DESIGNING GROUNDWATER VISUALIZATION INTERFACES

by

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ABSTRACT

Groundwater systems are inherently complex owing to their three-dimensional nature. The impacts of land use activities on groundwater quality and quantity, groundwater pumping, and the interaction of groundwater with surface waters are fundamental hydrogeologic concepts that require effective communication strategies. Using interactive visual interfaces may improve upon current educational techniques and encourage increased public participation in groundwater protection, conservation, and management. As part of a Canadian Water Network project, this research explores different methods of visualizing hydrogeologic concepts in order to identify interface variables that may improve public understanding of groundwater in the Okanagan Basin. Three groundwater education interfaces were designed and developed using Scalable Vector Graphics, Cellular Automata and principles from geovisualization and interface research. Interface development and empirical usability testing yielded results and observations that led to a set of geovisualization, interface design, and methodological recommendations that may help improve future public groundwater education interfaces.

Keywords: Geovisualization, Scalable Vector Graphics, SVG, Groundwater, Cellular Automata, Interaction Design, Interface Design, Canadian Water Network, CWN, Okanagan Basin

Subject Terms: Visualization, User Interfaces (Computer systems), Multimedia Cartography, Digital Mapping, Cellular Automata

DEDICATION

To my mother, who forced me go to my Trek interview rather than be a starter in a playoff basketball game.

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LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
CA	Cellular Automata
CABI	Cellular Automata Basin Interface
CSS	Cascading Style Sheets
CWN	Canadian Water Network
DGSFC	DRASTIC Groundwater Susceptibility Factors Comprehension
GIS	Geographical Information System
GOCAM	Groundwater OpenGL Cellular Automata Model
GSC	Geological Survey of Canada
HTML	HyperText Markup Language
HMD	Head Mounted Display
ICA	International Cartographic Association
IGW	Interactive Groundwater
NRCan	Natural Resources Canada
OB	Okanagan Basin
PC	Personal Computer
RGB	Red-Green-Blue
SFU	Simon Fraser University

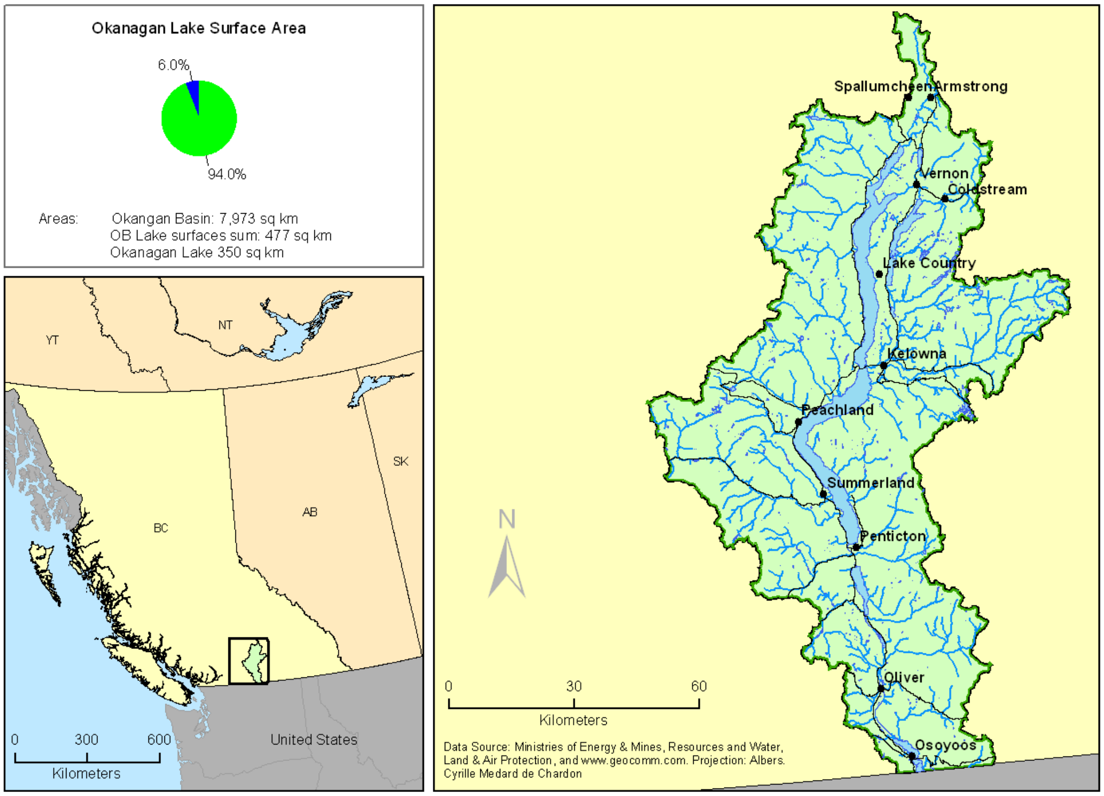
SGCN	Smart Growth Canada Network
SGOG	Smart Growth on the Ground
SIRN	Synergetic Inter-Representation Networks
SVG	Scalable Vector Graphics
W3C	World Wide Web Consortium
XML	Extensible Markup Language

CHAPTER 1: INTRODUCTION

1.1 Introduction

Water is a limited resource. In one of Canada's driest areas, the Okanagan Basin (OB) in south central British Columbia (Figure 1-1), overuse and contamination threatens its quantity and quality. Home to growing population and agricultural areas, available regulated water is in increasingly limited supply. The Canadian Water Network (CWN) project - “A Basin Approach to Groundwater Recharge in the Okanagan: Bridging the Gap between Science and Policy” under which this research was initiated was a basin-wide project spanning hydrogeologic data gathering, spatial modelling, pollution potential analysis, and the communication of hydrogeologic concepts. This CWN project aimed to gain further insight into surface and subsurface water in the OB and communicate findings to stakeholders.

Okanagan Basin



Data Source: Ministries of Energy & Mines, Resources and Water, Land & Air Protection, and www.geocomm.com. Projection: Albers. Cyrille Medard de Chardon

Figure 1-1: The Okanagan Basin, in south central British Columbia, has very visible and large water bodies.

Encouraging sustainable water use in the OB requires an understanding of the interplay of numerous social and political needs of the stakeholder groups involved. Communication is a key mechanism to facilitate dialogue and consensus-building between scientists, agriculturalists, regional planners, and many other parties. Stakeholders in this thesis refers to those who live, work, and holiday in the OB. Communicating to OB stakeholders how they divert, deplete, and contaminate surface and subsurface water within their basin is critical to the preservation and sustainability of this vital common resource. A number of conventional methods for communicating these concepts, which vary in complexity, have been used to date. Within the problem context of the OB's limited water supply, this thesis introduces several new interactive geovisualization interfaces and explores how it may be possible to improve stakeholder perception of groundwater by implementing those tools. Further it takes some initial steps to measure the ability of various non-conventional tools to communicate hydrogeologic processes using qualitative and quantitative empirical methods. This research perspective draws from several fields.

Geovisualization, a term coined by MacEachren (MacEachren and Taylor 1994), uses emerging technologies and an understanding of human cognition to display data spatially to, through induction, discover patterns, and formulate hypotheses. Since its introduction in 1994, the use of the term geovisualization has evolved to a broader meaning. The research field now represents the study of creating technologies to display data visually and interactively in novel ways for experts and non-experts alike, while considering human learning and interaction design to ease knowledge transfer. The discovery of knowledge can transition to action. The goal of the interfaces designed in this thesis work is for stakeholders to understand the target concepts and *apply* their knowledge.

This thesis approaches the OB research challenge by trying to determine how individuals are affected by variations in interface design from a constructivist perspective of learning. A constructivist theory of learning suggests that individuals learn by thinking about content in relation to past experiences and building connections and conclusions from it, rather than simply memorizing it (Jonassen 1994, 35). This research attempts to apply constructionist learning methodology, a subset of constructivism, to allow learning by the ‘building’ of knowledge (Phillips 1995). The tools built in this thesis allow users to interact directly with virtual models related to hydrogeologic data and concepts in the OB.

Since the formalization of geovisualization there have been many examples of 3D, dynamic, and interactive geographic interfaces designed for experts (Cartwright et al. 2001). However, during this time, little research acknowledged or engaged the question of how modes and mechanisms of interaction impact user perception and understanding of the geographic content being delivered for non-experts.

The literature in human-computer interaction (HCI) and education technology has demonstrated how various components of educational tools greatly affect how users will interact with content, whether it is in a passive manner such as a slideshow, or an interactive and constructionist manner (Lindgaard et al. 2005).

Interface design research focuses on the logic and modes of interaction that enable people to control and interact with content. Such interfaces may be tangible (buttons) and/or virtual (icons). While many different perspectives exist that propose broad guidelines for interaction design (Norman 1988; Moggridge 2007), every interface requires thoughtful design and empirical analysis to determine how individual interactions affect users in their learning or task completion experience. Interface design, a component of interaction design, focuses on the graphical, tactile, and auditory user experience of user interaction, while interaction design considers the overall experience.

Interface design is a simple process of planning interaction between a person and content. *Good* interface design, however, is a much harder task consisting of designing a process that achieves a goal while giving the interaction qualities that facilitate its use and understanding for the user (Moggridge 2007, XV). Interface design complexity is greater than the sum of its parts. Much like a car is controlled with relatively simple components consisting of steering wheel, brake, clutch, and accelerator, when combined they create a more complex driving experience.

In an effort to communicate to OB stakeholders their relationship with their water supply this thesis explores alternative ways of effectively communicating groundwater concepts via web-based graphical user interfaces (GUI) employing buttons, text, images, data input, and mouse controls. In particular, this research explores empirically how combinations and variations of interactive interface components, visual representation, feedback, frame of reference, animation, and interface size may be used to deliver and support improved stakeholder perception of hydrogeologic concepts and principles.

The advance of the personal computer (PC) has allowed more complex concepts to be communicated through new interactive means than through traditional paper and film media. Technologies which are becoming more accessible such as GeoWalls and Augmented Reality (Hedley et al. 2002; Shelton and Hedley 2003) allow viewing of 3D content in 3D, while modern PC monitors are constrained to displaying 3D content on a two dimensional (2D) surface. While these novel interface technologies exist, only a small percentage of the population has access to them and as such would not be suitable platforms for outreach to OB stakeholders. Desktop and laptop computers remain the lowest common denominator of computer/internet access to deliver multimedia experiences. Interfaces developed for this thesis are built to function on most PCs with internet browsers and modest performance requirements.

Several previous geovisualization tools aimed at similar topics for university courses and decision makers have been perceived as inaccessible by the general public due to cost or complexity (Slocum et al. 2003; Li & Liu 2004). The education tools created for this thesis were designed to communicate without being condescending to citizens or overwhelming due to complexity.

In other areas in North America where water scarcity is present stakeholders are playing a larger role in water management (Nyerges et al. 2006, 299-700; Cowie and O'Toole 1998). Stakeholders desire greater participation in decision making traditionally done by governmental organizations (Nyerges et al. 2006, 299), but it is also important that they understand the concepts which they voice opinions about. This research aims to explore geovisualization tools that may help citizens perceive and understand groundwater concepts thereby informing and empowering them. Furthermore, such tools may also help build consensus between stakeholders.

The educational tools constructed for this project focus on improving perception of hydrogeologic concepts and principals. Specifically, this thesis aims to determine how alterations to components of interaction, graphics, content, frame of reference, and feedback affect conceptual understanding and factual learning by stakeholders.

1.2 Research Objectives

This research aims to explore how variations of geovisualization interface variables may affect communication of 3D hydrogeologic concepts of phenomena present in the OB in an effort to improve the efficacy of educational tools. Using educational content from the CWN OB project, this thesis focuses on exploring new ways to communicate concepts that connect surface and subsurface water and stakeholder influences on them. To explore and compare which components of interface geovisualization tools affect conceptual and factual learning, multiple versions of the interface prototypes were made. Data were gathered through online and paper surveys including qualitative and quantitative measures of user background, interface performance, and conceptual change to provide explanatory context to the empirical data.

The thesis statement of this research is:

Variations in geovisualization interface design influence how stakeholders perceive volumetric hydrogeologic concepts.

In order to test this hypothesis the following steps were taken:

1. Three separate educational geovisualization interfaces that link to groundwater phenomena in the OB were designed and created based on existing public education tools.

2. Variations of the three interfaces were created in an attempt to determine the effects of interaction, content, representation, feedback, frame of reference, animation, and interface size to the learning process. A total of 13 interfaces were constructed in order to isolate individual factors between the different interface versions.
3. The 13 interfaces were planted in a testing framework to gather quantitative and qualitative data about users' abilities to perceive concepts, and externalize knowledge.
4. The gathered data were analyzed using conventional statistical methods as well as experimental geovisualization methods to try and identify and explain significant changes in user performance between interface versions.

By employing this methodology, this research aimed to discover how variations in interface design of these educational tools may have altered the communication of facts and concepts to stakeholders with a view to applying the resulting findings to the creation of guidelines for future outreach projects in the OB.

1.3 Canadian Water Network Okanagan Basin Case Study

1.3.1 Geographical Setting

The OB is an area of almost 8,000 square kilometres, located in south central British Columbia. Stretching 180 kilometres north from the Canada-US border, it is a semi-arid valley with a long deep lake and bench lands largely cultivated with vineyards and orchards. The OB is one of Canada's driest regions with most parts receiving 30 centimetres or less of annual precipitation (Northcote 1996).

The OB population has doubled over the last 30 years to 344,000 in 2007 (BCStats 2008). In addition to OB residents, the lakes and sunny climate attract over a million tourists each year (Northcote 1996). Both population and tourism are expected to continue growing. The low precipitation coupled with increased development and agriculture requires that water is managed efficiently. Okanagan Lake, which intersects the basin, covers 4.6 percent of the basin surface area. Lakes in the OB cover six percent of the total basin area. This may cause people to perceive an abundance of water. This is deceiving as only one to two metres (three to six feet) of Okanagan Lake's depth is replenished each year by streams (Turner et al. 2006). Overconsumption would decrease water levels impacting the environment, agriculture, tourism, and general sustainability of the area.

1.3.2 Okanagan Basin Water

Most surface water in the OB is already close to or fully allocated causing stakeholders searching for alternative water sources to consider groundwater, which is currently unregulated in British Columbia. The OB has a similar problem as Idaho, south east of the OB, where, "the impacts of groundwater pumping on surface water supplies have often been ignored because of the legal and technical difficulties that they invoke" (Nyerges et al. 2006, 700). As a result of the surface water shortage in the OB, there has been an increase in the number of wells drilled. In some areas these wells are being placed next to streams and lakes. This situation is cause for concern as there is potential for interaction between the groundwater and surface water bodies.

Okanagan citizens may have a good understanding of their impact on the availability and quality of surface water due to its direct and perhaps visual relationship. Subsurface water, however, is generally not well-understood. This is especially true in regards to interactions between surface and subsurface water. Current practices in the OB, such as placing wells next to rivers or lakes, suggests that water consumers largely view water availability in two dimensions across geographic space, rather than thinking of the surface as the ‘point of access’ of an inherently three dimensional resource. Communicating effectively the relationships between surface and subsurface water to stakeholders may hopefully improve their awareness and subsequent water management practices.

Some of the key issues faced by OB stakeholders have to do with land use choices and their underground consequences. The effects of large impervious surfaces, pesticide and fertilizer use, and cattle ranching are some examples. These phenomena all affect the soil and water below. Conventional static media such as posters and diagrams on websites are more limited to communicating these concepts compared to new multidimensional and interactive technologies. This research project provides a number of learning tools to OB stakeholders to communicate how they influence their limited water supply.

1.3.3 The Need for Communication in the Okanagan Basin

Groundwater is as equally susceptible to pollution from many small sources as it is from one larger agricultural or industrial site using fertilizers, pesticides, synthetic chemicals or other contaminants. For this reason effective prevention relies on all those interacting with an aquifer understanding their impacts on groundwater and its susceptibility to pollution. Public understanding of the phenomena may also give decision makers support when making land use change choices or passing legislation to protect and conserve groundwater. Water conservation requires attentiveness to the amounts of water being used, and to the prevention of water contamination. Contamination of water reduces supply necessitating greater resource efficiency and possibly the search of an alternate and, most likely, more expensive water source.

The significance of managing water resources has become an increasingly important social and political subject. Governments and municipalities are making an effort to educate the general public about how they affect water supply and quality. The creation of the CWN is one of these initiatives (Networks of Centres of Excellence 2007) with sub-projects engaging with many levels of government and universities. This thesis attempts to respond to the problems in the OB by investigating how new interactive and dynamic education software may improve conceptual and factual communication.

1.3.4 The Canadian Water Network Project

In an effort to encourage water supply sustainability, the CWN funded a project (Canadian Water Network 2004) to better understand the hydrogeology of

OB watershed and create informative tools for stakeholders such as decision-makers and educational groups. The project, “A Basin Approach to Groundwater Recharge in the Okanagan: Bridging the Gap between Science and Policy” was organized into four project sub-components aiming to understand groundwater recharge, enhance groundwater management strategies, create models of surface and subsurface interaction, and increase conceptual understanding of these processes by stakeholders in the area (Canadian Water Network 2004). Multiple subgroups within the project conducted hydrogeologic research in the OB. While three subgroups of the CWN project completed field and modeling research, this study was positioned within a fourth group exploring new ways to communicate the research results in an innovative and captivating manner (Canadian Water Network 2004).

This fourth project sub-component is responsible with providing “new ways to understand groundwater processes and recharge in the Okanagan Basin” through “compelling and informative educational outreach tools that may be demonstrated to stakeholders” (Canadian Water Network 2004). Stakeholders consist of decision-makers, residents, educational groups, and organizations such as the Smart Growth on the Ground (SGOG) team that was working in the Oliver region of the Okanagan watershed. While using the data provided by other researchers in the CWN project, this thesis project presents results in an innovative manner to stakeholders by using geovisualization principles on interactive platforms.

1.3.5 Current Educational methods in the Okanagan Basin

Currently in the OB there are various outreach methods communicating how OB stakeholders interact with surface and subsurface water in their communities. The Geological Survey of Canada (GSC), part of the Earth Sciences Sector of Natural Resources Canada (NRCan), officially released the ‘Okanagan Basin Waterscape’ poster in 2007 that addressed a variety of water issues specific to the OB (Turner et al. 2006). SGOG, a collaborative program to develop sustainable communities, organized charrettes to guide growth in the Town of Greater Oliver, communicate sustainable practices and bring consensus about which direction the town wants to grow in the future. The Smart Growth Canada Network, an SGOG affiliate, also created a series of online courses (www.smartgrowth.ca) similar to PowerPoint presentations that explain factors that allow for sustainable growth. Of these public communication initiatives, only the development of the Waterscape poster and the charrettes were interactive. Direct human interaction can be a powerful mode of communication and learning, but, unlike posters, charrettes are not a viable means of reaching the masses.

Caution is required in implementing web and desktop interfaces as communication platforms. Web and desktop interfaces may alienate those who do not use them or prefer traditional mediums such as paper or video. An interactive communication tool may not be what certain stakeholders enjoy or can easily comprehend. The tools built in this thesis target stakeholders who feel comfortable using computers, mainly the emerging generation of OB citizens.

In conclusion, the OB is a valley of what appears to be an abundance of water, yet is one of Canada’s driest locations. With expected growth and increased water demand it would be beneficial for more of the population to understand their relationship and impacts with surface and subsurface water. This thesis aims to create effective communication tools that can be used by a wide audience of OB stakeholders to more easily comprehend their bond to their water supply.

1.4 Thesis Overview

Following this introduction, the literature review (Chapter 2) identifies the research fields on which this project is based. This leads to a comprehensive specification of the conceptual framework and research question. The methods section (Chapter 3) describes the development of three different education tools, and 13 variations derived from these. Chapter 3 also explains the survey design and rationale. Chapter 4 (Analysis and Results) describes multiple methods of analysis of the data gathered from testing of each educational tool. A traditional statistical analysis of quantitative results was performed, as well as an analysis of qualitative observations. A new visual analysis technique was also devised combining user interaction behaviour data with geovisualization techniques. This is followed by a discussion of the results and methodological and interface specific recommendations in Chapter 5. The conclusion (Chapter 6) covers contributions the research has made to the CWN project as well as the body of literature, and finally the future directions of this work.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Approaches employed to date to help OB stakeholders characterize groundwater phenomena rely on the media and conventional public service announcements, such as the Waterscape poster. Some of the means used within the OB to communicate groundwater concepts consist of websites containing text and diagrams (www.obwb.ca, moodleserv.com/smartgrowthca/), posters (Turner et al. 2006), a symposium (Penticton BC, January 23, 2007), and books. Most of these communication means rely on 2D diagrams and text. How well these forms of outreach effectively communicate the required concepts is undetermined.

Groundwater flow, it's susceptibility to contaminants, and its interaction with surface water are complex and multidimensional phenomena that may be hard to communicate through traditional media, however, they are far from ineffective. The dimensionality of the phenomena may be more easily communicated using multiple dimensions of visualization and interaction. New multimedia systems as educational tools can more effectively communicate hydrogeologic concepts to users by allowing them more freedom to interact, explore at their pace, and follow their train of thought in order to make sense of the dimensions and complexity. Multimedia systems allow stakeholders to supplement their understanding of the phenomenon and apply it in new or everyday situations.

This thesis research aims to determine whether variations in interface design influence how stakeholders perceive volumetric hydrogeologic concepts. The literature guiding interface design draws from many distinct fields. Geovisualization, an approach to interface design, focuses on the idea of maximizing and facilitating communication of spatial concepts through modern technologies (MacEachren and Kraak 2001). Geovisualization draws from the fields of representation, interfaces, knowledge discovery, and cognition and usability. This research aims to apply geovisualization design recommendations and technologies to the creation of educational tools focusing on groundwater concepts.

This chapter introduces the conceptual framework underlying this research. It begins with a review of the subfields of geovisualization defined by MacEachren and Kraak (2001) that help distinguish individual yet heavily intertwined concepts. The chapter also provides a review of past projects and what can be learnt from them in order to guide this project. Past projects that use similar educational concepts can reveal common pitfalls and best practices for interface design and development. An analysis of these projects helps determine where they succeed and fail at their task and also establishes which principals are appropriate and transferable to this research project.

The end of this chapter briefly discusses the idea of Knowledge Transfer, the task of communicating academic work to stakeholders. Academic work from within universities and other research institutes is largely not communicated to the public despite research findings which may have impacts on stakeholders.

