provided by standard map roll-overs where the cursor changes when a user has rolled over an anchored property. Clicking on the anchored property will display the safety information in the lower frame of the Internet browser. This information is accompanied by an image of the property, property description, property address and flood warning information (Figure 10). Although the FWIS has been designed as a template, FWIS emergency management operators are able to customize the system so that additional flood warning information may be added or removed from the table shown in Figure 10.

<table>
<thead>
<tr>
<th>Image</th>
<th>Description</th>
<th>Address</th>
<th>Warning</th>
<th>Safety suggestion</th>
<th>Suggested exit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myrtleford Hotel</td>
<td>59 Standish Street</td>
<td>There is a high risk that floodwaters will surround and possibly enter this property today. Low-speed waters can be expected. This property is in an area that can expect floodwaters of around 0.25 meters or less, above ground level.</td>
<td>Raise valuables and any potentially harmful solvents (including petrol, paint) to a level at least 0.5 meters above floor level. Sandbag the front and back entrances. For sandbags, contact the 'local' SES on (55) 55 55555.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Since the FWIS is aimed at public use, it is important that the interface be as user friendly. Also, during times of emergency, it is imperative that the public receive forecasts in a manner that is clear and direct. Therefore a key in the design of the two interactive tools is simplicity.

**TESTING THE PROTOTYPE**
The FWIS has been customized to the town of Myrtleford in northeast Victoria (Figure 9). Myrtleford is a town of around 3500 occupants and is frequently inundated. The most costly flood was in October of 1993 where major flooding caused urban property damages of around AUS$3.72 million and at least AUS$7.4 million to tobacco crops [16].

Thirty participants who are familiar with Myrtleford and have at least a basic level of experience with computers are testing the prototype. It is important that test
participants have some experience with computers because it is expected that real-life users who use the system will be those who are familiar with computers and basically ‘like’ computer use. Using test participants who are representative as possible of the intended users is a strong trait of usability testing [17]. The participants range in age and gender and most have reasonable map skills. As well as testing the usability of the FWIS, participants will be required to evaluate how useful of a tool the FWIS is for interpreting flood forecasts and communicating local flood warning and safety information. Therefore, it was preferred that the test population consists of people who are affected by flooding or at least know that the town they reside in is flood prone.

There are several phases to the test. During each phase participants are allowed to ask questions and are encouraged to criticize and comment on any aspect of the FWIS. Each phase is outlined below.

1. **Pre-phase introduction**
   The participant will be asked to describe what it is they see on the map. They will also be asked to indicate the direction of other towns and to locate the local supermarket as it is expected that in a town of 3,500 occupants, most people would have been to the supermarket. The participant will be guided with clues only if they are struggling. The pre-phase will provide information on how well the participants are able to orientate themselves within the map and if the level of map abstraction is adequate. To conclude the pre-phase introduction, the purpose of the FWIS and how to use it will be explained and demonstrated to participants. Participants will then have a few minutes to familiarize themselves with the FWIS.

2. **Phase 1**
   The purpose of phase 1 is to collect data on whether participants are aware of current flood warning dissemination modes that are in use – radio and fax. Participants will also be asked to listen to a simulated radio broadcast of a flood warning and read a simulated fax flood warning and interpret the message. Participants will be asked to specify if or how the town will be affected by flood waters and if their property will be affected by flood waters.

3. **Phase 2**
   The learnability of the system will be tested here by timing how long it takes participants to locate properties on the map and how long it takes them to access the flood warning information and safety suggestions for the located property. Participants will be asked to find six properties, one after the other. The time taken to find each property will give an indication of how quickly participants learn to use the FWIS.

4. **Phase 4**
   Participants will be asked to compare the 3D map to a 2D map and will be asked which they prefer. This will test whether the novelty of a 3D map attracts the participants’ attention more so than a standard 2D map. Participants will also be shown four different versions of the 3D map where each version varies in Geographical Dirtiness. They will be required to evaluate each version. This will provide data on whether a Geographical Dirtiness level of 2a is adequate for orientation within the map.