This research is well positioned within the discussion of knowledge transfer at the individual level while being accessible to the masses through the internet.

2.2 Geographic Visualization

Geovisualization, coined by MacEachren (1994), has been an ambiguous term that evolved from its original meaning of a strictly interactive scientific research to a more general meaning of exploring data with learning and facilitation of communication in mind (Kraak and Ormeling 2002). In 2001 the International Cartographic Association (ICA) Special Commission on Geovisualization met to publish a description of the core subdisciplines of geovisualization in a white paper (MacEachren and Kraak 2001). The commission identified four intertwined main themes of geovisualization: Representation, Knowledge Discovery, Interfaces and Cognition/Usability. These will provide a structure for the following review of geovisualization literature.

2.2.1 Representation

It is important to question what types of representation and interactivity are effective, if at all (Fairbairn 2001). *Visual* representation is the most common in applications. Audible and haptic (sense of touch) representations are among other techniques that are rarely applied. This thesis focuses only on visual representation and refers to this when using the term representation.

Coding

Visual representations vary from iconic symbols, text, diagrams, photographs, and virtual environments, to name a few. Symbols are codes, and therefore need to be decoded before the content containing these symbols can be understood. Most symbols in human daily lives are learnt over years. Symbols can be highly context and place specific. Colours, shapes, and symbols can have very different meanings in other regions and context. The symbols used when creating content of international or even national exposure must be considered carefully for people to have an equal understanding of the representation throughout the whole region. This has important implications for defining the target user group. Text is obviously also heavily coded. Just as different languages are used in different regions, so are different symbols.

The representations of features in the programs created for this thesis are designed to be decoded mainly by people within British Columbia. While this may seem like a narrow target group, the base knowledge expected for the concepts communicated may be sufficiently different for an area not much farther than the west coast to cause complications.

Graphics

In their 2002 analysis of graphics and animation, Tversky et al. (2002, 248) explain that “simple graphics with less detail are often more effective than more realistic ones … provided that they abstract the essential conceptual information.” In addition, diagrams allow the representation of hidden or invisible concepts that photographs of reality cannot. The best photography can do to communicate concepts such as groundwater is show *symptoms* of it, such as well springs, while graphics can “promote inference and discovery by making the underlying structures and processes transparent” (Tversky et al. 2002, 248). In the OB context an abstract representation of reality may be more effective to show how groundwater functions. This can be seen by the frequency of diagram use in Groundwater textbooks (Freeze and Cherry 1979; Todd and Mays 2004; Fritts 2002; Schwartz and Zhang 2002). While non-photorealistic, simplified, and abstract diagrams may communicate concepts effectively (Lindgaard et al. 2005, 220; Dollner 2006, 238) graphics are not always best in every situation. Sometimes text can be equally powerful (Tversky et al. 2002, 248-250).

The abstraction and simplification of real world phenomena oppose the constructivist guidelines of not oversimplifying complex systems and showing real world examples (Jonassen 1994). The aforementioned examples are presented in instructionist mediums such as books, posters (Turner et al. 2006), and static graphics. The opposition lies between instructionist and constructivist teaching methods. Textbooks cannot communicate in the same manner as educational software; textbooks have constraints requiring simplification. Educational software also has constraints preventing it from matching real world experiences. While educational interfaces have reduced complexity they allow reification and can provide multiple representations in a learning environment. Virtual learning environments can facilitate constructive learning (Jonassen 1994).

Virtual Environments

Virtual Environments have become more popular and ubiquitous since Howard Rheingold’s (1991) ‘Virtual Reality’ book revealed a largely fringe world of virtual communities meeting in virtual environments. Consensus on defining virtual environments has become increasingly difficult. Roberts (2005, 233) defines a virtual environment as “a real world metaphor, including two- and three-dimension’s, and with all levels of immersion.” While Slocum et al. (2003, 233) consider virtual environments “3-D computer-based simulation[s] of a real or imagined environment that users are able to navigate through and interact with.” The range of what can be called a virtual environment spans from very abstract diagrams with little immersion to extremely photorealistic 3D models with complex interaction.

Graphic Dimensions

While it is tempting to believe that 3D graphics are more effective and enjoyable “it is not clear if they improve performance, speed of learning, accuracy or memory” (Lindgaard et al. 2005, 220). Depending on the task, 2D may be more efficient than 3D, or 3D more than 2D, and in some cases, to the same extent. For example, too many dimensions of freedom can cause disorientation and allow too much exploration outside the target concept area, while too little freedom can frustrate learners by constraining them from reaching the information they desire or forcing them to guess the contents of the additional dimension. Regardless, graphics may motivate the learner to explore the content and discover new ideas (Lindgaard et al. 2005, 220). Three dimensional representation may be more novel and therefore more motivating to use, but depending on the task, may not be the most efficient learning method. Hydrogeologic concepts in the OB area are 3D in nature. Creating effective learning tools for OB stakeholders will require striking a balance between the dimensionality of representation and controls.

Whether 2D or 3D content is communicated, the public will most likely view it using a 2D display device. While a large variety of 3D viewing devices exist that allow 3D content to be viewed in real 3D, only few people have access to these devices. It is also, as Tversky et al. (2002, 250) noted, “simply not clear if 3D displays improve performance, speed, accuracy, or memory for data”. They explain that for certain tasks 3D and 2D visualization are comparable in memory tasks, while in others, such as estimation, 3D is less effective. Even though users may not have access to 3D displays, 3D content projected in 2D on a monitor may still be comprehended as 3D. Rotated 2D content allows the brain to create a 3D cognitive representation of the object or terrain (Proffitt and Kaiser 1991, 52) due to “the characteristics of the human perception to reconstruct genuinely 3D scenes from 2D retinal projections” (Demsar 2005, 39-40). This means that designing 3D models for OB stakeholders who are expected to have 2D displays is a worthwhile exercise.

Animation

Representations that change over time are called animations. Lindgaard (2005, 219) describes animations as “graphic structures that convey spatial and temporal pictures which change during presentation.” The line between what is an animation and an interactive animation in the literature is fuzzy. Whether a start/pause button to control an animation or brushing through time is considered an interactive animation is debated. In this thesis all animation that contain some interaction are considered interactive animations. An animation must start and stop, or loop beyond the control of the user.

Many experiments attempting to empirically show that animations are superior communicative tools to images are open to attacks due to the added content presented in the animated versions (Tversky et al. 2002). Many studies have shown little difference between animation and static maps (Slocum et al. 2005, 386). In question is not only whether animations are effective but also for whom. Studies are still contradictory in regards to whether multimedia content is more beneficial for low or high knowledge/ability students (Lindgaard et al. 2005, 221-2) or experts (Slocum et al. 2005, 379). Many proponents believe graphics "benefit comprehension and learning, and foster insight" (Tversky et al. 2002, 247-248). This may be due to graphics being "aesthetically appealing or humorous, [or] attracting attention and maintaining motivation" (Tversky et al. 2002, 248).

In their 2002 work, Tversky et al. analyze many different publications stating animations superior to graphics. They systematically break down the studies to show inequalities between animation and graphics. In their view animation cannot be considered superior to graphics because they are unequal. Animations have the advantage of micro steps showing a continuous process, while graphics show stages of a process. Animations are useful to "provide a sense of change over time" (Slocum et al. 2005, 396) as states Tverky et al.'s congruence principle:

> “The content and format of the graphic should correspond to the content and format of the concepts to be conveyed. From this, it follows that animated graphics should be effective in portraying change over time.” (Tversky et al. 2002, 247)

According to the congruence principle, interfaces communicating 3D hydrogeologic concepts should use time to show changes in groundwater flow and multiple dimensions to show the 3D nature of the phenomena.

Animations have advantages over static graphics, but also limitations. They can inspire, improve, and ease learning but learners may “treat the material more superficially” than it deserves (Lindgaard et al. 2005, 221). Animations take a set amount of time to experience and as a result have a greater cost than a diagram (Tversky et al. 2002, 255). The strengths and weaknesses of animations are still contested. Koussoulakou and Kraak (2002) find animated maps can be “processed significantly faster than static” small multiple maps (Slocum et al. 2005, 386). Either way animations may not be “universally preferred” (Tversky et al. 2002, 255).

Complexity in animations can challenge the correct translation of the target concepts (Tversky et al. 2002, 251). Often “animations are too complex or too fast to be accurately perceived” (Tversky et al. 2002, 247). Animations have inadequacies including users having to watch portions of an animation that they already know or understand, the fixed speed of the animation, the inability to review portions, rewind, or pause. Tversky et al.’s (2002, 258) Apprehension Principle provides good design guidelines to avoid cognitively taxing animations:

> “To accord with the Principle of Apprehension, animations must be slow and clear enough for observers to perceive movements,

> changes, and their timing, and to understand the changes in relations between the parts and the sequence of events. This means that animations should lean toward the schematic and away from the realistic, an inclination that does not come naturally to many programmers, who delight in graphic richness and realism. It also may mean annotation, using arrows or highlighting or other devices to direct attention to the critical changes and relations. Schematizing is simpler than it sounds; clear understanding is a prerequisite to including only the information essential to the processes to be conveyed and eliminating extraneous but sometimes appealing information." (Tversky et al. 2002, 258)

Simplicity and clarity are often forgotten in order to package as many concepts as possible within an animation. To alleviate the complexities and drawbacks of animations, interactivity may resolve some of the problems and build on its strengths (Tversky et al. 2002, 258). In the context of the OB educational tools this means that content should be limited and offloaded to the interaction to constrain how many concepts are present at once.

There are large varieties and levels of representation that must be considered to communicate the target content in the most efficient and clear manner. There are endless varieties in the type, style, and content of animations that may be successful in one combination but not another. Focusing on simplicity and using abstract diagrams can provide better results. When designing interfaces regarding groundwater concepts for OB stakeholders testing of multiple versions with representation variations is necessary in an attempt to define which style is best.

2.2.2 Interfaces

Interfaces are virtual or physical feedback mechanisms that allow interaction. The term *interface* refers to a system used to "transfer signals across human and machine boundaries” serving as “a means to an end, and not the end itself” (Furness 2003, 6). Interfaces are tools for accessing and interacting with data. They return feedback or noticeable change due to an action. Interfaces consist of the physical “means of accessing … parameters” through a mouse, keyboard, vocal commands, and/or display device and the interactions possible using the physical controls (Zeltzer 1992). While Microsoft Word, for example, may be considered an interface, there are in fact many layers of interfaces, physical and virtual, between the user and the virtual document.

Metaphors

Microsoft Word requires the use of two interface types, physical and virtual. The physical interfaces consist of the mouse, keyboard, and display device. The virtual interface components are Microsoft Windows and Microsoft Word. The virtual interface layers may each use different metaphors. Operating systems, such as Microsoft Windows and Apple’s OS X, commonly use a desktop and window metaphor containing icons and menus. The desktop metaphor containing file and folder icons transfers the expected physical affordances and behaviour to the virtual desktop. Using this metaphor, icons representing files, folders, or data can be arranged, placed in cabinets or other folders, or placed in the garbage bin. Other programs/interfaces embedded on the platform contain other varied metaphors.

Knowledge or familiarity with interfaces can enhance their transparency, as can good design.

> “Certain kinds of interactive techniques promote an experience of being in direct contact with the data. Rutkowski (1982) calls it the principle of transparency; when transparency is achieved, ‘the user is able to apply intellect directly to the task; the tool itself seems to disappear.’” (Ware 2004, 245)

Interfaces can allow a direct conduit of information between the content and the user. There are however many ‘layers’ of interfaces between the content and user that may use a different metaphor set. In the example of an online word processor, the user may be running the program through an internet browser, such as Firefox or Internet Explorer, using OS X or Windows, using a desktop PC or laptop, in a lecture or at home, while bringing all their past experiences to bear on how they will use and interpret its contents. When certain interface layers are unfamiliar or difficult to use they become filters that dampen communication and productivity. There are numerous variations in interface layers between online content and the user (Figure 2-1 below).

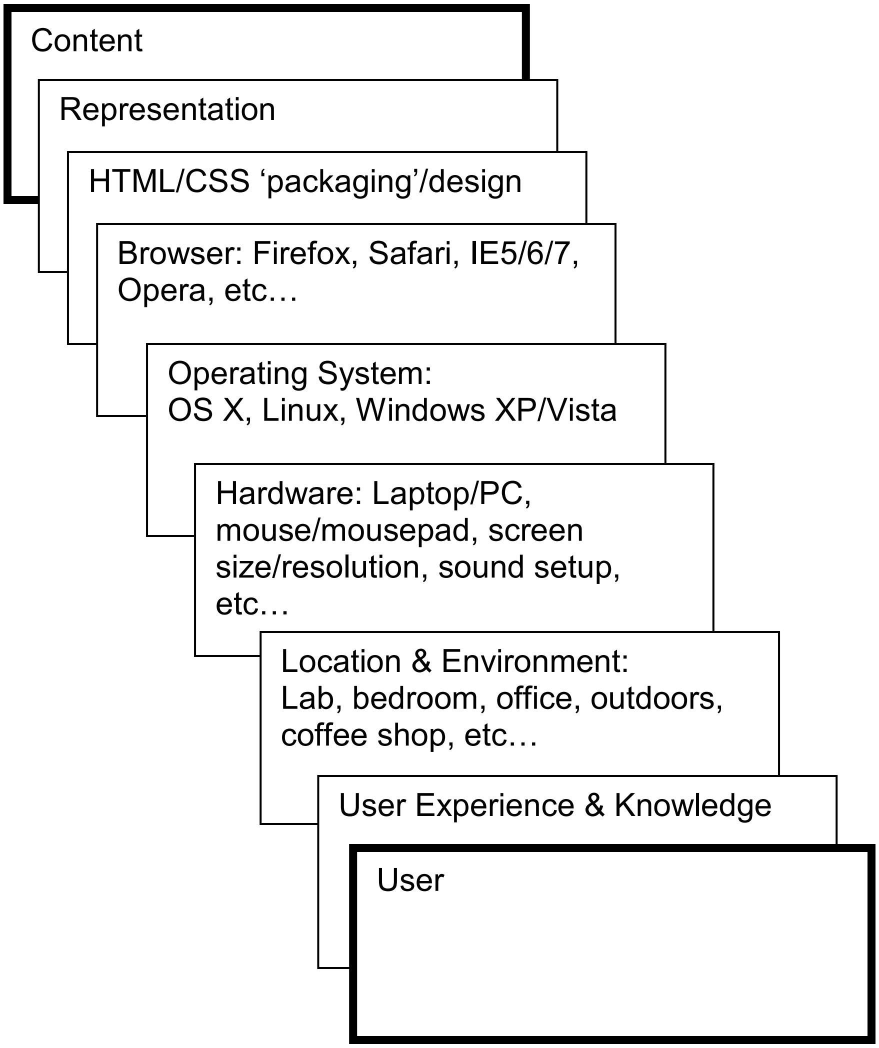


Figure 2-1: Examples of interface layers of between the user and content.

A good user experience is dependent on each layer of interface allowing the user to reach the embedded content with minimal distraction and allowing the user to immerse themselves in the content. A “well designed human-machine interface” provides “efficient and effortless flow of information between the device and its human operator” (Ellis 1996, 12).

In regards to creating an educational tool for the OB project, choosing a platform the users most likely are familiar with lessens the filter effect and allows easier access to the message. Since the users' experience with the educational tool is most likely short, there is not much time to communicate a new set of operational rules.

Immersion & Interaction

Immersion, the feeling of being so focused on something that it decreases awareness of physical surroundings, can be caused by visual as well as mental or emotional stimulation (Robertson et al. 1997, 12). Immersion is important in keeping the users interested in the content presented. Interfaces with feedback through multiple representation types commonly increase immersion by implicit reinforcement of actions/inputs (Furness 2003). Using the senses of vision and hearing, which people are most aware of (Ellis 1996), may also increase immersion. An extreme form of immersion is called presence. Novel interfaces that provide multiple forms of inputs force the user to concentrate on a broad spectrum of sensory stimuli causing “a heightened sense of presence [that] would facilitate performance” (Fontaine 1992). Keeping OB stakeholders immersed will depends on visual stimulation since the interfaces are deployed using the internet. While this may not foster the sense of presence described by Fontaine (1992), the visuals and narrative may immerse them enough to complete the exercise and gain an understanding of the target concepts.

Interaction, which can encourage immersion but is not required, is an important element of geospatial interfaces and their use. Tversky et al. (2002)

believe that interaction alone benefits learners. Koussaoulakou and Kraak (1992) agree, stating that interaction can give better results than animations alone. Overall “interactivity with … learning material generally improves learning” (Lindgaard et al. 2005, 220). There is however “accumulating evidence suggest[ing] that the key to learning lies in immersion rather than in mere interaction with the lesson material” (Lindgaard et al. 2005, 223). Work by Winn et al. (2002, 502) supports that head mounted display (HMD) immersive virtual environments are worth while, yet only when “the content to learn is complex, three-dimensional and dynamic, and when the student does not need to communicate with ‘the outside’ while working”. In the context of the OB project, using HMDs to enable virtual reality is not an option for large-scale knowledge transfer. But immersive virtual environments need not rely on HMDs to still be immersive (Robertson et al. 1997, 12).

An interface is an extremely vague term. Whether it is physical or virtual (hardware and software) or both, it needs to be designed with many concepts in mind. Geovisualization interfaces must consider representation, human cognition, usability, and ultimately the user it is destined for in order for it to facilitate knowledge discovery (MacEachren and Kraak 2001). Crampton Smith (Moggridge 2007, XV) defines good interaction design from an applied perspective as having a clear mental model, reassuring feedback, navigability, consistency, and intuitive interaction. The many perspectives on interface design follow different approaches but ultimately the same goal – to facilitate the transmission of a message. This research project explores various interface interaction types in an effort to determine which may be the most effective to communicate groundwater concepts to OB stakeholders.

2.2.3 Knowledge Discovery

Following the constructivist theory of learning, the goal of this project is to create an environment where users of learning tools focusing on issues relevant to the OB can hypothesize and draw their own conclusions from the information and interaction presented to them. Knowledge discovery within geovisualization is the creation of a hypothesis from *seeing* or *detecting* a spatial pattern within the data projected to the user. This is the fundamental goal of MacEachren's original definition of geovisualization (1994). Human visual pattern recognition combined with cognitive abilities is a powerful tool to make a hypothesis (Gahegan et al. 2001).

In the example of the OB, knowledge discovery may include the Greater Oliver stakeholders discovering how surface and subsurface water interact or how fertilizers affect groundwater quality. How easily knowledge discovery occurs is dependent on representation, interfaces, and cognition/usability. Knowledge discovery is not necessarily a global discovery of unknown knowledge. It can simply be some common knowledge that an individual has yet to understand in their own way. Knowledge discovery can be achieved through knowledge construction. How knowledge is learnt can dramatically alter the form and quality of that knowledge. According to constructivist Jonassen (1994), knowledge construction can be eased through learning environments that:

1. Have multiple representations;
2. Do not oversimplify complex systems;
3. Help build knowledge rather than memorize facts;
4. Are based on real world cases;
5. Encourage questioning of evidence;
6. Communicate the situations that the phenomenon exists in;
7. Encourage group learning that fosters positive discussion.

The difference between knowledge construction and discovery are few. Knowledge discovery refers mainly to finding knowledge largely unknown, while knowledge construction refers to communicating knowledge published in textbooks and such in an alternate manner. Knowledge construction focuses on real world cases and concepts, while knowledge discovery explores patterns within data about the real world. Both however rely on interfaces containing beneficial representations and which are created with an understanding of interaction design and human cognition.

2.2.4 Cognition & Usability

Developing a geovisualization interface requires an understanding of how data representations and interaction may be interpreted and internalized by users. These variations may alter conceptual understanding. An understanding of cognition and usability will provide guidelines regarding which representation types and interactions are most successful at communicating concepts. It is critical that groundwater processes be understood correctly by the OB stakeholders when using the interfaces. Incidental or unintended learning can occur (Lindgaard et al. 2005, 222) that is typically not measured or checked for accuracy by typical testing methodology. MacEachren and Kraak (2001, 7) state:

> “A fundamental problem for geovisualization is to understand (and take advantage of) the mechanism by which the dynamic, external visual representations offered by geovisualization serve as prompts for creation and use of mental representations.”

Consideration of cognition literature may help better understand what is required to facilitate the creation of mental models of the hydrogeologic concepts in the OB. This section discusses cognition and usability. Cognition refers to the process of learning, or understanding. Cognition needs to be understood so it may be applied through the creation of usability guidelines.

Cognition

Humans process only a miniscule amount of the information that is constantly streaming through their senses (Lindgaard et al. 2005, 213). Cognition or learning is a three step process of selecting material, organizing it, and integrating it with existing knowledge (Mayer and Moreno 2003; Lindgaard et al. 2005, 216). Although “it is not clear exactly how sensory information is processed,” (Lindgaard et al. 2005, 214) there are various theories (Mayer and Moreno 2003, 44).

How “sensory codes are stored” is disputed (Lindgaard et al. 2005, 215). Pylyshyn (1981) argues that representations are “built from basic linguistic propositions” (Lindgaard et al. 2005, 215), while the mainstream literature backed by Kosslyn (1994) suggests that visual representations are stored in the brain as images. Pylyshyn believes that brains only mimic reality giving the impression of images (Peterson 1994: 34-35). Paivio (1986) spearheads the camp believing sensory codes are “verbal and visual” with his book ‘Mental Representations: A Dual Coding Approach’.

Mayer and Moreno (2003) present a model of how the mind learns multimedia information (Figure 2-2) based on dual coding. The learning process begins with sensory memory observing multimedia content and selecting words and images from it into working memory. While visualization content allows some cognition to be offloaded on perception, a lot of cognitive power is still needed to absorb and digest new information. Once in working memory, sounds and images organize into verbal and pictorial models, respectively. These models finally integrate with long-term memory prior knowledge.

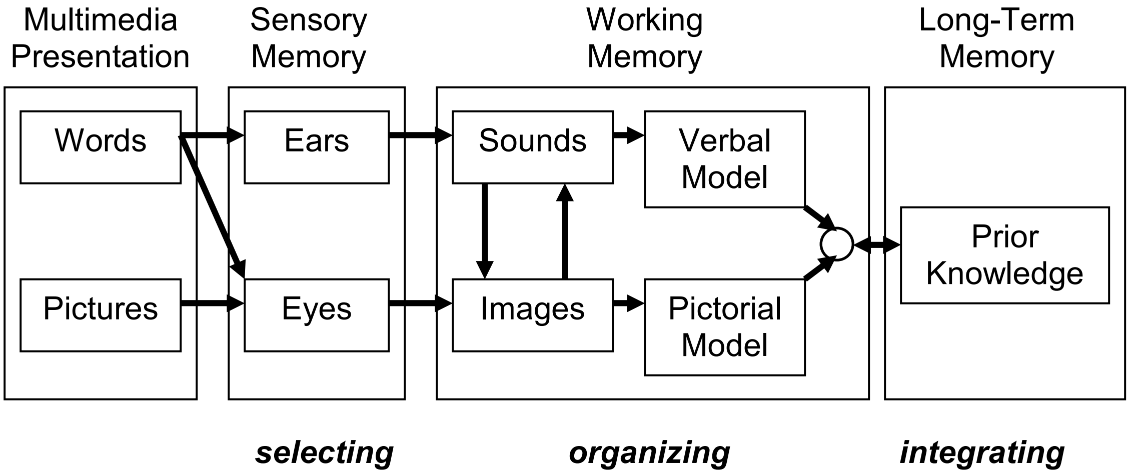


Figure 2-2: Mayer and Moreno’s (2003) cognitive model of learning (based on Mayer and Moreno 2003).

Learning is a continual process of internalizing new experiences with the previous. The final step in Mayer and Moreno's (2003) model focuses on the integration of long-term knowledge with newly gained knowledge. The continual "self-organizing" of prior knowledge with the new may be understood through synergetic inter-representation networks (SIRN) (Portugali 2002; Haken 1983; Haken and Portugali 1996). SIRN "is an approach to cognition [which] propos[es] that many cognitive processes, cognitive mapping included, are the product of a synergistic self-organizing network composed of interacting internal and external representations" (Portugali 2002, 428; Haken and Portugali 1996). How information is interpreted and understood by users can help refine interfaces to communicate a more accurate message. Mayer and Moreno's (2003) model is particularly useful in explaining why cognitive overload, in the form of overstimulation of information, can occur in the process of selecting, organizing, and integrating information. This project uses this cognitive model in the design of educational tools for OB stakeholders.

Further, this research also draws on a constructivist learning model for its conceptual framework. There is some discussion as to the definition of constructivism (Phillips 1995). This project uses the definition that constructivist learning is the building and structuring of knowledge through primary and secondary learning. Primary learning is the first hand experience of, for example, seeing a spring at the base of a slope, while secondary learning is reading about why and how this occurs. Both are valid and useful methods that help construct a better mental model of the spring as a concept. Constructionism, a subset of constructivism, emphasizes primary learning through doing, building or assembling physical or virtual objects. A constructionist example of learning about how springs occur would require placing tracers, cutting into the slope or creating models to provide a hands-on experience. Papert and Harel (1991) believe this provides a more complete understanding.

Some processes, such as groundwater recharge or groundwater interaction with surface water, are commonly taught through secondary learning due to their inaccessibility. Reification of groundwater processes through virtual environments allows a constructionist way of learning for OB stakeholders.

How representation, animation, virtual environments, interfaces, immersion, and interaction are designed is based on a the adoption of a cognitive model by the interface developer. Past literature, which applied an understanding of human cognition to interface design, has defined a series of best practices to facilitate the creation of cognitive models through usability guidelines, but many research challenges still exist in regards to emerging technologies (Slocum et al. 2001).

Usability and Interface Use

It is possible to establish guidelines for interface designs that facilitate learning by drawing on the understanding of human learning. Usability guidelines will help provide early design prototypes of learning tools for OB stakeholders. Regardless of what usability principals are applied, users “bring their previous experiences to bear in learning or understanding how to use [a] system” (Lindgaard et al. 2005, 255). For this reason it is a good idea to model your system to function similarly to other familiar systems (e.g., Microsoft Windows, Internet Explorer, etc…). Another hurdle Lingaard et al. (2005, 255) mention is that users will “assign a meaning or interpretation to a wide variety of inputs, regardless of whether that meaning or interpretation was intended by the designers.” These factors vary between users. The goal is to design an interface that guides the user towards learning the content in the easiest (least cognitively taxing) and most accurate manner.

Designing an interface that has a short use time also means it must have an even shorter learning time. A simple interface should not and cannot have complexity in interaction unless it mimics a well-know similar system or metaphor.

> “A violin has an extraordinarily difficult user interface, and to reach virtuosity may take thousands of hours, but once virtuosity is achieved, the instrument will have become a transparent medium of expression. This highlights a thorny problem in the development of novel interfaces. It is very easy for the designer to become focused on the problem of making an interface that can be used rapidly by the novice, but it is much more difficult to research designs for the expert. It is almost impossible to carry out experiments on expert use of radical new interfaces for the simple reason that no one will ever spend enough time on a research prototype to become truly skilled.” (Ware 2004, 350)

In this project, thankfully the tools built for OB stakeholders have the goal of the controls being mastered in minutes if not seconds by novices.

When users are faced with a new interface their first task is to understand what they are looking at and how it can be interacted with. The interactions possible with an interface are called its *actual* affordances. Gibson (1979) posits that humans view their surroundings as sets of possible interactions. He coined the term affordances to refer to what interactions are perceived as being possible. Affordances in a similar setting differ between people based on their own physical properties, knowledge, history, etc. What a small child may perceive as a table may afford seating for an adult. Norman (1988) further distinguishes affordances between those that are possible and those that are perceived. Ideally they should be the same set but rarely are. Microsoft Word is a good example of grossly disproportionate possible affordances to those perceived. Past user experiences alters interface use due to what affordances are perceived. If a user has moderate computer experience then ‘hot buttons’, which are buttons that change their representation noticeably when a mouse curser hovers over them, will implicitly communicate that the item can be clicked on, while to a novice user this may be meaningless.

Ultimately an interface is trying to communicate a target concept to the user, but an interface also contains an operational conceptual model determining how it is used. An interface contains two conceptual models, the way the interface functions, that is, what interactions will provide what feedback, and of the content, groundwater pumping or groundwater recharge concepts, for example. The goal is to make the interface as transparent as possible so that the user can concentrate on developing the more complex conceptual model of the content presented. Interfaces are to be designed to become transparent so as “to be easy to use, and to fade into the background” (Clark 2003, 44). Designing an interface to be transparent “involves supporting eye-hand coordination, using well-chosen interaction metaphors, and providing rapid and consistent feedback”

(Ware 2004, 349). Transparency, which allows cognition to focus on the content, is achieved by good usability design.

An interface becomes transparent when "a *natural* relationship or *natural mapping* between the control and its function" (Norman 1988, 27) occurs. A natural relationship for interface use can be facilitated by making things visible, providing feedback, making affordances perceivable, constraining incorrect use, and providing natural mapping (Norman 1988). A rudimentary interface with good usability may be more effective at allowing spatial cognition than a complex one with poor usability. In the case of OB stakeholders an interface that is hard to operate will probably quickly be abandoned, while a simpler well crafted interface with perhaps a smaller message may actually communicate more. The goal is to make the interface invisible after little use. If an interface attracts attention, "How do I do this? What do I do next?", it breaks focus and interrupts learning.

> "When a user must stop thinking about the task at hand and switch attention to the computer interface itself, the effect can be devastating to the thought process. The result can be the loss of all or most of the cognitive context that has been set up to solve the real task." (Ware 2004, 350)

Interface usability eases learning. Therefore making the interface transparent and intuitive helps ease learning. The goal of interface design is to have the user "concentrate on the content, not the interface" (Lindgaard et al. 2005, 217). Convincing OB stakeholders to try to use educational interfaces may be difficult – they cannot be welcomed with a cryptic or confounding interface. The operational interaction model for interfaces for OB stakeholders must be quickly learnt so that it may become transparent and facilitate learning of the more important groundwater concepts.

Geovisualization consists of many factors that are heavily intertwined. The goal of geovisualization is knowledge discovery. This is best facilitated through an easily usable interface. The creation of such an interface requires implementing usability and representation guidelines established from cognition research on interaction design and representation. This is an iterative process always requiring more testing to understand how variations in interaction design and representation alter learning.

2.3 A Survey of Volumetric Visualization Interfaces

Research tools commonly provide a framework to study a wide variety of data sets input into the system rather than being built strictly to view a fixed data set. Educational tools do not usually require this versatility since a focus or case study is already chosen from which context and narrative are drawn from. The following section looks at three existing educational and scientific tools created to communicate volumetric concepts such as hydrogeology.

2.3.1 Future Global Water Balance Uncertainty Visualization Tool

The Future Global Water Balance Uncertainty interface (Slocum et al. 2003) provides a refreshing look at the iterative process of developing a visualization tool for a hydrogeologic application. Approaching the design from a usability engineering approach, Slocum et al. (2003) created a wall-size display depicting interactive 3D models of future water balance with an emphasis on its uncertainty. The goal of this wall projected map is to create a collaborative environment for decision makers to become informed about uncertainty of the future global water balance. A critical issue was how to present the combining of multiple water models that sometimes contradict each other. In this instance the range between the two extreme values became the uncertainty. The data and uncertainty can be visualized differently through the menu allowing the user to choose various options such as precipitation, temperature, and moisture.

With a working prototype in place, six domain experts utilized the prototype and gave feedback that inadvertently led to a stronger scientific focus that ultimately prevented it from being as effective for decision makers. Some of the suggestions, such as the addition of state boundaries and putting the rotation of the model under user control, were beneficial for all users. The software was updated to meet the domain experts' concerns and then presented to four usability experts. Their comments ranged largely from giving selected boxes thicker borders to simulating miniscule perspective changes of the model. These small shifts of the camera help break the appearance of 2D by simulating minute 3D changes to the environment. Subtle perspective shifts within a 2D display mimic the subtle head movements that humans constantly perform when viewing 3D content.

The depiction of uncertainty was done implicitly through an RGB palette. Each colour represented the uncertainty of a variable, with white representing all three variables being uncertain, and black representing high certainty. MacEachren et al. (2005), however state that the opposite with white representing certainty is more successful. Slocum et al. (2003) discovered that expert users prefer explicit data (in this case bar glyphs of the colour of the uncertainty) that express more accurate uncertainty, while decision makers prefer the implicit method that communicates more easily an abstract message. Decision makers found the multiple future water models to be frustrating. Most likely it is expected that general populace non-experts feel the same way and would be best served by implicit information as well.

What makes this example interesting is that it failed to achieve its goal due to testing the prototype early in the development cycle with expert users while the system was meant to be for decision makers. Only at completion was the polished system presented to decision makers, at which point they found it too complicated. This signals that testing should occur with the target user group iteratively throughout the development process.

2.3.2 Interactive Groundwater

Interactive Groundwater (IGW) is a powerful query and visualization software giving insight regarding how groundwater variables, usually hidden, interact. Combined with pollution and contamination inputs, IGW is a multivariate visualization tool.

Li and Liu's (2004) IGW design responds to problems with many programs focusing on subsurface flow that lack continuity and immersion due to fragmentation. In other words – hydrogeologic programs too often require iterative setup, manipulation, and visualization with periods of data processing in between that prevent students from performing cognitive tasks. The users spend too much time focusing on using the tools rather than focusing on what the tool allows them to see.

Li and Liu's (2004) interface is impressive in its depth and accessibility of detailed graphs, tables, and even equations controlling groundwater models that can be visualized concurrently while moving through time, paused, or backwards. Due to its layered time display it allows the uncommon ability to pause and reverse the model procession, interact, and analyze as well as the adding new inputs/outputs in the model to help strengthen students' conceptual understanding of groundwater interaction.

This tool is designed for professors as a teaching tool, students for individual exploration and problem solving. IGW with its layout similar to Adobe Photoshop in complexity is designed for technically advanced users who have received some training as to its operation and knowledge of the fundamental groundwater concepts. While IGW can display simple variables to understand some of the more basic concepts more thoroughly, its strength is in giving students the ability to build their own environments and then manipulate the large set of variables that control the model and can each be modified and visualized in multiple manners. Developed to be a student driven interface that actively engages and allows real-world situations to be investigated, IGW succeeded in its aim to be an innovative groundwater interaction system.

Applying a design similar to the IGW Interface (Li & Liu 2003) for the CWN case study would not be appropriate due to its cryptic controls and discrete 'slice' or layer based time system. This is similar to an animation with a slow frame rate causing the image to look choppy. The less distracting alternative is a continuous smooth representation of changes over time. Providing better visualization and less complexity than the IGW interface may increase user attention, motivation, and learning by OB stakeholders.

Designed to run on the common PC, IGW uses the keyboard and mouse as the sole interaction controls. As mentioned earlier the displayed interface is similar to a graphics editing program with many buttons that have cryptic symbols (to those who don’t understand them) hinting as to their function only to those who are familiar with the program. Being a specialized tool, the affordances need to be taught, as they are not intuitive.

The ability to execute a model iteratively, while changing individual variables each time, creates an understanding of how that variable interacts with the environment. Displaying graphed variables that change over time with the main display helps create connections between multiple variables. This repeated interaction is how the user develops cognitive concepts.

IGW allows a composite 3D view of the groundwater system by allowing cross-sections, and top down views. Whether these can be viewed simultaneously in real-time while variables change is not clear in the paper. This does not communicate as strong a message as a real 3D interface where the user can rotate the perspective, zoom-in and out, and pan across the environment. Cross-sections may be cognitively taxing as they must be transformed into a 3D object mentally rather than being implicitly communicated as a 3D model. Providing better visualization experiences (such as real-time and 3D) increases retention (Peterson 1994, 34) of the material. The IGW interface is a success with its complex abilities for advanced education and its destined user group, but an interface for OB stakeholders requires a simpler and less abstract representation.

2.3.3 Radon visualization in groundwater

Demsar and Skeppstrom (2005) use ArcGIS to create 3D stills of radon distribution with a variety of other factors to determine if there is a visual correlation with increased radon concentrations. Demsar and Skeppstrom (2005, 39) look for “structures, patterns and relationships” by displaying “bedrock, soil type, slope of a terrain, the occurrence and distribution of uraniumin soils and the effect of fracture zone near a well” on the x-y axes while radon concentrations are displayed on the y-axis as elevation. This paper describes the ability of visualization to coincide with statistical results to determine its ability as a knowledge abduction tool.

The interface being used, ArcGIS, is a multidisciplinary tool used to conduct visualization and analysis but is expensive and complex to use. ArcGIS, however, is a powerful visualization tool when used by an expert. The risk in communicating an overly complex message to a non-expert, however, lies in “contradict[ing] established scientific facts” (Demsar and Skeppstrom 2005, 48) or communicating random information. In these situations novice users may be learning unrelated, wrong, or unnecessary concepts (Lindgaard et al. 2005, 222). These could be called learning externalities, which may be positive or negative, but generally detract cognitive powers from the task. Visualization may be a good abduction tool (Gahegan et al. 2001) but requires statistical and/or other methods to discover and reinforce truths. Repetition of the target concept through various modes (visual, graph, text) can reinforce that the correct message has been understood by the user. Demsar and Skeppstrom (2005) discover that while 3D ArcGIS visualizations can convincingly communicate a message, some areas contradict (visually) statistical findings. Consequently there is a need for redundant media types reinforcing the central message.

For the three volumetric visualization interfaces discussed little or no empirical testing was attempted to determine the suitability of the visualization tools. Most visualization tools require empirical testing to be evaluated objectively. These interface reviews do however provide usability guidelines and pitfalls to avoid in the development of OB educational tools before commencing testing.

2.4 Knowledge Transfer (Translation)

During the 2006 Montreal Annual General Meeting of the CWN, decision makers, practitioners, and academics met to discuss the increasingly important issue of communicating research findings to the general public. While schools provide the infrastructure to communicate the “latest” relevant research to students, the general public, aside from the popular media, largely does not receive information about recent applicable scientific findings or developments. This prompts the question of what methods are best at communicating simple and complex concepts to the general public or specific stakeholders. Knowledge transfer (or translation) refers to the area of research of communicating scientific or professional research results to the public. A common example is teaching the public to conserve water due to limited supply. Educating the public can be done through an array of methods such as water metering, rebates on low-flow showers and toilets, or lawn watering regulations. This research aims to gain insight into how knowledge communication to non-experts using interactive online tools is received. It attempts to gain an understanding of how to ease knowledge transfer between research results from within this CWN project and the OB stakeholders. With a large target population, a strong framework of community ties is required to effectively distribute any online educational tool. Creating the interfaces alone is not sufficient to communicate findings and concepts to stakeholders. These interfaces may be captivating but there must be a motivation to try and use them. These tools may serve as good supplements to regional educational programs such as Smart Growth Canada Network (SGCN) and the OB Water Board. The SGCN has developed online educational courses consisting of foundation concepts, case studies, and implementation paths to educate stakeholders about more sustainable lifestyles and city planning (http://moodleserv.com/smartgrowthca/). This would be a good example platform to present constructionist educational tools to supplement learning and stimulate and ease knowledge transfer.

2.5 Conclusion and Conceptual Framework Summary

This chapter looked at the highly intertwined fields of geographic visualization. Interfaces, representation, cognition, and usability shape how knowledge discovery takes place. Allowing users to interact intuitively, explore without seeing the interface, and easily recognize data representations with the least amount of cognitive effort will allow a maximum of learning. Building conceptually focused interfaces with clear controls can serve as base lines of good design. From these, variations of the interfaces can be created to explore how interaction, representation, frames of reference, quantity of content, and feedback alterations affect learning.

In an attempt to address a lack of understanding about groundwater in the OB as a whole, the CWN funded a project to better comprehend surface and subsurface water in the OB. This stems from its limited water supply and increasing population and land use. The other focus lies in communicating relevant findings to stakeholders in an engaging and digestible form. This is the case study challenge on which this thesis focuses, communicating select surface and subsurface water concepts to OB stakeholders in the most effective manner possible.

This thesis aims to contribute to a better understanding of whether variations in interface design influence the perception and understanding of volumetric hydrogeologic concepts. In order to achieve this, three separate educational geovisualization interfaces with multiple variations were constructed, tested quantitatively and qualitatively, and analyzed. This thesis also explores new ways of visually representing groundwater concepts, and how variations in interface design influence the perception of 3D groundwater visualization and user behaviour.

As guidelines to create educational interfaces, this thesis draws from a wide range of literature and theories. This work follows constructivist learning principals defined by Jonassen (1994) based on the building of knowledge through primary and secondary learning with emphasis on constructionism which is ‘learning by doing’. At the cognitive level, this thesis uses Paivio’s dual coding approach, with Mayer and Moreno’s (2003, 44) model of selection, organization and integration of knowledge. Animations are considered beneficial and useful for depicting changes over time (Slocum et al. 2005, 296; Tversky et al. 2002). In an effort to increase interface transparency to focus user attention on the content Gibson’s (1979) and Norman’s (1989) affordances will be considered, and Norman’s usability guidelines will be applied during interface design. Building on the past interface design literature, this thesis attempts to iteratively test interfaces with end users during development and keep interfaces conceptually focused and uncluttered.

Applying these concepts from the literature may better support the design and development of more effective volumetric interfaces for OB stakeholders to comprehend the hydrogeologic concepts that surround them. Participant testing of interface variations can determine which versions of the interfaces are more effective communication tools. Analysis of results contributes to the geovisualization, interaction design, and educational literature.

CHAPTER 3: METHODS

3.1 Introduction

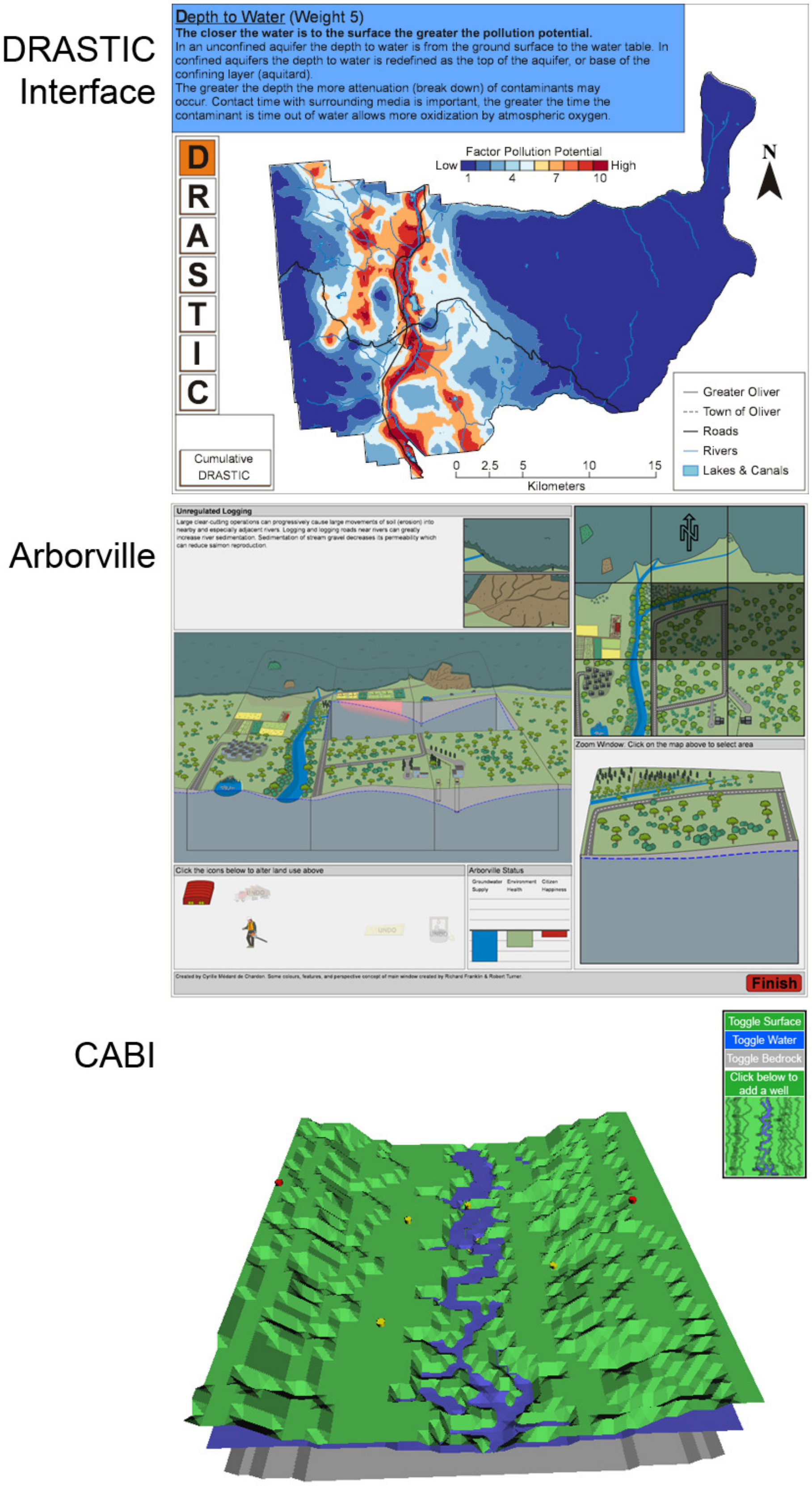
This chapter describes the design and development of three educational tools focusing on groundwater concepts. The three interfaces, DRASTIC, Arborville, and CABI, were designed following the literature recommendations in an attempt to communicate pollution potential, human surface and subsurface interaction, and well pumping concepts, respectively. New versions were created deriving from each of the three interfaces to empirically test the effect on stakeholders of changes to interaction, content, representation, feedback, frame of reference, animation, and interface size.