5. **Phase 5**
   Participants will be asked to complete a measurement of satisfaction questionnaire which will be followed by a short debriefing session.

**RESULTS**

The feedback from the satisfaction questionnaire indicates that 85% of participants would use the FWIS to access flood warning information. Although not all participants would use the FWIS if implemented, every participant would encourage others to use the FWIS. Reasons as to why some would encourage others to use the FWIS but not use it themselves includes:

- A lack of self-confidence when using the Internet;
- Having enough trust in community networks, local knowledge and personal experience not to need to refer to a secondary source of information.

Although the majority of participants stated that they would use the FWIS, 66% of participants preferred the 2D version of the map than the 3D version and 26% were undecided. Many appreciated the ability to show the water heights on the 3D map but felt more at ease with the familiarity of a 2D planimetric perspective.
The results of the Pre-phase through to Phase 4 are in the process of being analysed and will therefore not be included in this paper. If you wish to obtain a summary of all the results, please contact the authors after June of 2005.

DISCUSSION

ViSC allows dynamic information to be displayed and accessed from a computer with an Internet connection. In the case of the FWIS, ViSC is used to generate a map showing the forecast flood waters for a particular event. The advantage of the FWIS over other methods of dissemination is that users are shown a forecast of where the flood waters are expected to inundate. Users are able to use the FWIS to access warnings on a more local level and have more time to absorb the information. Even though the depicted flood extents are not exact representations of where the water will flow, a visual gives the public an idea of what the foreseen consequences are. Time is crucial before flood waters hit and therefore the flood warning message needs to be as clear as possible. Using a visual representation is a direct way to disseminate a message as the interpretation of an image showing the flood extents takes less time than an interpretation of a river height at a gauging station 20 kilometres upstream.

From an emergency management point of view, the FWIS is a tool that allows officials to distribute updated reports to many people by using minimal resources. Updates to both imagery and text information can be done so by one person uploading altered files to the server. Even though the amount of resources necessary to update the FWIS during heavy rainfall and periods of anticipated flooding is small, the initial set up of the FWIS can be quite time consuming. The FWIS is a template and map object are dynamically generated, but at this stage coordinates that define each object and all text information must be manually entered into the text file. Since the FWIS has been created as an open ended system using open source technologies, developing efficient ways to enter the initial map object characteristics are possible.

Although the Internet is not a common mode of accessing emergency flood warning information, it is a growing medium for communication. Between 1998 and 2003, the number of Australian households that used the Internet at home rose from 16% to 53% - a staggering increase of 37% over a period of 5 years [18]. There was a concern that people would not find the time to log onto the Internet when a flood warning had been issued. This is not so much an issue for areas where a lengthy lag time between the warning and the time of inundation exists providing that the public are reminded to visit the FWIS website. This concern is more prevalent during times of flash flooding which is a category of flooding that, at this stage, the FWIS is not applicable to. Although Australian workplaces, homes, schools and emergency services are ‘wired’ to send and receive information using the Internet, the concept of ubiquitous computing has the potential to improve upon inconveniences associated to having to sit in front of a computer to use the Internet. With ubiquitous computing, users do not need to think about carrying a computer at all [19]. Designers of ubiquitous systems envision seeding private and public places with sensors and transmitters. Once this is achieved, technology recedes into the background and users have services delivered to them, where needed and when needed.

ACKNOWLEDGMENTS

Thank you to: all test participants; Trevor Matthews, principal of The Myrtleford Secondary College; Debbie Goonan from The Myrtleford Town Library; Jonathan Wright from ABC Radio Wangaratta; Alan Baker from the Bureau of Meteorology; and Emergency Management Australia, the Alpine Shire, and the North East Catchment Management Authority for project support.

REFERENCES