Interface development for these educational tools was driven by the question, “Is there a better way to communicate this phenomenon?” The response was constrained by the realities of the delivery mechanism, time, money, and the end users. The four geovisualization subfields introduced in Chapter 2 played an important role in guiding the interface design to rough paper prototypes. Development of an interface is an iterative process that can quickly show weaknesses in the initial design. Constraints from the programming language, programmer, or system requirements also influence the design. Eventually a balance must be reached between adding further content and interaction or refining functionality of the program and determining that it is completed.

Determining if an interface is an effective educational tool requires empirical testing. This research explores not only whether the interface is effective, but also how certain components of the interfaces alter learning of the target concepts. Derivations of the educational tools were created with individual components removed and tested to better discern how effective these components communicate the message. This chapter discusses, in depth each educational tool's design rationale, development, variation creation, testing, and how it responds to the OB problem statement.

The DRASTIC interface (Figure 3-1), based on the DRASTIC method (Aller et al. 1987) of determining groundwater pollution potentials, allows interaction similar to that of ArcGIS. Users can toggle individual layers or cumulatively view them using transparent layers. The DRASTIC interface had two variations developed from it: a conventional HTML web page, and a hybrid version that contains the same content but in an interactive version.

Arborville (Figure 3-1) is based on a segment of the Waterscape poster published by the GSC (Turner et al. 2006) exploring how urban sprawl, stream side cattle, and logging can negatively impact streams and groundwater levels. Arborville presents content in a perspective. Bridging the differences between the poster and final Arborville version required 6 additional intermediary versions to isolate interface variation factors.



Depth to Water (Weight 5)

The closer the water is to the surface the greater the pollution potential.

In an unconfined aquifer the depth to water is from the ground surface to the water table. In confined aquifers the depth to water is redefined as the top of the aquifer, or base of the confining layer (aquitard).

The greater the depth the more attenuation (break down) of contaminants may occur. Contact time with surrounding media is important, the greater the time the contaminant is time out of water allows more oxidization by atmospheric oxygen.

Unregulated Logging

Large clear-cutting operations can progressively cause large movements of soil (erosion) into nearby and especially adjacent rivers. Logging and logging roads near rivers can greatly increase river sedimentation. Sedimentation of stream gravel decreases its permeability which can reduce salmon reproduction.

Zoom Window: Click on the map above to select area

Click the icons below to alter land use above

Created by Cyrille Médard de Chardon. Some colours, features, and perspective concept of main window created by Richard Franklin & Robert Turner.

Figure 3-1: The three main interfaces in the order they were created for this research.

CABI (Figure 3-1), unlike the previous interfaces, displays a 3D model that can be rotated and interacted with through the placement of groundwater pumping wells. CABI allows users to explore the relationships between surface and subsurface water in real time through the use of cellular automata (CA) to visualize groundwater volumetric models. The origin of CABI is a proof of concept used to test whether the degree of freedom in mouse controls alters the learning experience.

3.2 DRASTIC

The DRASTIC interface is based on the DRASTIC method (Aller et al. 1987). DRASTIC is a method of determining if an area's groundwater is likely to be contaminated when a pollutant is placed on the surface. The DRASTIC method considers generic contaminants (such as animal waste, fertilizers, spills, land-fill, etc.) introduced at the surface and moving downward due to precipitation at the speed of water (Aller et al 1987). DRASTIC is an acronym for the seven factors that determine how likely an area's groundwater is to be contaminated. Figure 3-2 illustrates the seven factors on a fictional cut block.

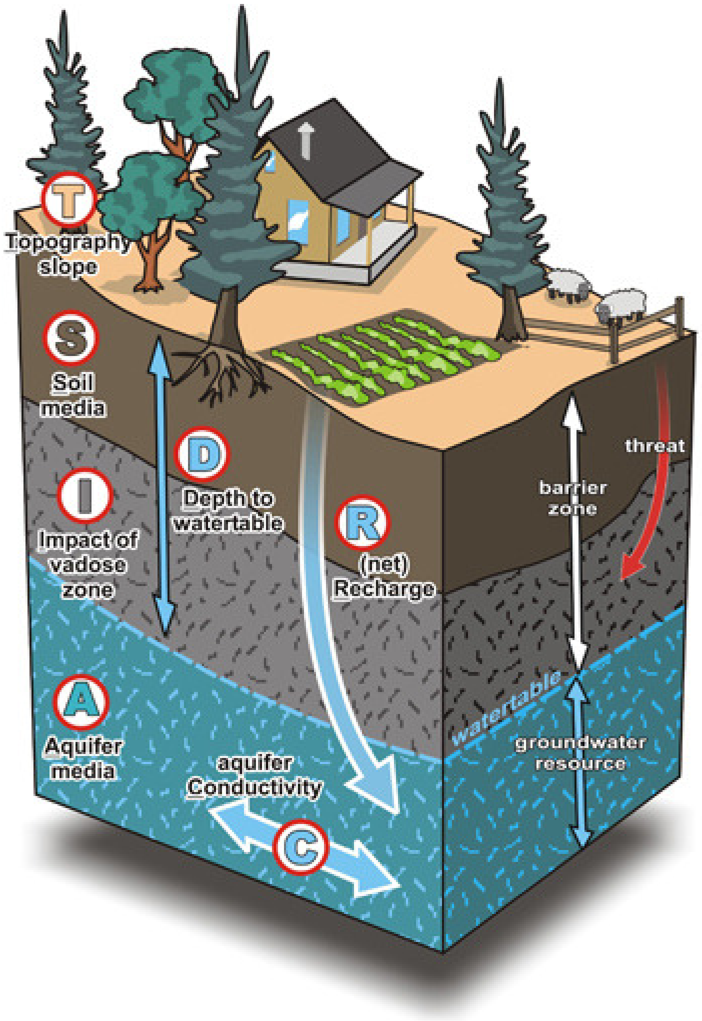


Figure 3-2: The seven factors of DRASTIC. Created by Richard Franklin & Robert Turner of the GSC. Modified by Cyrille Médard de Chardon.

DRASTIC is one way of determining groundwater pollution potential. It is important to acknowledge there are other methods (Stempvoort et al. 1992). The seven weighted factors of DRASTIC defined by Aller et al. (1987) are:

- **D**epth to water table
- **R**echarge
- **A**quifer media
- **S**oil media
- **T**opography

- **I**mpact of the vadose zone
- hydraulic **C**onductivity of the aquifer

For a given location each of the seven factors is rated and given a score from one (the lowest vulnerability) to ten (the highest vulnerability). The factor scores are then weighted and summed to determine an area's vulnerability to contamination according to the equation:

$$\boxed{V = 5D + 4R + 3A + 2S + 1T + 5I + 3C}$$

Equation 3-1: DRASTIC calculates an area's vulnerability based on weighted factors that are summed for a relative score.

The resulting vulnerability is a relative measure of the pollution potential of that area, ranging from 23 (low vulnerability) to 230 (high vulnerability).

There are limitations to DRASTIC. It has difficulty representing partially confined, leaky, or stacked aquifers and does not take into account recharge and discharge areas (Aller et al. 1997). For DRASTIC to be applied to measure aquifer vulnerability of an area it must be larger than a 100 acres (~40 ha) (Aller et al. 1997). Finally, DRASTIC does not replace site investigation, nor is it suitable to determine site suitability for waste disposal.

Despite its limitations, DRASTIC provides a relatively easy manner of measuring an area's relative pollution potential due to its straightforward factors and is comparable to other methods of measuring pollution potential (Wei 1998). This method can be useful for preliminary studies, city planning, and determining groundwater protection zones.

The DRASTIC interface evolved from collaboration within the CWN project. An SFU collaborator (Jessica Liggett 2008) who was also part of the CWN project, calculated groundwater pollution potentials for the Town of Greater Oliver using the DRASTIC method developed by Aller et al. (1987). Communicating these results through a web-delivered application was part of the knowledge transfer mandate of the CWN project. The interactive interface created, based on the concepts from the literature review, presents groundwater pollution potential results.

3.2.1 DRASTIC Interface Design

This section summarizes the considerations underlying the DRASTIC interface design. DRASTIC needed to be web-based to allow wide access while not being too complex to operate for those familiar with e-mail, word processors, and web surfing. Time to communicate content was also considered as decision makers and stakeholders may have only limited time to interact with the interface. The concepts communicated must be explicit and effortless to learn to keep the users interested and prolong interaction and conceptual learning.

The key concepts the interface attempts to communicate are: the seven factors of DRASTIC (Figure 3-2), which areas are generally more and less vulnerable to contamination, and which factors have the strongest impact in determining an area’s vulnerability. The goal is to have users understand how these factors, depending on their state at a location, can help determine the susceptibility of the groundwater to contamination.

The design of the DRASTIC interface required a strong reinforcement of what the seven DRASTIC factors are and how they allow groundwater to be susceptible to contamination. The guiding theme in design was the DRASTIC acronym to help users associate each letter with a different factor. Having the word DRASTIC be highly visible, as well as the individual factors, the user would remember the acronym and factors to connect with their understanding of the factor. Acronyms are often used to ease memorization of a set of connected ideas. The acronym DRASTIC may be especially effective because it is an existing word that communicates importance to the reader.

To communicate how the DRASTIC factors varied across space required spatial data showing the weighted distribution of groundwater pollution potential for Greater Oliver. Information was also needed to explain how each factor allows groundwater contamination. This could be done through text and diagrams. Different users prefer one to the other and offering both can provide a more complete understanding. It was initially thought that all this information would fit in the interface and users would understand the target concepts.

Upon consideration it was assumed that the average user would have difficulties with the terminology, how DRASTIC factors are weighted individually, and how the final vulnerability is calculated. In addition, users with varying knowledge levels require different amounts and kinds of information. How much information each user wants or needs may vary. The initial cognitive load of having all the DRASTIC introductory information in the interface was considered too great. Without some understanding of what the DRASTIC interface was trying to communicate beforehand, users could have difficulties understanding what they are viewing and lose interest.

To remedy the problem an introductory page was designed and placed before the interface use. This page would allow users to gain a quick fundamental understanding of the concepts through text, diagrams, and tables. It would also introduce narrative to the interactive experience increasing immersion. After reading the introduction, the user would be able to view the spatial data using the interface and gain a better understanding of how these representations were calculated and what they meant.

The interface needed to provide brief explanations of the DRASTIC method through text and diagrams to those who skip reading the introductory page as well as to provide a reminder for those who had read the previous page. The CWN collaborator provided seven factor maps and the final DRASTIC weighted map (for a total of eight maps). It is logical to have a short explanation of each when the respective one is visible.

The manner in which the eight different maps would be visible was chosen to reinforce the acronym DRASTIC. To do this each letter was to be designed as a button that when clicked would show the map resulting from that factor being applied to Greater Oliver. At all times the Greater Oliver boundaries, roads, rivers, lakes, and Town of Oliver boundaries would be visible. The DRASTIC data would underlay these features to provide frames of reference for those familiar with the area as well as help reinforce connections between surface features such as rivers and pollution potential. To help reinforce connections between terrain and DRASTIC pollution potential it was decided that a shaded elevation model would be useful. This would increase the total number of layers (to use a GIS metaphor) to nine. How these nine buttons were to be organized and located was to be determined during development. The seven DRASTIC buttons were to be adjacent in a column or row. The aesthetic appeal of the button layout as well as usability and compactness would determine the final locations of the buttons, textbox/diagrams, legend, and other information during development.

Besides allowing users to see the distribution of individual and all seven DRASTIC factors combined, allowing users to combine selected factors could prove to be helpful. To accomplish this, users would need to be able to toggle on or off the seven factors individually so anywhere from zero to seven of the factors were viewed concurrently. It would also be beneficial to have the shaded elevation model visible concurrently with the selected factors.

Initial sketches of the DRASTIC interface consisted of a box containing text and/or diagrams explaining the concepts being viewed. The Greater Oliver area is located in the middle of the interface surrounded by the DRASTIC button column on the left and hill shade button on the bottom right. Additional items such as scale, north arrow, and legend were omitted for the time being as relocations and modifications were expected for some of the major items.

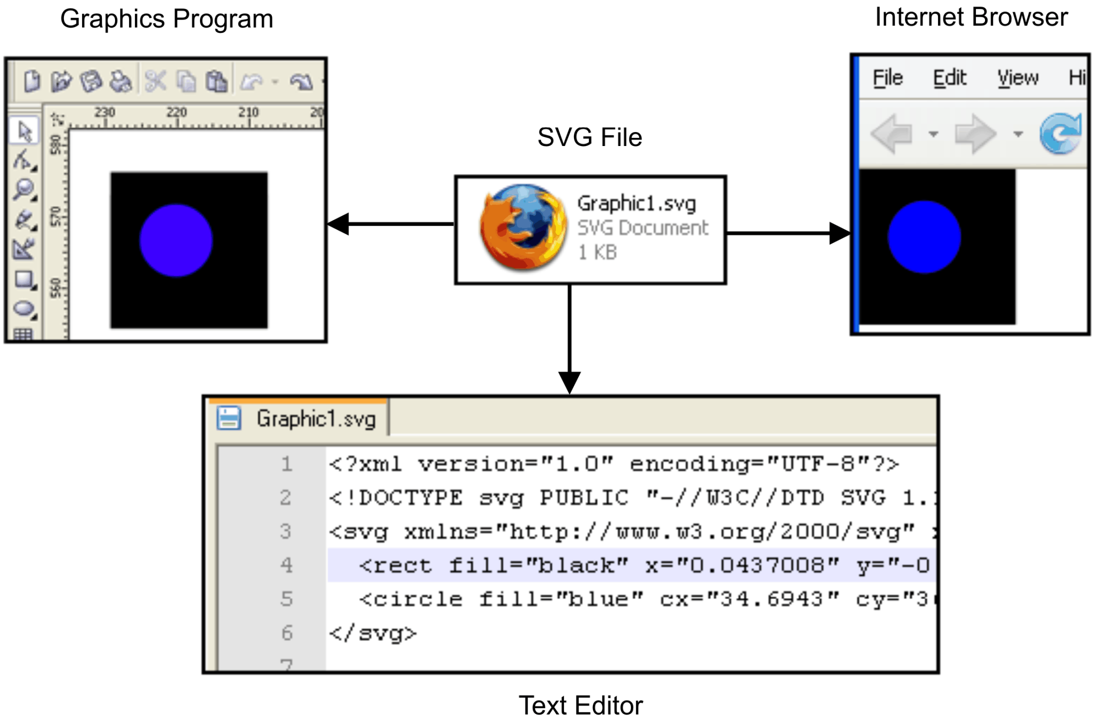
3.2.2 DRASTIC Interface Development

To create an online interactive 2D graphics interface several graphics platforms are available. The most popular 2D graphics program is Adobe's Flash (formerly by Macromedia). Flash, however, is proprietary and the best alternative that is open standard is Scalable Vector Graphics (SVG). This vector-based human readable language "is a powerful and flexible way of publishing interactive cartography on the Web" (da Silva Ramos et al. 2006, 429). Using SVG requires other tools to perform advanced tasks. SVG is commonly embedded in HTML and requires JavaScript and Cascading Style Sheets (CSS) to perform advanced interactions efficiently.

Scalable Vector Graphics use in DRASTIC Interface

SVG is part of the Extensible Markup Language (XML) and was created by the World Wide Web Consortium (W3C). SVG was designed to present interactive and dynamic 2D graphics from text-based code. All code is machine and human readable. This allows a degree of precision not always easily available in other 2D graphics multimedia programs. All features in SVG can have a set of actions associated when a cursor moves over, out, hovers, or clicks on an area. This allows for high interactivity and can become much more complex and engaging when combined with JavaScript. Due to its textual form it is inherently compact and is increasingly being used in desktop and mobile GIS applications (Yang and Wang 2004; Quint 2006; Schiller 2006).

SVG code or graphics can be created either through a text editor or graphics program. Graphics programs allow faster creation of content which can later be edited by text editor. Different programs will interpret SVG code differently, either as text or as graphics. Figure 3-3 shows how an SVG file will be displayed as text in a text editor (bottom) and as a graphic in a graphics program and internet browser (top left and right).



```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE svg PUBLIC "-//W3C//DTD SVG 1.
<svg xmlns="http://www.w3.org/2000/svg"
  <rect fill="black" x="0.0437008" y="-0
  <circle fill="blue" cx="34.6943" cy="3
</svg>
```

Figure 3-3: SVG files will be interpreted differently by different programs.

SVG is viewable through a browser such as Internet Explorer and Firefox and can be interacted with using a mouse and keyboard. While Firefox 3 has SVG included, Internet Explorer requires a plug-in. Users can easily download the plug-ins at multiple locations online. Complications arise, however, due to differences in how SVG is interpreted by various browsers. This requires customizing the program for multiple individual browsers or developing it for one browser specifically. While an SVG file can have some interaction built-in on its own when viewed in a browser, it becomes much more powerful when embedded in HTML and allows the use of JavaScript.

JavaScript use in DRASTIC Interface

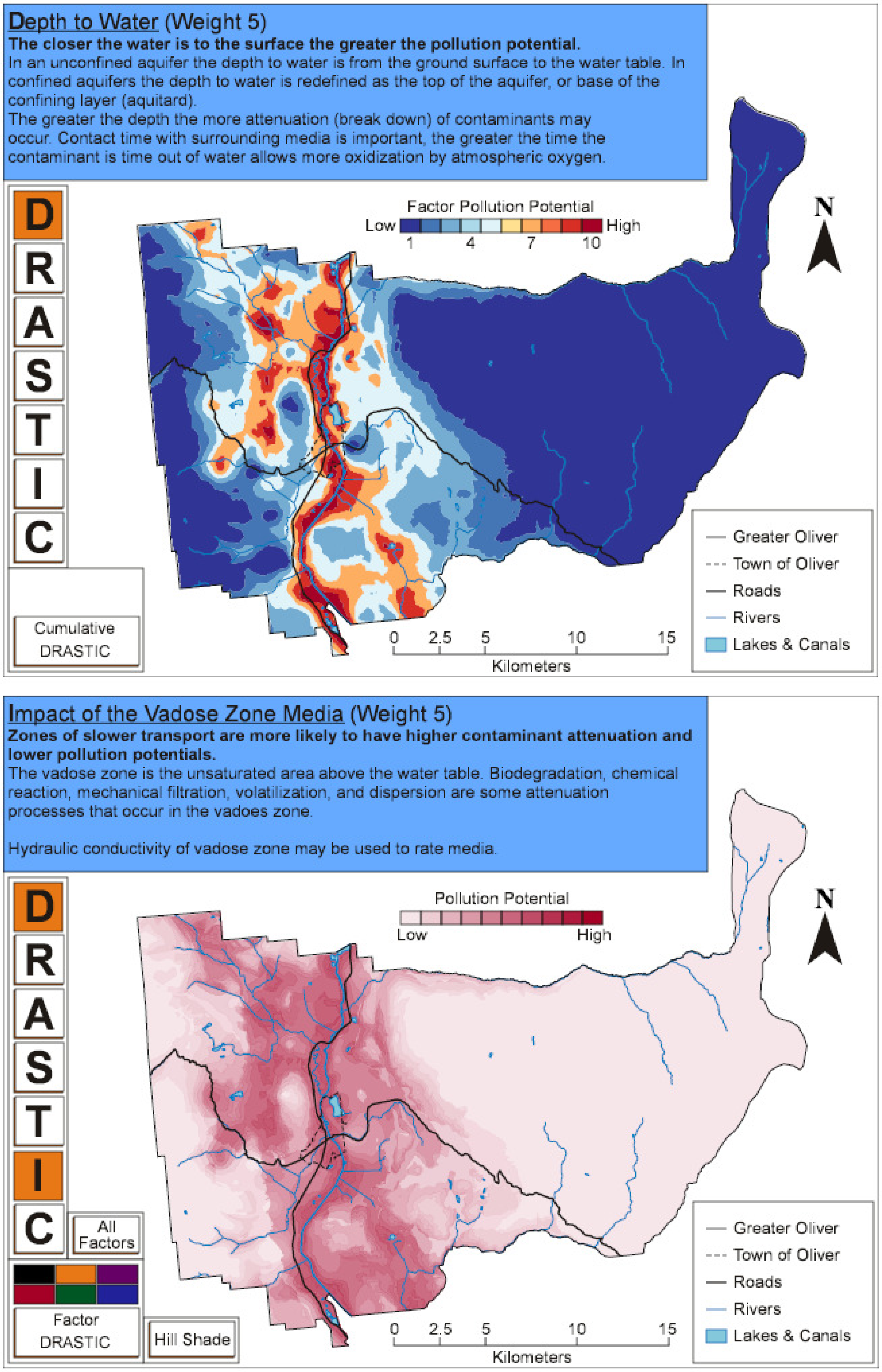
JavaScript consists of human and machine readable code that can perform many of the tasks a standard programming language can achieve. SVG combined JavaScript allows complex interactions, most importantly, the tracking of interface use through the gathering of interaction types, time, and mouse movement. JavaScript, like SVG, can be coded in any text editor. SVG has some inherently powerful features to create interactive and dynamic processes, but some of its limitations can be overcome when combined with JavaScript.

Creation of DRASTIC Interface

The interface uses raster ArcGIS files containing the spatial variability of the seven DRASTIC factors as well as a final vulnerability and hill shad raster provided by CWN collaborator Jessica Liggett (see Liggett 2008). These files, except for the hill shade raster, were converted to vector data to take advantage of the smaller file size of this format. The data would have been more precise if they were initially vector-based. The transformation of raster files to vector adds minor errors to the data causing jagged edges and noticeably increasing the file size. However, due to the scale difference between the data and visible result in the interface, the error introduced is largely invisible. The resulting vector ArcGIS coverage files were exported as SVG files.

Using Corel Draw the different factor layers and raster hill shade were overlaid and a rudimentary prototype was created. This allowed all the layers to be easily combined with the buttons and stylistic features in one SVG file. The SVG file was then edited using a text editor and linked to an HTML and JavaScript file. Text editors such as Microsoft Visual Studio and Notepad++ greatly facilitate coding by formatting and colouring code automatically to clarify the function of different fragments of text. The majority of the interface design creation time was spent modifying the SVG and JavaScript files to create a clean looking and easy to use interface. The SVG file was edited to move the interactive features, such as the text box and buttons. The JavaScript file allowed interaction between buttons, one button enabling other buttons, and displayed relevant text information regarding a current interaction.

Creation of the final interface was an iterative process of adding dynamic functionality, changing representation or interaction, and judging the resulting usability, intuitiveness, and clarity.



Depth to Water (Weight 5)

The closer the water is to the surface the greater the pollution potential.

In an unconfined aquifer the depth to water is from the ground surface to the water table. In confined aquifers the depth to water is redefined as the top of the aquifer, or base of the confining layer (aquitard).

The greater the depth the more attenuation (break down) of contaminants may occur. Contact time with surrounding media is important, the greater the time the contaminant is time out of water allows more oxidization by atmospheric oxygen.

Impact of the Vadose Zone Media (Weight 5)

Zones of slower transport are more likely to have higher contaminant attenuation and lower pollution potentials.

The vadose zone is the unsaturated area above the water table. Biodegradation, chemical reaction, mechanical filtration, volatilization, and dispersion are some attenuation processes that occur in the vadoes zone.

Hydraulic conductivity of vadose zone may be used to rate media.

Figure 3-4: The final version of the DRASTIC Interface (top and bottom) has two modes allowing users to explore individual factors (top) or combinations of factors (bottom).

The resulting interface has two modes (Figure 3-4) allowing individual factors (Factor DRASTIC mode) and multiple factors (Cumulative DRASTIC mode) to be viewed simultaneously. Factor DRASTIC mode represents data using opaque diverging colour values calculated from colorbrewer.org to insure visibility for colour blind viewers. Colour blindness software from vischeck.com confirmed this. Cumulative DRASTIC mode uses transparency of one selectable colour to view individual or combined factors. While this may not provide an as easily viewable representation it allows combining multiple factors together to see their relative spatial representations. The benefit of this interface is that only the seven factor polygon shapes are used to create all possible representations. The interface simply changes the fill of the factors from a variety of colours to a variety of transparencies of one defined colour. Overlaying of seven transparent layers allows over a hundred possible combinations of representations with a very small file size.

A colour swatch is also provided in Cumulative DRASTIC mode for two reasons. Another benefit of the transparency of the factors is that it allows factors to be visible when overlaid on the grey hill shade. This however works better in certain colours than others. Black, for example, is particularly bad, but works very well when overlaying several or all factors without the hill shade. In addition allowing users to change representation colours may encourage them to explore further and spend more time using the interface which may increase the user’s learning.

In both modes, various subliminal associations were made to guide users regarding their interactions and where relevant information became available. Placing the mouse cursor above certain buttons will glow blue or green and upon clicking will provide information in a blue or green text box respectively.

Also, an interactive legend was created but as a hidden affordance. While the DRASTIC buttons may be perceived as buttons the legend has no sign of its potential. When users move their mouse cursor over the legend item it will glow orange and highlight the particular feature on the map clearly showing where the features is located. Depending on the colour scheme and DRASTIC mode being used, the orange feature colouring may be more or less effective. Hiding this ability was done to keep the interface simple.

The final version of the DRASTIC interface is versatile with its dual modes and provides a versatile set of representations using simple controls that may ease understanding of the concepts communicated. Yet it also has some limitations. Factor DRASTIC mode does not have an option to view the final vulnerability of all the layers combined that is available in Cumulative DRASTIC mode. Inclusion of the feature would have required an additional vector layer roughly near the size of the seven drastic layers combined. While the Cumulative DRASTIC mode seems to provide good combined monochromatic representation, having different transparent colours overlaid may be an alternative that could more explicitly show how factors vary spatially from one another.

3.2.3 DRASTIC Interface Variations

In order to determine how the DRASTIC interface compares against conventional communication methods two other versions of it were used. The version described above will be referred to as Version 3 or the advanced SVG interface. The two other interfaces are an HTML page with images (Version 1), and a Basic SVG interface (Version 2). Version 1 is a fair conventional representation of current practices of knowledge transfer. SGOG displays a map and information provided by Liggett (2008) in their Greater Oliver Concept Plan (www.sgog.bc.ca). Version 2 exists to help limit the number of variables between the conventional and advanced interface. The three versions were designed to empirically test and determine whether some of their differences alter learning. Trying to determine what individual factors allow increased learning between the conventional (Version 1) and advanced (Version 3) version's empirical results would be difficult. Determining the differences between version 1 and 2 and version 2 and 3 should be easier.

Versions 1 and 2 of the DRASTIC interface, named in the order of their complexity, are described below. Version 3, the most advanced, has already been described thoroughly above.

DRASTIC Interface Version 1 (Conventional / HTML)

The HTML conventional medium has the benefit of being flexible and visible to all users, while SVG may require plug-ins making it only available to a subset of the population. The conventional version consists of the same introduction, and text as the advanced interface only packaged as a regular web site. The content is laid out with intermittent text and maps of the individual drastic factors, hill shade, and final cumulative vulnerability map. The one advantage this version has is that the site designer can dictate the order in which the user will experience the different maps. While this may be considered non-interactive, there are links that allow the user to jump to individual factors.

In 2007, the final vulnerability map of Greater Oliver was integrated into the Greater Oliver concept plan. The format consisted of text supporting the image in a PDF file distributed online. The PDF software used to view PDF files strongly resembles a web browser. Due to this, results from testing Version 1 should provide an adequate representation of how scientific findings are communicated to stakeholders.

DRASTIC Interface Version 2 (Basic SVG Interaction)

In order to bridge the conventional version and the advanced SVG version a simplified SVG version was created. Resembling perfectly the HTML version, but simply overlaid as sheets, users click the letters of the DRASTIC acronym to select which of the seven factors they desire to see. The final vulnerability is visible as well as the hill shade. Due to this version's simplicity it could have been created using standalone SVG. This means it would not have required being embedded into HTML and connected with the JavaScript file. This has benefits for propagation and sharing. The physical file can be emailed around without users having to go to a specific website or worrying about breaking the connections between the HTML and JavaScript. Version 2, however, requires

JavaScript for user tracking reasons. This also allows the reuse of code from Version 3 with minor modifications.

Differences between DRASTIC Versions

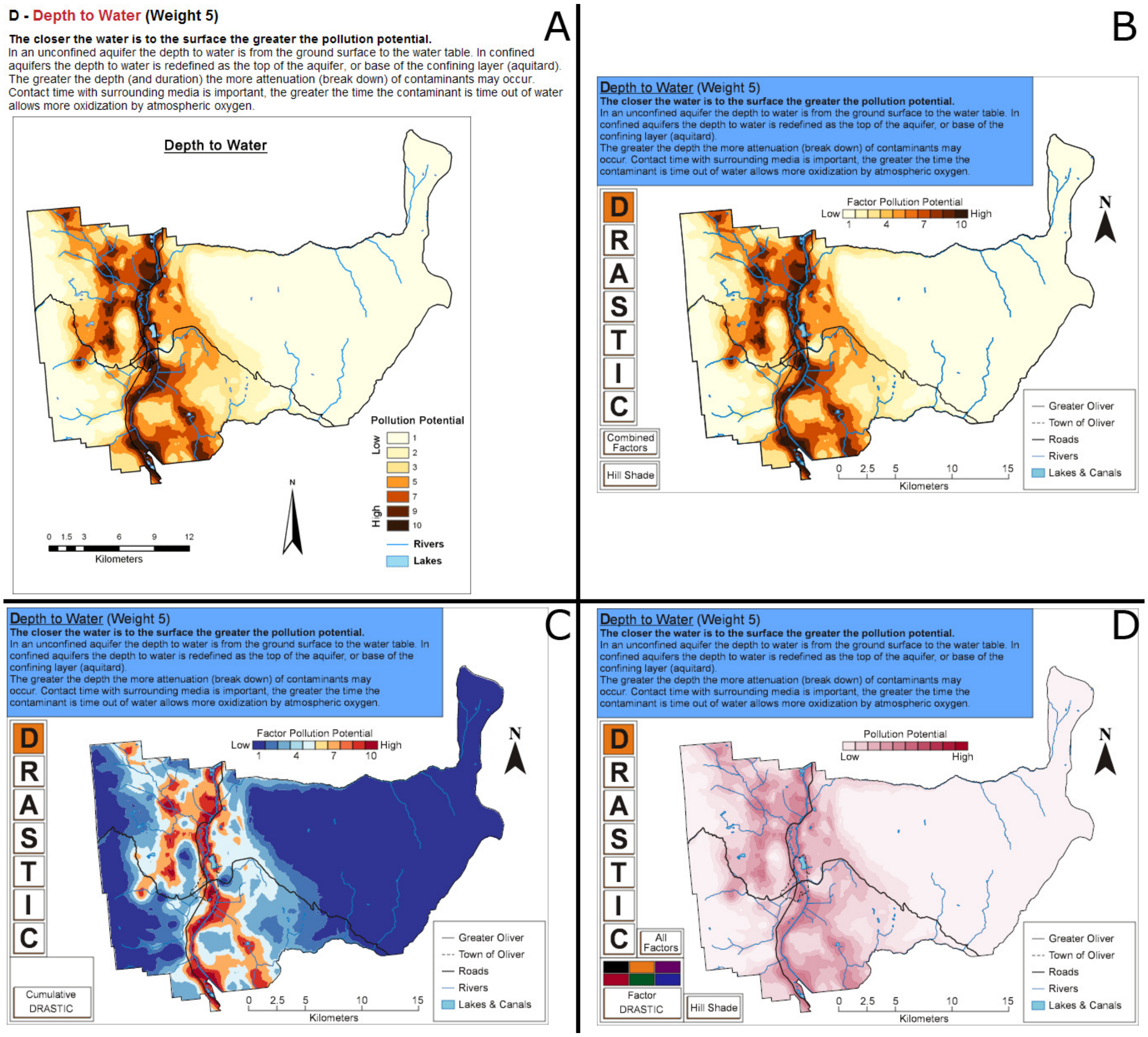
To determine why one version of DRASTIC may result in higher test scores than others requires that there be relatively few variations between sequential versions. The construction of the Basic SVG version (Version 2) was created specifically to isolate some of the many differences between Version 1 and 3.

The main difference between Version 1 and 2 is that Version 1 users must scroll to view the different factors, while in Version 2 they click on one of the buttons using the DRASTIC acronym. This is an interaction design difference. There are, as well, some minor aesthetic differences. The north arrows and scales are different yet have the same meaning. Perhaps a more significant inconsistency is the incomplete legend of Version 1. While Version 1 has the bounds of the Town of Oliver and Greater Oliver, roads, rivers, and lakes on the maps, it does not have the legend descriptions of the boundaries and roads Version 2's legend contains all elements including the boundaries and roads. This unwanted variation was noticed after data gathering. The effects of this may be minor since all users viewed a task map that had a full legend before using any of the DRASTIC versions. The task map was also visible at any time from the interface page.

Differences between Version 2 and 3 relate to changes in content and representation. Version 2 is almost exactly equivalent to Factor DRASTIC mode of Version 3. In both versions the users can view the seven factors independently and represented by polychromatic ratings, as well as the hill shade. The colour scheme for the factors, however, is different between the Versions. Versions 1 and 2 use sequential brown colour schemes, while Version 3 uses a diverging from white to red and blue colour scheme.

The big difference between Version 2 and 3 is the final vulnerability representation and the concept in entirety of Cumulative DRASTIC mode. While the final vulnerability map in Version 2 has the same colour scheme as the individual factors, Version 3 uses the monochrome colour scheme. The concept of combining a selected number of factors together to see their resulting vulnerability is not present in Version 2. This may stimulate users to try and further understand the concepts, or possibly overwhelm. Versions 2 and 3, in retrospect, have more differences than desired.

The resulting three versions of DRASTIC provide a range of interaction complexity that may attract and be more beneficial to users of different knowledge and experience levels with the subject. Snapshots of the three versions of DRASTIC in Figure 3-5 show some of the differences visually described above. The top left image (A) shows the Depth to Water map and text segment of the HTML page (Version 1). The top right (B) shows the equivalent information in the Basic SVG interface (Version 2). The bottom images show snapshots of Version 3 Factor DRASTIC mode (C) and Cumulative DRASTIC mode (D).



A

D - Depth to Water (Weight 5)

The closer the water is to the surface the greater the pollution potential.
In an unconfined aquifer the depth to water is from the ground surface to the water table. In confined aquifers the depth to water is redefined as the top of the aquifer, or base of the confining layer (aquitard). The greater the depth (and duration) the more attenuation (break down) of contaminants may occur. Contact time with surrounding media is important, the greater the time the contaminant is time out of water allows more oxidization by atmospheric oxygen.

Depth to Water (Weight 5)
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In an unconfined aquifer the depth to water is from the ground surface to the water table. In confined aquifers the depth to water is redefined as the top of the aquifer, or base of the confining layer (aquitard).
The greater the depth the more attenuation (break down) of contaminants may occur. Contact time with surrounding media is important, the greater the time the contaminant is time out of water allows more oxidization by atmospheric oxygen.

Figure 3-5: The three versions of the DRASTIC interface. A) A portion of the Version 1 HTML page. B) SVG basic interface (Version 2). C) SVG advanced (Version 3) in Factor mode D) also the SVG advanced version but in Cumulative mode.

3.2.4 Testing of DRASTIC Variations

An online testing framework was created in order to determine whether variations in interface design for the three versions of DRASTIC alter user perception. This was aimed at having an unbiased random assignment of one of the three versions to a user. Having the user interact through a computer in a setting they feel comfortable minimizes testing impacts relative to a laboratory setting where the user may feel monitored. By testing online where educational tools are commonly available qualifies this as a type of field testing.

In an attempt to motivate completion of the survey the layout was made as clean and simple as possible. Additional details not required that supplement learning were added through pop-up windows that could be viewed if desired. In addition to this, a status bar of how far along the survey the user has progressed is displayed at the bottom of each page. This was created in an effort to increase survey completion.

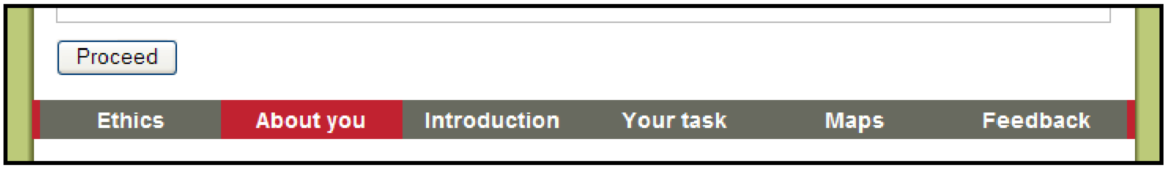


Figure 3-6: The status survey bar shows how far the user has progressed in the survey and how much is left.

The online survey consists of eight web pages (Figure 3-7). A simple page invites the visitor to try the DRASTIC educational tool and participate in a survey. The following page informs the users that they are participating in a study and asks them for consent. Page 3 asks some demographic and scale pre-test questions (Table 3-1).

Table 3-1: DRASTIC Groundwater Susceptibility Factors Comprehension (DGSFC) Scale. Numbers represent points given for each response. Five's represent the expected correct answer.

In general…	*Strongly Disagree*	*Dis-agree*	*Un-decided*	*Agree*	*Strongly Agree*
1. Groundwater near the surface is less likely to be contaminated (polluted).	5	4	3	2	1
2. Greater recharge (rain, snow etc...) is more likely to increase groundwater contamination (pollution).	1	2	3	4	5
3. Aquifer media (the material through which water moves underground) with larger grain sizes and more fractures (openings) can more easily be contaminated (polluted). *	1	2	3	4	5
4. A thick layer of fine textured soils is more likely to allow groundwater contamination (pollution) below.	5	4	3	2	1
5. Steeper slopes are more likely to allow groundwater contamination (pollution) directly underground.	5	4	3	2	1
6. Vadose media (the material between underground water and the surface) with slow water transport is less likely to allow contamination (pollution) of water below.	1	2	3	4	5
7. Soil type is more important than the depth of the groundwater when determining pollution potential of an area.	5	4	3	2	1
8. The vadose media (the material between underground water and the surface) is more important than the aquifer media (the material through which water moves underground) when determining pollution potential of an area.	1	2	3	4	5

* Due to Aquifer media and Aquifer Conductivity being too similar, there is no aquifer conductivity question.

There are eight questions in the DRASTIC Groundwater Susceptibility Factors Comprehension (DGSFC) scale (Table 3-1). Six questions (1 – 6) focus on the seven DRASTIC factors, the DRASTIC aquifer conductivity factor is omitted due to its similarity with aquifer media. The two additional questions (7 and 8) ask about the DRASTIC factor weight relative to others. The DGSFC scale questions were designed to measure user understanding of the DRASTIC method and factors. Limitations to the DGSFC scale were later revealed from testing by a hydrogeologic expert who did not agree with some of the scale's designated correct answers. Future research will incorporate testing the DGSFC scale prior to live user testing.

The online survey pre-test page (Figure 3-7) provides a pop-up window clarifying some of the terminology used in the survey questions. Page 4 and 6 of the survey contain the actual educational material. Page 4 provides introductory information regarding the DRASTIC pollution potential mapping method, while page 6 contains one randomly selected version of the DRASTIC interface. Page 5 presents the task to the user to give them focus when viewing the DRASTIC interface information on the following page. Page 5 tasks participants to monitor how the various DRASTIC factors vary at three locations. Page 7 presents the same questions as in the pre-test. Both times, in the pre-test on Page 3 and post-test on Page 7, the scale questions are presented in a random and most likely different order. The final page of the online survey thanks the user for completing the exercise and provides links to the three versions of the DRASTIC interface for users to experiment with the other versions. This removes the need for participants to complete the survey again if they are aware of the multiple versions and desire testing them as well.

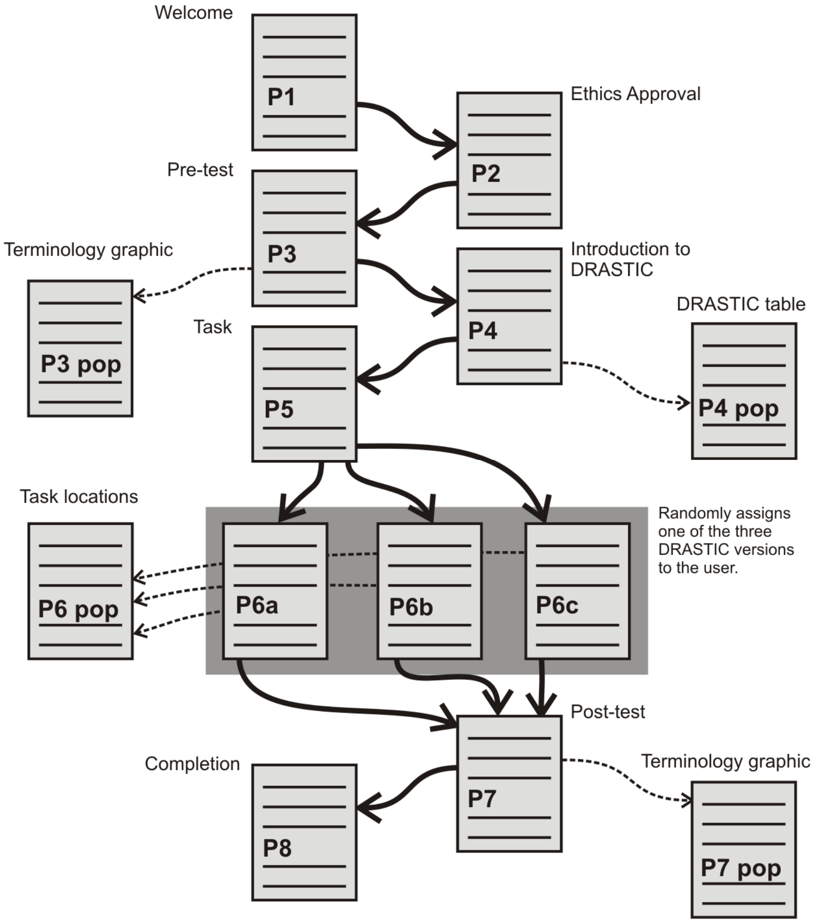


Figure 3-7: DRASTIC online survey sequence structure. Users will receive one of the three versions of DRASTIC randomly assigned to them.

Data were collected through online survey questions but also by tracking users interaction. The online survey records the duration of each page view, whether users view pop-up links that provide additional information, and detailed interaction with the DRASTIC maps. All three versions track mouse movement over the interfaces or images provided. Additionally, Versions 2 and 3 record what interactions are performed and the time done so. The repeated measures pre-test and post-test survey questions completed by participants serve to measure user learning. The additional data gathered helps to deduct the motivation and behaviour of the user.

Online surveys have drawbacks. There is no list or phone book of contacts, so there is no easy way of outreach except word of mouth and emails. The coverage or population is biased to those comfortable with and have access to the internet. Those who complete the survey do so voluntarily, perhaps already being interested in the topic. It is hard to determine the motivation and interest of the user. They could merely be completing it as part of their lab work, having no interest in the material or any wish to learn it. Respondents could potentially complete the survey multiple times. There are some measures to prevent this, such as a question asking if this is the user’s first visit as well as tracking IP addresses (location) and the time the survey was completed. These are challenges that future CWN and OB interface developers will also face during testing of online public outreach educational tools. DRASTIC interface testing participants were mainly recruited from an introductory geography class at SFU, but also included departmental and personal contacts. Details on the DRASTIC participants and solicitation are in the following chapter describing analysis and results.

3.3 Arborville

Arborville is a 2D interactive web delivered interface containing a perspective view of a virtual town where users can make land use decisions. The user, as the mayor, explores land use possibilities while considering their impacts to groundwater, the environment, and citizen happiness. Arborville originated from a combination of a proof of concept interface that serendipitously resembled a feature in a poster created by the Geological Survey of Canada (GSC) (Figure 3-8). This poster attempts to communicate how OB stakeholders can impact water quantity and quality locally and what they can do to reduce their water consumption and impact footprint. The poster was the result of a large amount of community and scientist engagement in order to create a common framework for communication. Arborville combines the proof of concept and poster style and layout with expanded interactivity.

Managing our land for healthy streams

Moisture-loving trees, shrubs, and other plants adjacent to streams are vital ecosystems that provide habitat for diverse wildlife, stabilize stream banks, and protect water quality. These streamside corridors have been damaged in the past by urban development and farming in the valley, and poor forestry practices and livestock management

Paving our paradise damages streams

Most rain falling on forests and grasslands infiltrates the soil. This water flows slowly to streams via underground pathways that act as natural filters. Streams receive a steady supply of clean water. However, extensive areas of pavement and rooftops in urban areas prevent infiltration. Instead, unfiltered rainwater flows quickly into streams, causing high flows that damage stream life. Between rains, stream flow can almost disappear. This cycle of floods and low flows makes urban streams stressful places for fish and other organisms.

Figure 3-8: The portion of the 'Okanagan Basin Waterscape' poster (Turner et al. 2006) that Arborville is based on.

The topics covered by Arborville are based on a portion (Figure 3-8) of the GSC poster ‘Okanagan Basin Waterscape’ (Turner et al. 2006). The topics are:

- Logging near streams is likely to harm fish habitats
- Large urban areas decrease groundwater levels
- Large urban areas damage stream habitats by reducing stream base flows

- Large urban areas increase rainfall runoff causing high intense flows
- Natural groundwater levels recharge streams
- Cattle by streams are likely to contaminate the water
- Cattle damage vegetation that filters surface runoff
- Paved surfaces allow rapid flow of unfiltered rainwater into streams

The design of a new interactive interface using the same topics as the poster section, a familiar public education tool, would allow a comparison of whether various interaction methods alter learning.

3.3.1 Arborville Design

Arborville was meant to be an exploratory environment where users could alter land use and see changes to the environment related to the key topics communicated by the GSC Waterscape poster. These changes would occur implicitly not drawing any more attention than the changes on the surface. Text and diagrams were to be displayed as well showing explicitly what occurs. The idea was to let the user, through repeated interactions, discover how land use changes generally alter the surroundings and the environment within the Arborville scenario.

Like the DRASTIC interface, Arborville attempts to combine interaction on an online platform with concepts relating to groundwater. Usability needed to be considered from the earliest prototype (Dumas and Redish 1993, 8) to avoid a final product unfit for the target user group. To achieve this several proofs of concept were created before Arborville. The most important proof of concept is *Terrain*, a much simpler version of Arborville from which Arborville evolved.

Proof of Concept Terrain

Terrain provided a first look at how concepts could be interacted with and visualized using the metaphor of blocks to communicate the three dimensional behaviour of a groundwater system. In Terrain the blocks are displayed orthogonally making the blocks in the back appear the same area as those in the front. Whether users expecting a perspective view perceive the cubes in the back as having a larger volume is unclear. Elevation changes between the model segments may more greatly distort users' perceptions of volume than falsely believing they are experiencing a perspective view. The interaction to make the blocks appear or disappear is achieved through the smaller blocks in the top right corner. However, the smaller blocks are also viewed at the same angle and do not correct users who may believe they are viewing perspectively displayed content. Additional interaction was made possible by placing the mouse cursor over a well, forest, and orchard, causing text to pop-up providing feedback of what could be done by clicking on the icon. For example, clicking on the well and forest would lower groundwater levels and increase run-off into the river, respectively.

While Terrain was rudimentary and not formally tested it received positive reviews from CWN partners that led to its interaction style being combined with the selected concepts from the GSC OB Waterscapes poster.

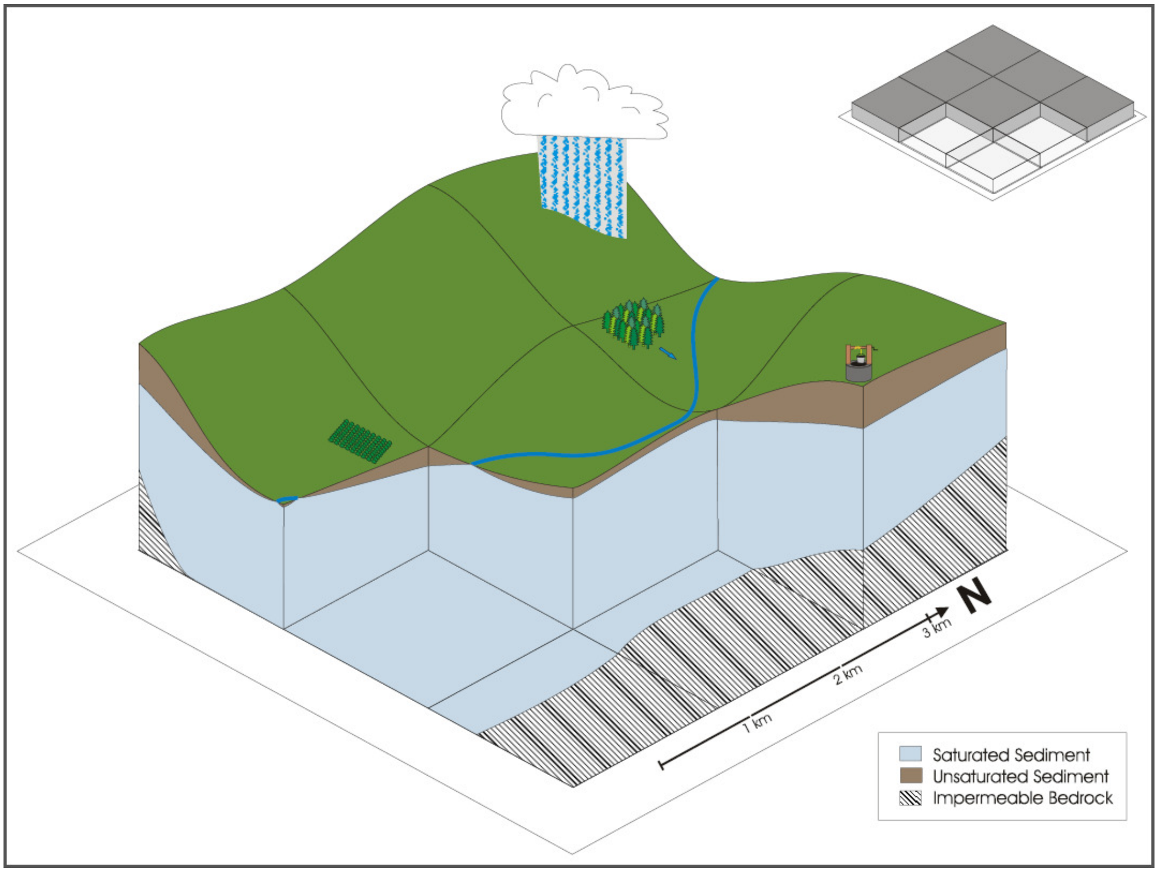


Figure 3-9: Terrain, an Arborville proof of concept.

Arborville Prototyping

Terrain briefly introduced the user to three concepts without multiple feedback types to confirm or correct what the users think they understand. Arborville was designed to provide multiple representations and feedback mechanisms to ensure a clear understanding of the concepts. Similarly to the DRASTIC interface, a textual window with graphics would explicitly state how the interaction the users performed alters land use and water. The representations of the terrain would be enhanced with views of individual blocks as well as an orthogonal map from above. The enhanced or zoom view of the cube allows the users to see the cube in a larger and stand alone manner.

When using Terrain, the user could click on the well or forest located on the model to interact with it. The possibility to interact was only indicated by text bubbles that appeared when the user placed their mouse cursor on the forest or well. Rather than have the users search for and click on objects already placed on the terrain users can choose where to place the objects on the terrain using a drag and drop metaphor. This would utilize a virtual constructionist metaphor of building features onto a terrain followed by seeing how they alter their surroundings. In addition to receiving textual, diagram, and terrain change feedback a city status graph would provide concisely how their action altered the city in terms of quantity of groundwater supply, environment health, and citizen happiness. All the features described above would be arranged as illustrated in Figure 3-10. SVG code allows effortless spatial translation of graphic modules. This allows easy testing of various component window layouts (Figure 3-10).

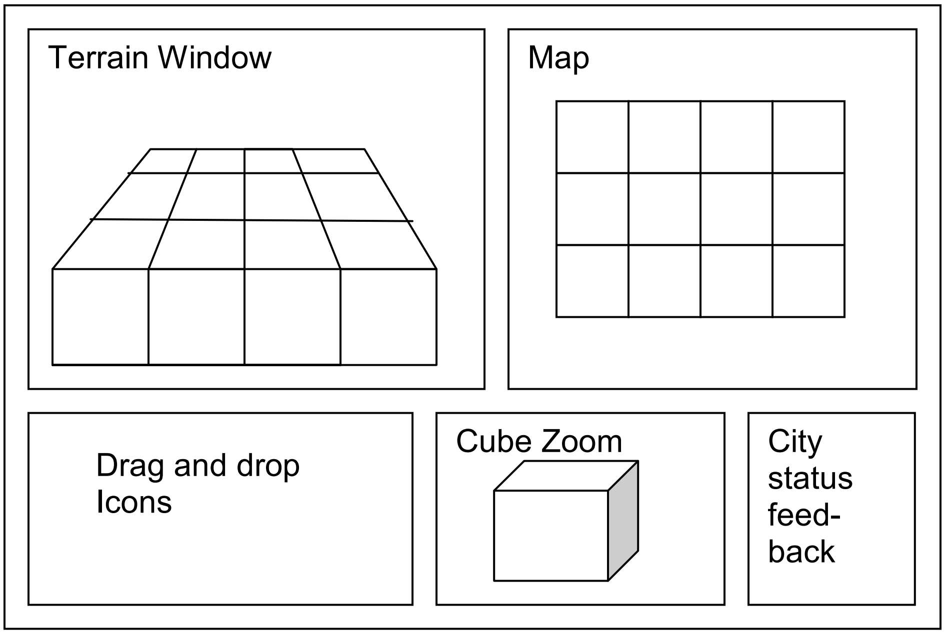


Figure 3-10: Early Arborville interface prototype missing textual feedback window.

In order to provide a model where users can place different land use types it was originally thought that the OB Waterscape poster's Corel file could be altered. Upon inspection the Corel file proved to be too restrictive and complex to manipulate in the manner desired. A similar version of the Waterscape component was sketched out allowing more spatial flexibility since a new graphic file with discrete layers was required to program the interaction. The rough draft of the model was sketched on paper (Figure 3-11).

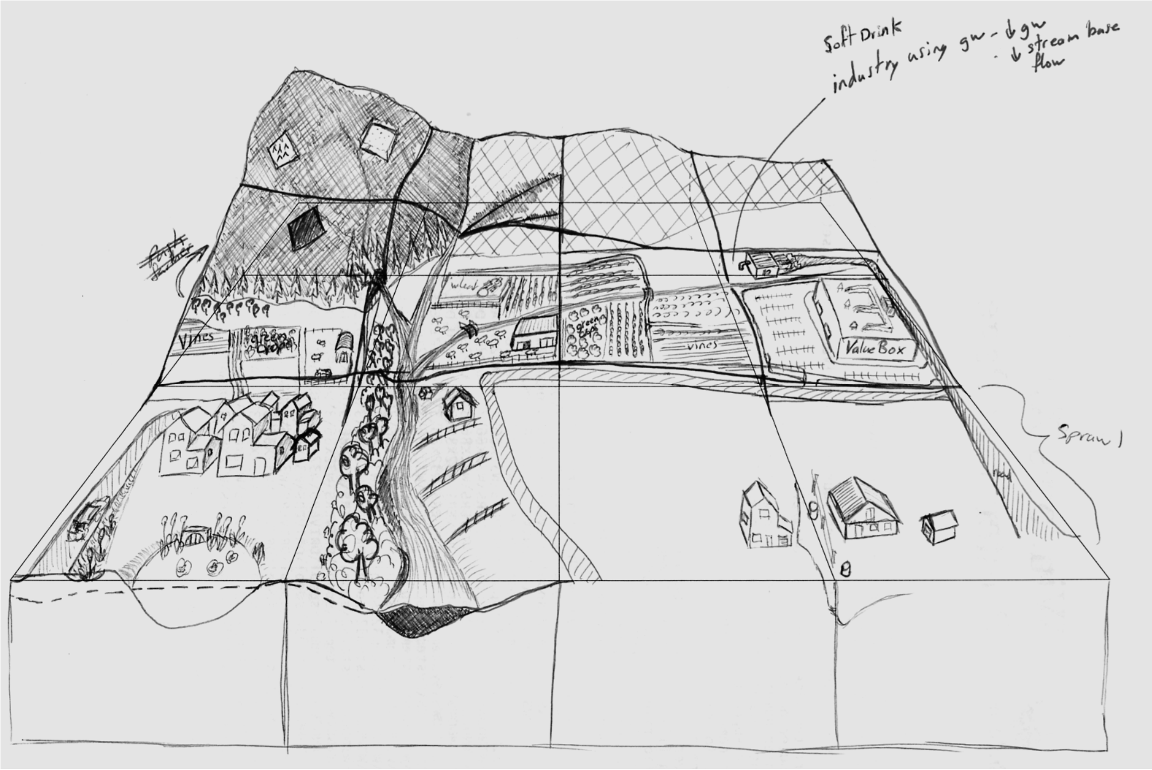


Figure 3-11: Arborville terrain prototype sketch modeled after the GSC OB Waterscape Healthy Streams figure.

3.3.2 Arborville Development

Similarly to the DRASTIC interface, Arborville needed to be web-based and use a dynamic graphics platform. These requirements allowed for either Adobe Flash or SVG. SVG was chosen due to its open source nature allowing subsequent collaborators and researchers to build and improve upon the work. This can especially be beneficial to those who find the cost of Adobe Flash prohibitive but would like to construct similar interfaces by using its code. Adobe Flash includes additional functionality such as a graphics and text editor to create Flash applications. SVG is simply a coding standard. Free software such as Inkscape and Notepad++ are effective alternative graphics and text editors.

The first task was to create the model of the town of Arborville. Using Corel Draw X3, a vector-based graphics editor, a perspective outline of the cubes was created. Corel Draw allows complex manipulation of shapes. Features such as object abstraction, grouping, and layers greatly simplify the manipulation and organization of the creation of a perspective view of terrain. The groups and layers export to SVG with their name or description intact greatly simplifying the interaction programming later. Once the cubes roughly resembled the same perspective angle as the GSC poster scene, elevations were inserted and surface features added. The creation of the content was very time consuming, as the initial landscape and all possible outcomes and combinations of land use had to be created. The latter are necessary to create the transitions from one land use type to another.

Corel Draw was used to create the terrain model of Arborville as well as the map. The interface as a whole with its windows containing the different sections and textual instructions was programmed directly in SVG due to the graphics being human readable code. Customizing the SVG graphics using a text editor allowed faster layout and style testing. This is one of the big advantages of SVG over Adobe Flash.

The creation of the interface from this point on was an iterative process of editing graphics, interaction, and functionality between informal testing of the resulting usability. Figure 3-12 illustrates the process. SVG has some inherently powerful features to create interactive and dynamic processes. Some interaction that cannot be done using simply SVG's animation potential can be powered using JavaScript.

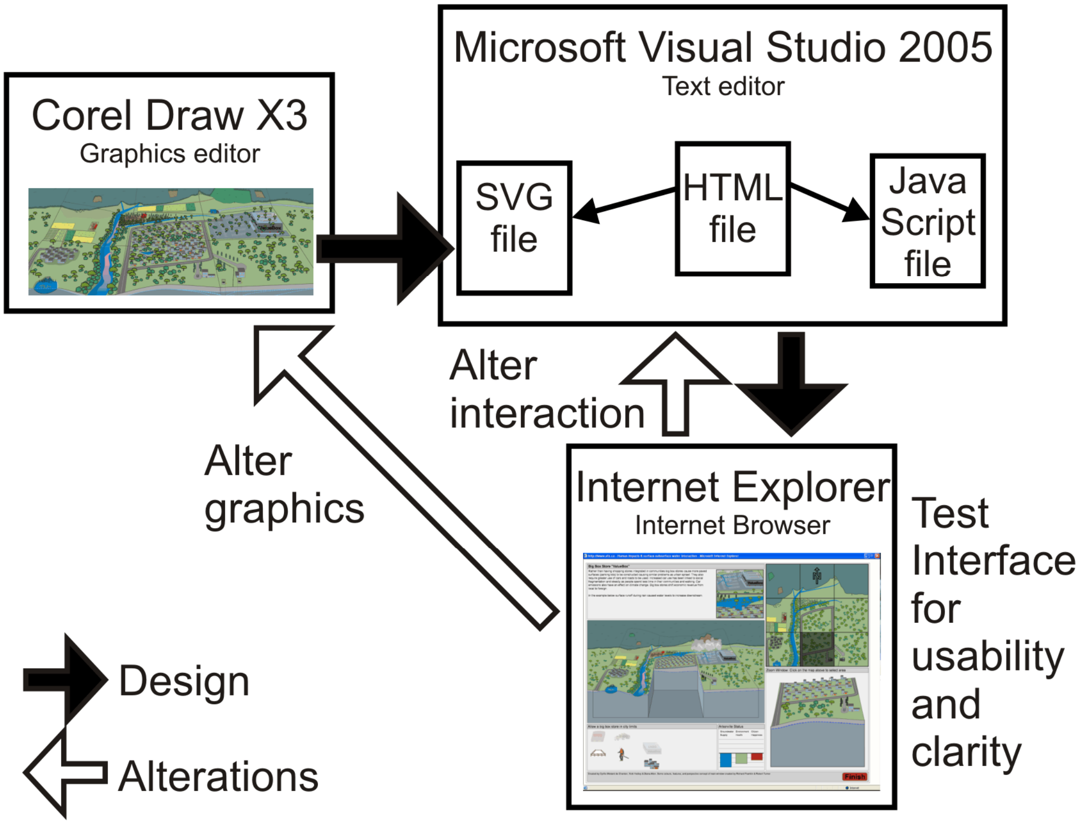


Figure 3-12: Creation of Arborville was an iterative process of altering graphics with Corel Draw and modifying interaction by altering of the SVG and JavaScript files.

The initial model plan contained 12 cubes (see Figure 3-11), but due to the time/labour intensive process the number of cubes was reduced to nine.

From Corel Draw the Arborville scene was exported as SVG with dimensions of 815 pixel width by 530 pixel height. An important benefit of using vector animation is that vector data can be resized without altering the quality of the image. The Arborville scene was resized so that it would fit perfectly within the window designed for it. In addition, the main perspective window was moved down to the middle left of the screen to better position the text window and be more prominent for the user.

In order to maximize the opportunity for users to gain a correct understanding of the concepts, multiple forms of feedback were provided. The visual alterations as a result of land use were designed as primary means of feedback, text and diagrams at the top of the interface as secondary feedback, and the status bars as tertiary feedback. The Arborville status bars (Figure 3-13) attempt to make Arborville more entertaining by mimicking those of SimCity, a popular urban planning video game since the late 1980’s with the “most thoroughly tested and usable cartographic interface available” (Greenspan 2005, 314). These status bars may also provide users with a sense of regret for performing poor land use choices. Although the status bars have no explicit quantities associated with them they do have a hidden range of 60 units maximum and -60 minimum. To what degree individual interactions alter these status bars is described in Appendix B. The value associated with each land use change was determined relative to the other land use outcomes. Review by a hydrogeologic expert later revealed that placement of irrigated crops, which altered environment health and citizen happiness should have also lowered groundwater supply.

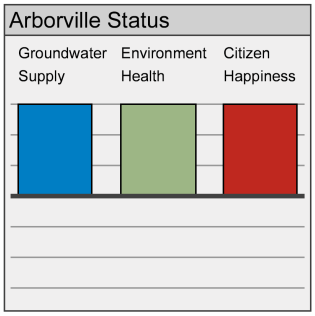


Figure 3-13: Interaction status bars.

The drag and drop interaction was built with ‘physical’ constraints so that the icons could only be dropped in the main terrain window. When the icon is clicked on and dragged over the terrain window, the designated area it is to be dropped on is highlighted yellow with an eye catching red border. Upon mouse button release within the terrain window the icon will slide to the location where the interaction will take place to draw the user’s attention to that point. When a user tries to release the icon outside the terrain window the icon will slide back to its original position in the icon tray at the bottom of the interface. The effect of keeping the icon visible regardless of where it is released rather than letting it disappear strengthens the physical and constructionist metaphor.

Throughout the design and development phase of Arborville, informal testing was conducted by peers within the department. One such tester indicated that the red cross symbolizing “undo” communicated an error to them rather than a button to reverse their actions. The tester believed the program was trying to display/load an image that could not be found. This miscommunication may stem from a similar graphic used in Internet Explorer when an image cannot be found in a webpage. In response, the symbol was replaced by the word “UNDO”. Further, the tester found the light blue dashed line indicating the water table to not be clearly visible. The dashed spacing and colour was adjusted to longer strokes and a darker blue, respectively, to provide more contrast.

Initially users could only click on the mini-map in the top right corner to toggle the visibility of the terrain cubes. Clicking on the squares on the mini-map put the selected cube in the zoom box where they appeared larger. When a second mini-map square was clicked on, the first cube would disappear from the zoom window, not returning to the main terrain window, but being replaced by another cube. Clicking on the terrain cubes in the zoom window or terrain window initially had no effect. Testers felt it was more intuitive to click on the terrain directly to toggle the zoom/un-zoom of the terrain cubes. In response, the possibility to click directly on the main perspective terrain cubes to see them in the zoom window and enlarged was added. Feedback in the form of fading of the cubes during ‘mouse over’ was provided to inform the viewer an interaction could occur. The cube fading effect has some limitations due to latency between mouse over and fading of the cube over which the mouse is hovering. The feature stayed in the final version due to its benefits of easily seeing through a cube without removing it to the zoom window. The lag is approximately a half second long, but any lag longer than a tenth of a second is considered undesirable (Ware 2004, 245). The severity of the lag is believed to be partially due to the mouse tracking slowing the user experience but mainly due the number of features that need their transparency modified.

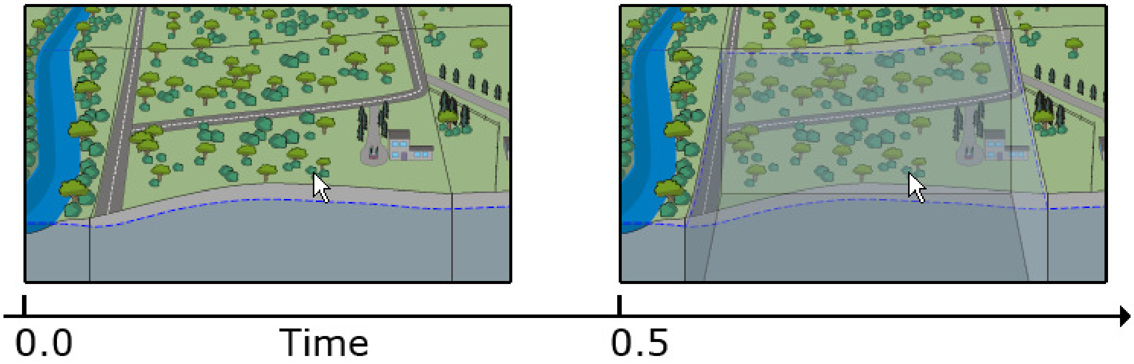


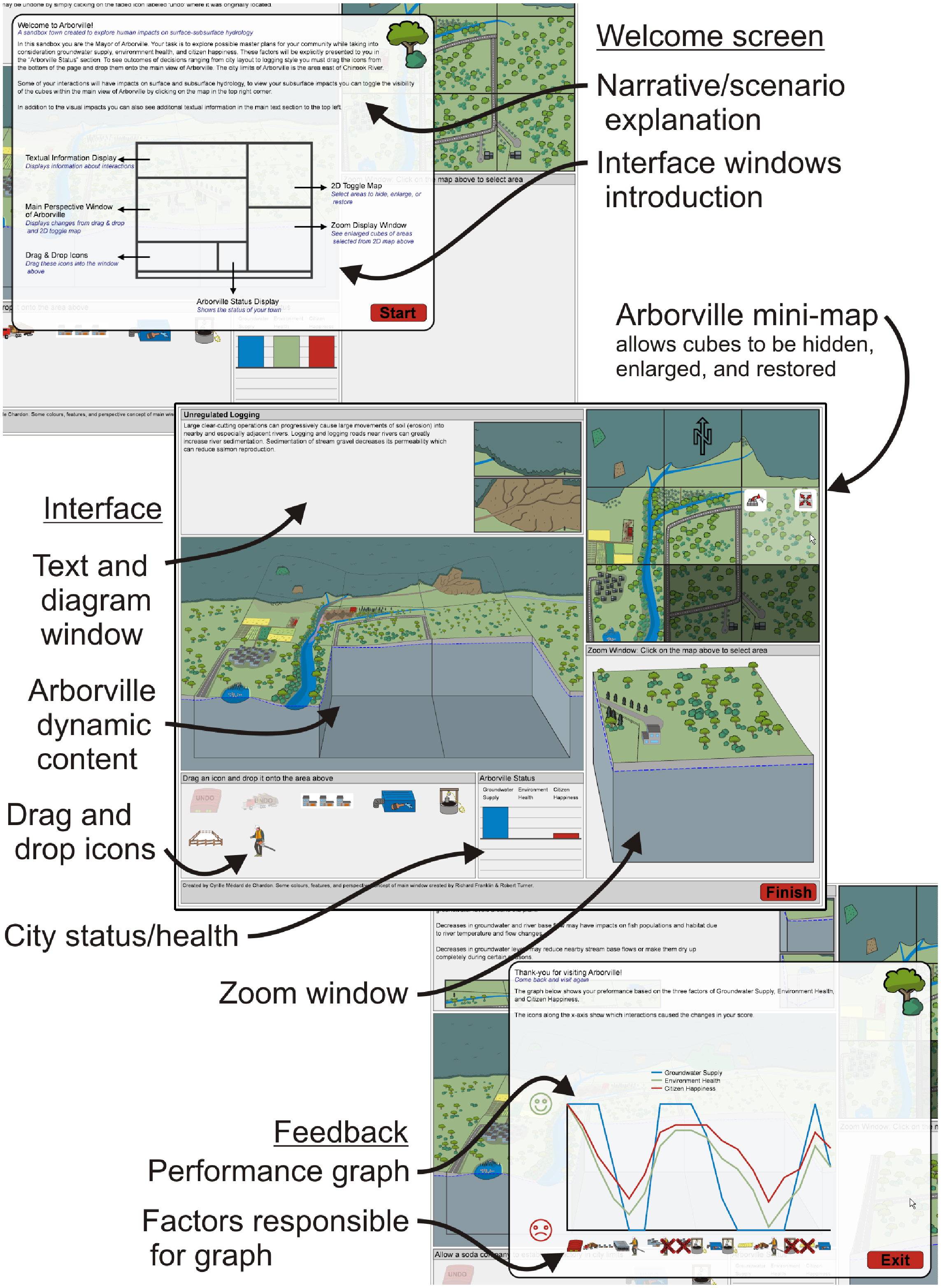
Figure 3-14: Lag in fading of blocks caused by number of features to modify and mouse tracking.

Regarding navigation, Arborville is quite limited. Rather than allowing the user to move relative to the environment, one piece or block of the many in the terrain is brought ‘forward’ towards the user, growing larger, so he or she may examine it better. In order to prevent disorientation the blocks cannot be rotated. The user is not pulled into the virtual environment, but rather a spectator from a perspective bird’s eye view; the immersion is low. Rather, Arborville, gives the user secondary survey knowledge to understand the spatial relationships between the land use types in the model.

Arborville, like the GSC poster, uses a perspective view of the environment. A concern with perspective view is that it may communicate a distorted model to the user. Arborville uses grid lines that correspond in the top-down orthogonal view as right angle lines. They are included to delineate the cubes and to communicate that cubes in the front are actually the same size as those which appear smaller in the back. The grid lines in Arborville may reduce distortion of the user’s mental map of the perspective view content by providing corrective guidelines.

Interactions in Arborville are multi-linear. Each initial interaction allows new interaction types. Performing certain interactions, however, causes others to become unavailable. Constraints were added to only allow certain land use types to occur concurrently. It was too time consuming to allow all land use changes concurrently. Due to the scripted nature of the interactions every possible outcome must be created graphically and programmed. When two concepts are in proximity and alter the same feature, such as groundwater, changes are cumulative and therefore require a greater number of outcomes. Outcomes grow geometrically with the number of concepts combined. For example, two features with three possible states that affect the same feature will require nine scripted outcomes. For this reason, land use decisions were located to not interfere with one another or constrained from occurring at the same time.

The resulting Arborville (Figure 3-15) greets the user with a welcome screen containing a narrative and explaining the components of the interface and briefly how they function. It tasks the user with exploring land use possibilities for Arborville as its virtual mayor while considering groundwater supply, environment health, and citizen happiness. The narrative helps prime the user while providing information about how to operate interface. This keeps the focus on using the interface for a purpose rather than simply learning how to operate for its own sake.



may be undone by simply clicking on the faded icon labeled 'undo' where it was originally located.

Welcome to Arborville!

A sandbox town created to explore human impacts on surface-subsurface hydrology

In this sandbox you are the Mayor of Arborville. Your task is to explore possible master plans for your community while taking into consideration groundwater supply, environmnent health, and citizen happiness. These factors will be explicitly presented to you in the "Arborville Status" section. To see outcomes of decisions ranging from city layout to logging style you must drag the icons from the bottom of the page and drop them onto the main view of Arborville. The city limits of Arborville is the area east of Chinook River.

Some of your interactions will have impacts on surface and subsurface hydrology, to view your subsurface impacts you can toggle the visibility of the cubes within the main view of Arborville by clicking on the map in the top right corner.

In addition to the visual impacts you can also see additonal textual information in the main text section to the top left.

Unregulated Logging

Large clear-cutting operations can progressively cause large movements of soil (erosion) into nearby and especially adjacent rivers. Logging and logging roads near rivers can greatly increase river sedimentation. Sedimentation of stream gravel decreases its permeability which can reduce salmon reproduction.

Created by Cyrille Médard de Chardon. Some colours, features, and perspective concept of main window created by Richard Franklin & Robert Turner.

Decreases in groundwater and river base flow may have impacts on fish populations and habitat due to river temperature and flow changes.

Decreases in groundwater levels may reduce nearby stream base flows or make them dry up completely during certain seasons.

Thank-you for visiting Arborville!

Come back and visit again

The graph below shows your preformance based on the three factors of Groundwater Supply, Environment Health, and Citizen Happiness.

The icons along the x-axis show which interactions caused the changes in your score.

Figure 3-15: Arborville's three stages: Introduction, Interaction, and Feedback.

The interface is laid out similarly to the original design (Figure 3-10) with some changes to the scales of the windows and location shifts. The text and diagram window in the top left is not interactive but provides contextual feedback dynamically when an interaction with the land use icons is performed. The map in the top right corner containing nine equally sized squares of terrain can be clicked on to enlarge, hide, or restore cubes from the main perspective window. The main perspective window can also be used to click on the cubes to make them enlarge in the zoom window located in the bottom right, or the base of the cube to make it reappear. The icons in the lower left window are dragged onto the terrain window to add the selected land use type to Arborville. As stated earlier, each land use icon has only one possible destination within Arborville. As long as the icon is released within the terrain window it will slide to the correct location which is highlighted yellow. The highlights help attract user attention to the location where the land use changes take place.

As the interface grew in complexity and the JavaScript file to over a thousand lines of code it became a struggle to comprehend all the relationships between functions. JavaScript functions controlled the Arborville interface but a method of recording users' interactions was required. To add the functionality to the JavaScript code better comprehension of the relationships was necessary. In order to facilitate comprehension of the interaction between the JavaScript functions a small program was created that visually depicts the relationships between functions in JavaScript code. PHP, a server side scripting language, was used to parse the JavaScript code and generate SVG code to create graphic representations of the function relationships. This new program, named CodeVis, was used repeatedly for the creation of different versions of Arborville. Figure 3-16 shows the relationships of Arborville's JavaScript code. The functions that call a greater number of other functions are represented by larger circles (importance). Those functions which call themselves have a white concentric circle. The black lines show which functions call which. Finally, the gray, red, blue and green colours represents whether it is not called from within the JavaScript file, called from within the file, called from within the file and calls other functions, and only calls other functions, respectively.

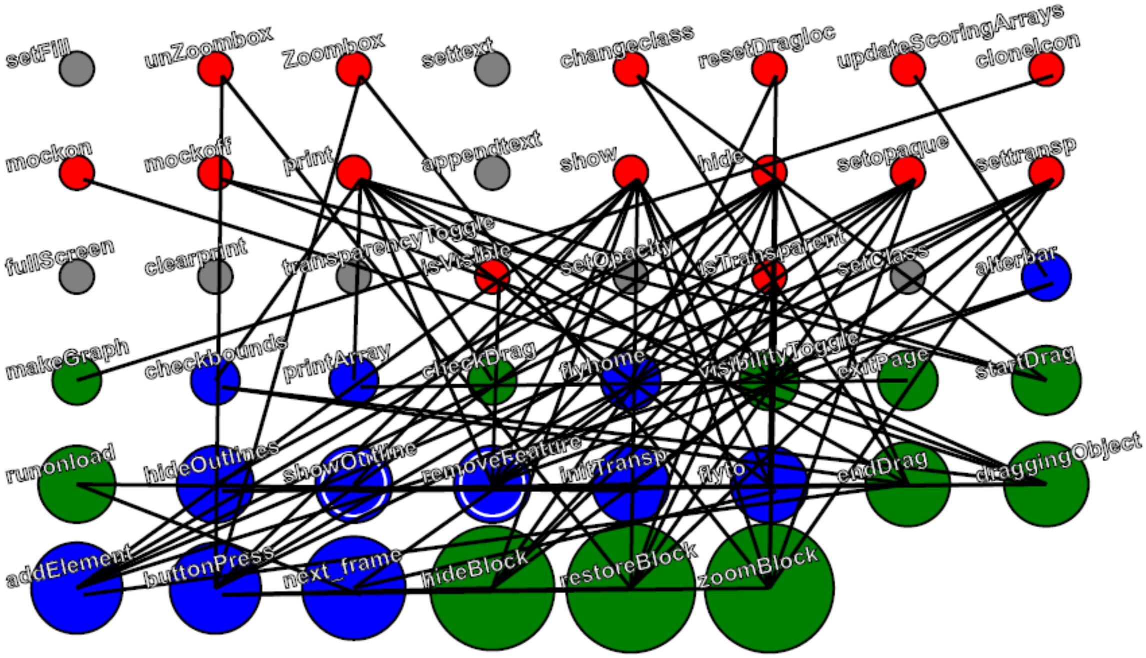


Figure 3-16: CodeVis created graphic representations of the relationships between JavaScript functions.

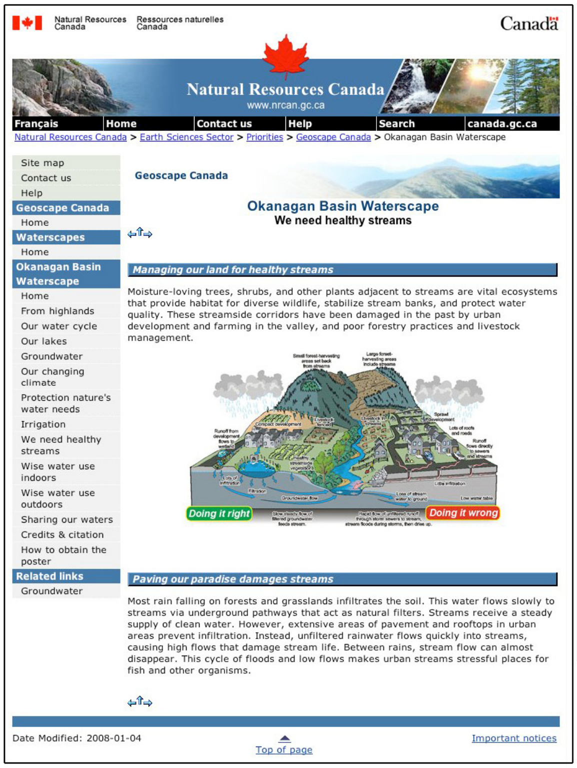
3.3.3 Arborville Variations

In order to determine if there are differences between the Arborville interface and conventional communication methods, new interface versions based on Arborville were created that bridge conventional educational methods and the Arborville interface. Six additional interface versions based on Arborville were created, each with one or two variations from the most basic version based on the GSC waterscape poster. The versions are number from the simplest (Version1) to the most complext (Version 8). Version 1 is the GSC Waterscape poster segment and Version 8 is the Arborville described in the previous section. These two interface versions bookend the six others created for testing. The eight interface versions provide an opportunity to isolate various factors such as interaction, representation, frame of reference, and feedback. Each of the following versions was created to provide a detectable difference from its previous version.

Arborville Version 1 (Static)

The static version of Arborville is a copy of a section of the GSC OB Waterscapes poster (Figure 3-8). Using the original Corel vector data file it was embedded into the SVG interface layout to have the similar look as the other Arborville versions, but provides no further information or interaction than the paper poster. Arborville Version 1 is almost identical to the online distribution of the OB Waterscape poster located on the NRCan website (Figure 3-17) (http://geoscape.nrcan.gc.ca/h2o/okanagan/streams_e.php). The online OB Waterscape website presents each concept on separate pages. The NRCan OB Waterscape website (Natural Resources Canada 2008) and Arborville Version 1 contain the exact same content with layout and size changes. The online OB

Waterscape version’s presence validates Arborville Version 1 as a conventional baseline to test other versions against.



Okanagan Basin Waterscape

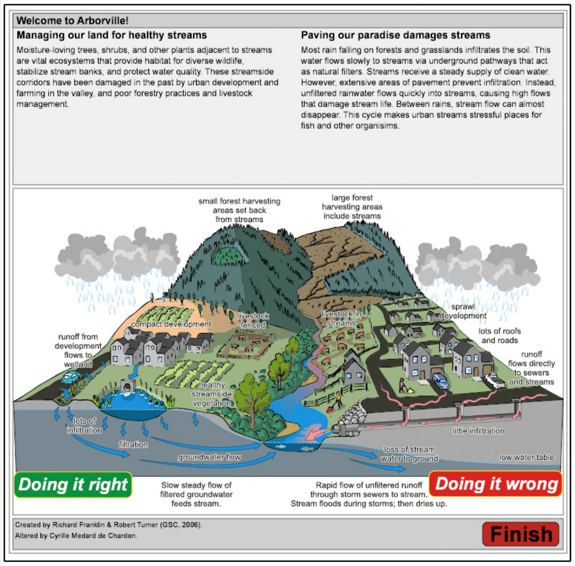
We need healthy streams

Managing our land for healthy streams

Moisture-loving trees, shrubs, and other plants adjacent to streams are vital ecosystems that provide habitat for diverse wildlife, stabilize stream banks, and protect water quality. These streamside corridors have been damaged in the past by urban development and farming in the valley, and poor forestry practices and livestock management.

Paving our paradise damages streams

Most rain falling on forests and grasslands infiltrates the soil. This water flows slowly to streams via underground pathways that act as natural filters. Streams receive a steady supply of clean water. However, extensive areas of pavement and rooftops in urban areas prevent infiltration. Instead, unfiltered rainwater flows quickly into streams, causing high flows that damage stream life. Between rains, stream flow can almost disappear. This cycle of floods and low flows makes urban streams stressful places for fish and other organisms.



Managing our land for healthy streams

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Paving our paradise damages streams

Most rain falling on forests and grasslands infiltrates the soil. This water flows slowly to streams via underground pathways that act as natural filters. Streams receive a steady supply of clean water. However, extensive areas of pavement prevent infiltration. Instead, unfiltered rainwater flows quickly into streams, causing high flows that damage stream life. Between rains, stream flow can almost disappear. This cycle makes urban streams stressful places for fish and other organisims.

Slow steady flow of filtered groundwater feeds stream.

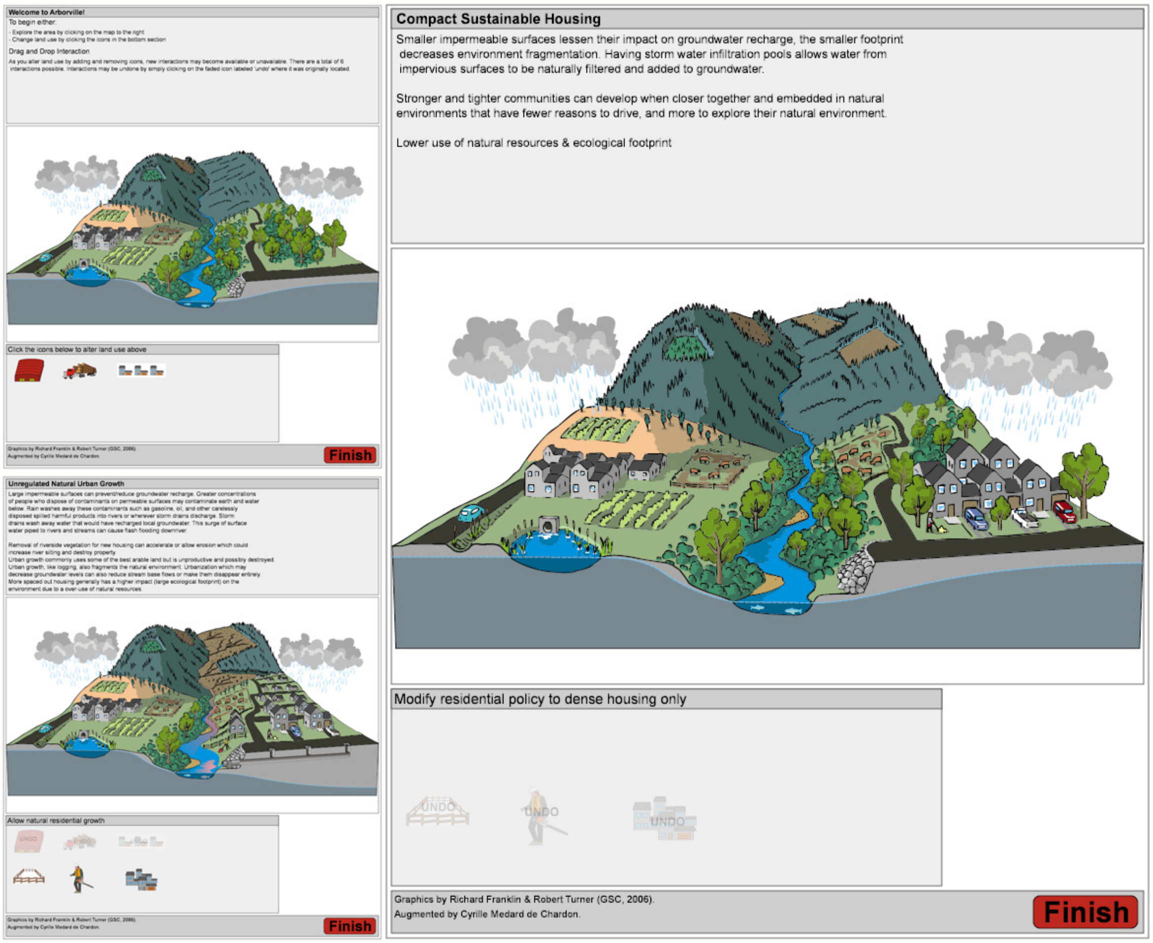
Rapid flow of unfiltered runoff through storm sewers to stream. Stream floods during storms; then dries up.

Created by Richard Franklin & Robert Turner (GSC, 2006).
Altered by Cyrille Medard de Chardon.

Figure 3-17: Conventional approaches to disseminating the GSC OB Waterscape poster online (left) (Natural Resources Canada 2008). The Arborville Version 1 equivalent (right).

Arborville Version 2 (Interactive)

Arborville Version 2 is the only other version using graphics from the GSC poster, yet it has been augmented to allow interactions. Using graphic elements from the original scenario alternate land use choices were created. The user is initially greeted with a blank slate, a pristine environment, and can alter three types of land use: cattle, logging, and housing (Figure 3-18). Interaction can increase attention by facilitating the finding of relevant information for users and benefit their experiences (Tversky et al. 2002, 250). Interaction is also an essential component of constructionist learning (Ketterfeld et al. 2006, 300).



Welcome to Arborville!

To begin either:

- Explore the area by clicking on the map to the right
- Change land use by clicking the icons in the bottom section

Drag and Drop Interaction

As you alter land use by adding and removing icons, new interactions may become available or unavailable. There are a total of 6 interactions possible. Interactions may be undone by simply clicking on the faded icon labeled 'undo' where it was originally located.

Click the icons below to alter land use above

Graphics by Richard Franklin & Robert Turner (GSC, 2006).
Augmented by Cyrille Medard de Chardon.

Unregulated Natural Urban Growth

Large impermeable surfaces can prevent/reduce groundwater recharge. Greater concentrations of people who dispose of contaminants on permeable surfaces may contaminate earth and water below. Rain washes away these contaminants such as gasoline, oil, and other carelessly disposed spilled harmful products into rivers or wherever storm drains discharge. Storm drains wash away water that would have recharged local groundwater. This surge of surface water piped to rivers and streams can cause flash flooding downriver.

Removal of riverside vegetation for new housing can accelerate or allow erosion which could increase river silting and destroy property.
Urban growth commonly uses some of the best arable land but is unproductive and possibly destroyed.
Urban growth, like logging, also fragments the natural environment. Urbanization which may decrease groundwater levels can also reduce stream base flows or make them disappear entirely.
More spaced out housing generally has a higher impact (large ecological footprint) on the environment due to a over-use of natural resources.

Allow natural residential growth

Graphics by Richard Franklin & Robert Turner (GSC, 2006).
Augmented by Cyrille Medard de Chardon.

Compact Sustainable Housing

Smaller impermeable surfaces lessen their impact on groundwater recharge, the smaller footprint decreases environment fragmentation. Having storm water infiltration pools allows water from impervious surfaces to be naturally filtered and added to groundwater.

Stronger and tighter communities can develop when closer together and embedded in natural environments that have fewer reasons to drive, and more to explore their natural environment.

Lower use of natural resources & ecological footprint

Modify residential policy to dense housing only

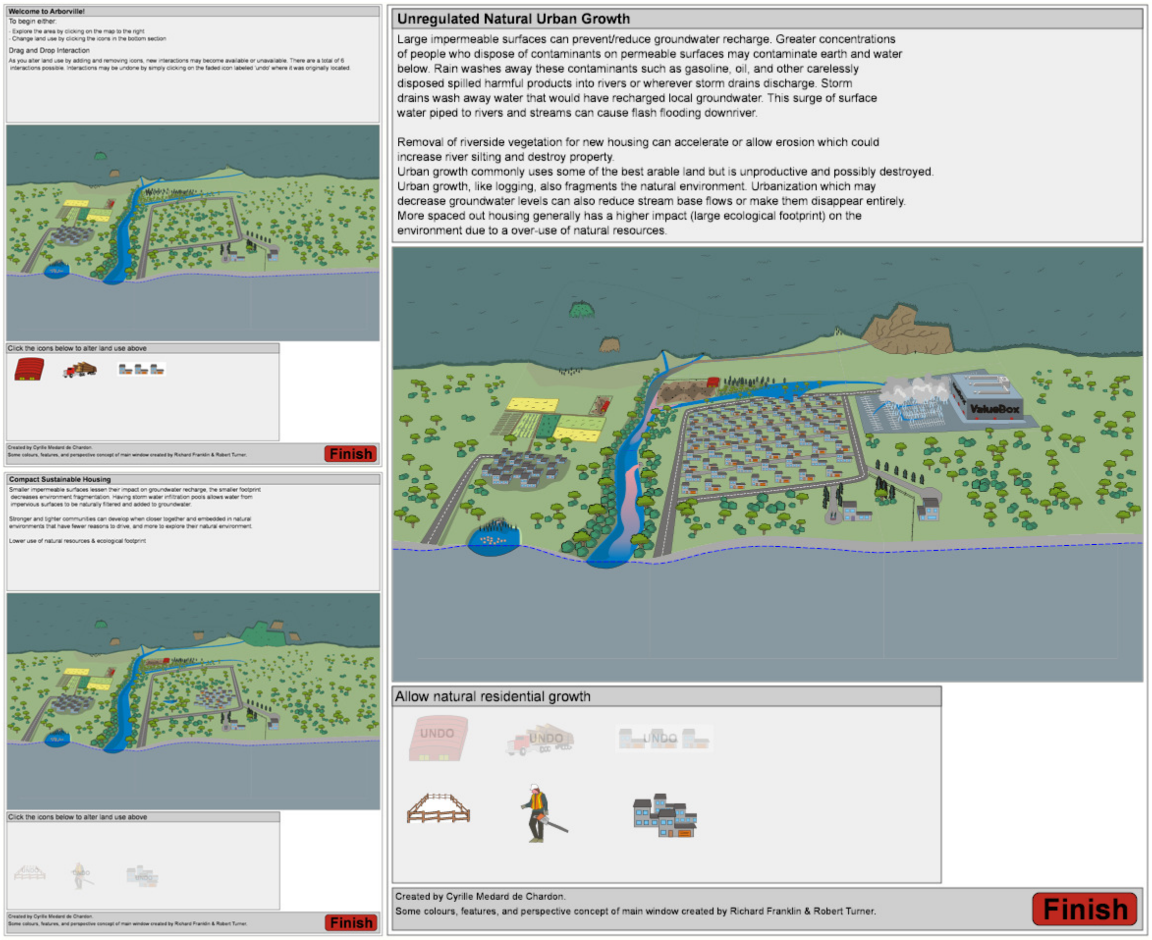
Graphics by Richard Franklin & Robert Turner (GSC, 2006).
Augmented by Cyrille Medard de Chardon.

Figure 3-18: Arborville Version 2 created interactive alternatives users could explore.

Arborville Version 2 has lost the original text as well as the arrows showing the flow of contaminants explicitly from Version 1. The glyphs communicate the dynamic nature of groundwater flow. Version 2 replaces the glyphs with dynamic graphics. The original and more general text has been replaced with information more specific to the interaction performed.

Arborville Version 3 (Modified graphic style)

The graphical style is the largest difference between Arborville Version 2 and 3. To allow more complex interaction than that those present in Arborville Version 2 new graphic representations were required. The graphics file used to create the OB Waterscape poster was too difficult to modify to add complex interaction. Version 2 and 3 contain the same interactions, icons, layout, and text. Only the graphical style is different (Figure 3-19).



Welcome to Arborville!

To begin either:

- Explore the area by clicking on the map to the right
- Change land use by clicking the icons in the bottom section

Drag and Drop Interaction

As you alter land use by adding and removing icons, new interactions may become available or unavailable. There are a total of 6 interactions possible. Interactions may be undone by simply clicking on the faded icon labeled 'undo' where it was originally located.

Created by Cyrille Medard de Chardon.
Some colours, features, and perspective concept of main window created by Richard Franklin & Robert Turner.

Compact Sustainable Housing

Smaller impermeable surfaces lessen their impact on groundwater recharge, the smaller footprint decreases environment fragmentation. Having storm water infiltration pools allows water from impervious surfaces to be naturally filtered and added to groundwater.

Stronger and tighter communities can develop when closer together and embedded in natural environments that have fewer reasons to drive, and more to explore their natural environment.

Lower use of natural resources & ecological footprint

Created by Cyrille Medard de Chardon.
Some colours, features, and perspective concept of main window created by Richard Franklin & Robert Turner.

Unregulated Natural Urban Growth

Large impermeable surfaces can prevent/reduce groundwater recharge. Greater concentrations of people who dispose of contaminants on permeable surfaces may contaminate earth and water below. Rain washes away these contaminants such as gasoline, oil, and other carelessly disposed spilled harmful products into rivers or wherever storm drains discharge. Storm drains wash away water that would have recharged local groundwater. This surge of surface water piped to rivers and streams can cause flash flooding downriver.

Removal of riverside vegetation for new housing can accelerate or allow erosion which could increase river silting and destroy property.
Urban growth commonly uses some of the best arable land but is unproductive and possibly destroyed.
Urban growth, like logging, also fragments the natural environment. Urbanization which may decrease groundwater levels can also reduce stream base flows or make them disappear entirely.
More spaced out housing generally has a higher impact (large ecological footprint) on the environment due to a over-use of natural resources.

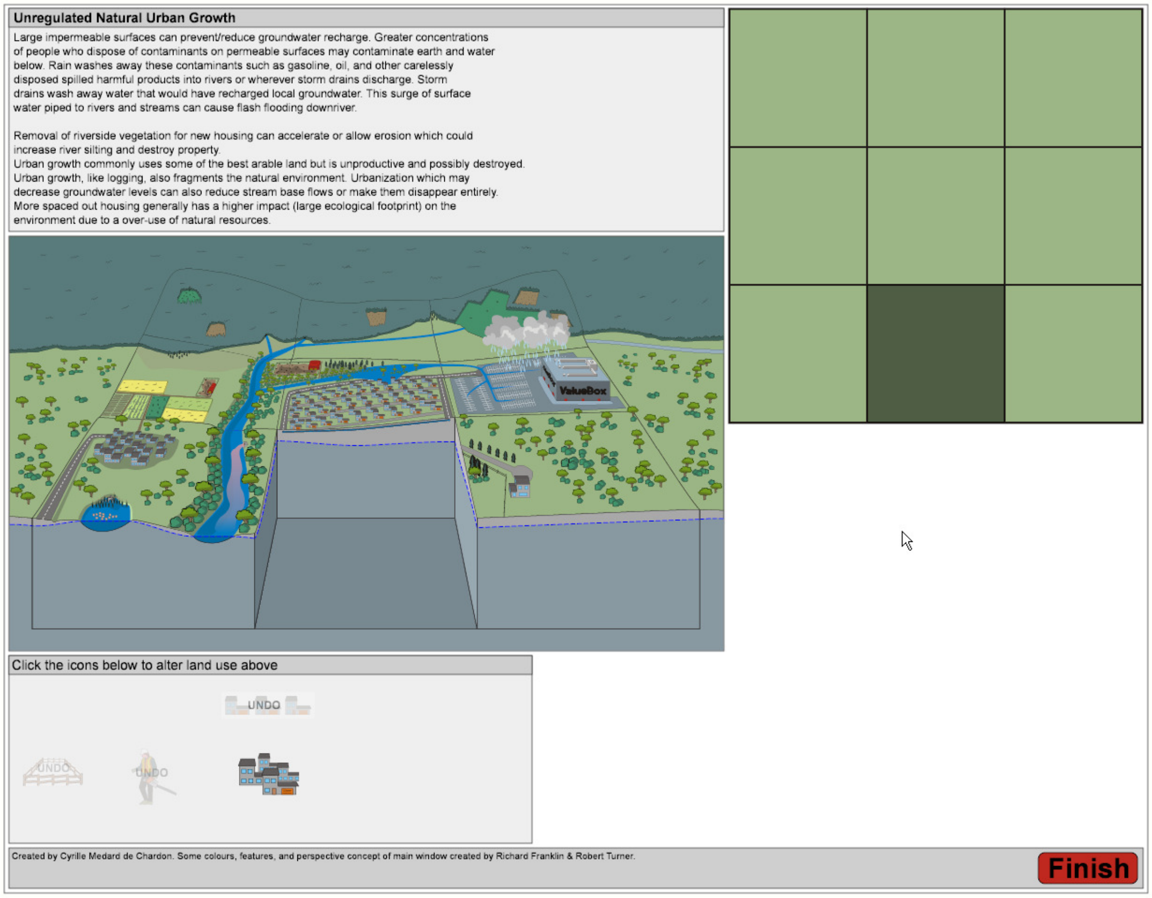
Allow natural residential growth

Created by Cyrille Medard de Chardon.
Some colours, features, and perspective concept of main window created by Richard Franklin & Robert Turner.

Figure 3-19: Arborville Version 3 has similar interaction, icon, layout and text as version 2. The graphic style is the only difference.

Arborville Version 4 (Cubes toggle)

Compared to Arborville Version 3, Version 4 includes the ability to toggle the visibility of nine discretized cubes. To implement the new interaction the user can click either the blocks themselves or the blank ‘map’ of Arborville in the top right corner. In addition to this interaction and slight graphic variation, the transitions of land use changes are no longer abrupt but animated.



Unregulated Natural Urban Growth

Large impermeable surfaces can prevent/reduce groundwater recharge. Greater concentrations of people who dispose of contaminants on permeable surfaces may contaminate earth and water below. Rain washes away these contaminants such as gasoline, oil, and other carelessly disposed spilled harmful products into rivers or wherever storm drains discharge. Storm drains wash away water that would have recharged local groundwater. This surge of surface water piped to rivers and streams can cause flash flooding downriver.

Removal of riverside vegetation for new housing can accelerate or allow erosion which could increase river silting and destroy property.
Urban growth commonly uses some of the best arable land but is unproductive and possibly destroyed.
Urban growth, like logging, also fragments the natural environment. Urbanization which may decrease groundwater levels can also reduce stream base flows or make them disappear entirely.
More spaced out housing generally has a higher impact (large ecological footprint) on the environment due to a over-use of natural resources.

Click the icons below to alter land use above

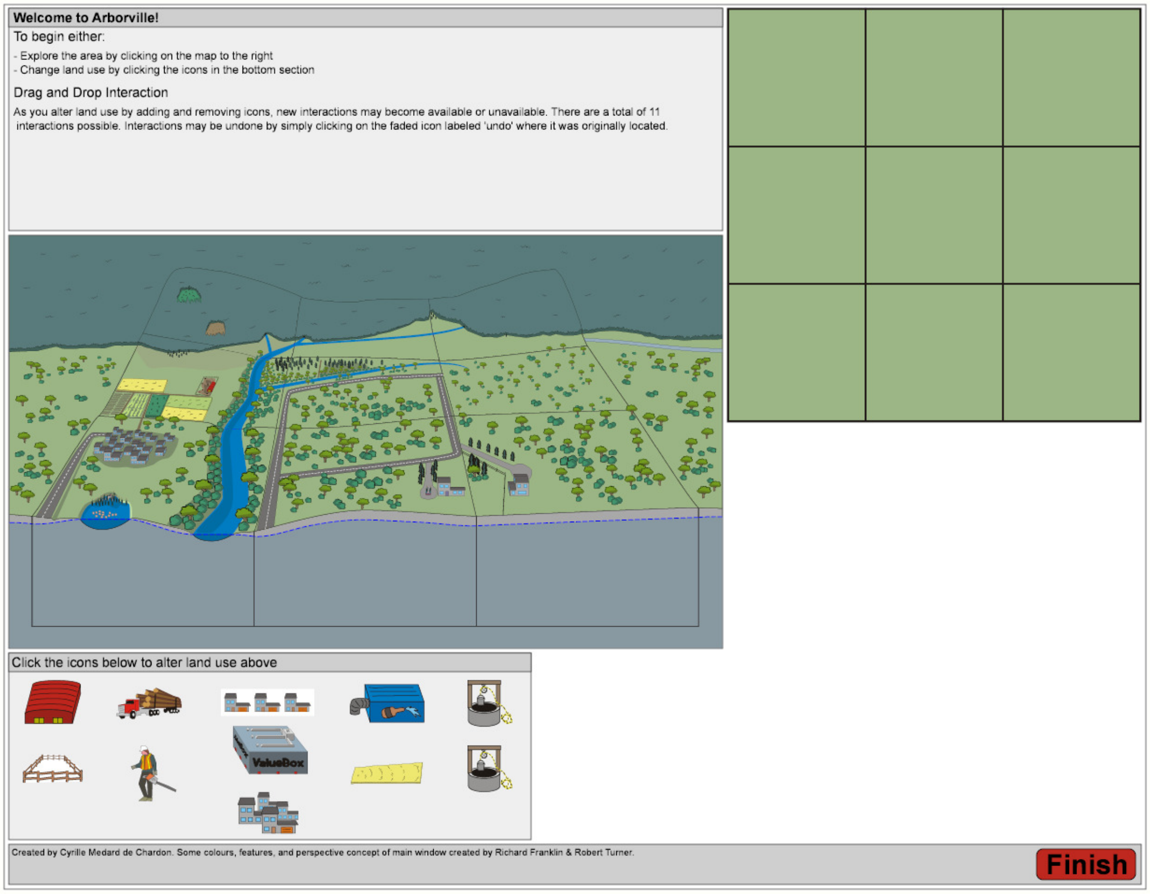
Created by Cyrille Medard de Chardon. Some colours, features, and perspective concept of main window created by Richard Franklin & Robert Turner.

Figure 3-20: Arborville Version 4 allows the toggling of cubes and provides animated transitions to land use changes.

Animation is thought to benefit the user by showing the micro steps between two stages. This version of Arborville was created to determine whether the animations are effective. The grid lines on the terrain, while minor, may add definition and greater depth perception compared to version 3. Version 4 (Figure 3-20), in addition, is a wider interface than the previous versions. This may cause viewing problems for users with low-resolution displays.

Arborville Version 5 (Added content)

Arborville Version 5 has no interaction changes to Version 4, only added content. The number of interactions possible in version two through four was increased in version 5. The user can now explore agricultural land use, and industrial and residential groundwater pumping (Figure 3-21).



To begin either:

- Explore the area by clicking on the map to the right
- Change land use by clicking the icons in the bottom section

Drag and Drop Interaction

As you alter land use by adding and removing icons, new interactions may become available or unavailable. There are a total of 11 interactions possible. Interactions may be undone by simply clicking on the faded icon labeled 'undo' where it was originally located.

Click the icons below to alter land use above

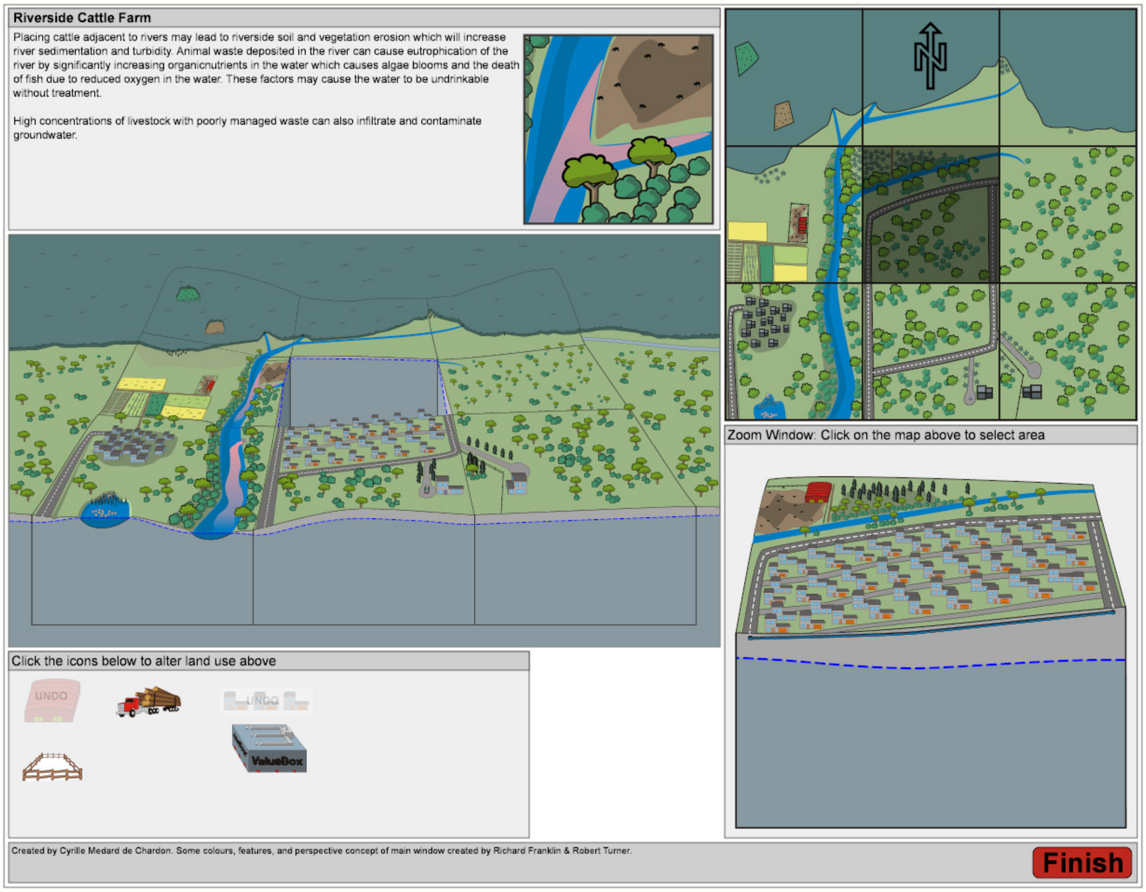
Created by Cyrille Medard de Chardon. Some colours, features, and perspective concept of main window created by Richard Franklin & Robert Turner.

Figure 3-21: Arborville Version 5 contains addition land use interaction types (this screenshot is a mock-up to show all possible interactions that otherwise would not be visible at the same time).

Arborville Version 5 was created in an attempt to determine the impact of incidental learning, what the user learns beyond the intended target information (Lindgaard et al. 2005, 222). Learning externalities may be cognitively taxing or have no impact on participant performance.

Arborville Version 6 (Zoom and map)

Arborville Version 6 adds the zoom window allowing the terrain cubes to be viewed as larger individual blocks. In addition, version 6 has terrain details on the map in the top right corner (Figure 3-22). The alterations were added to determine whether detailed maps and enlarged content are effective in communicating target concepts.


Riverside Cattle Farm

Placing cattle adjacent to rivers may lead to riverside soil and vegetation erosion which will increase river sedimentation and turbidity. Animal waste deposited in the river can cause eutrophication of the river by significantly increasing organicnutrients in the water which causes algae blooms and the death of fish due to reduced oxygen in the water. These factors may cause the water to be undrinkable without treatment.

High concentrations of livestock with poorly managed waste can also infiltrate and contaminate groundwater.

Zoom Window: Click on the map above to select area

Click the icons below to alter land use above

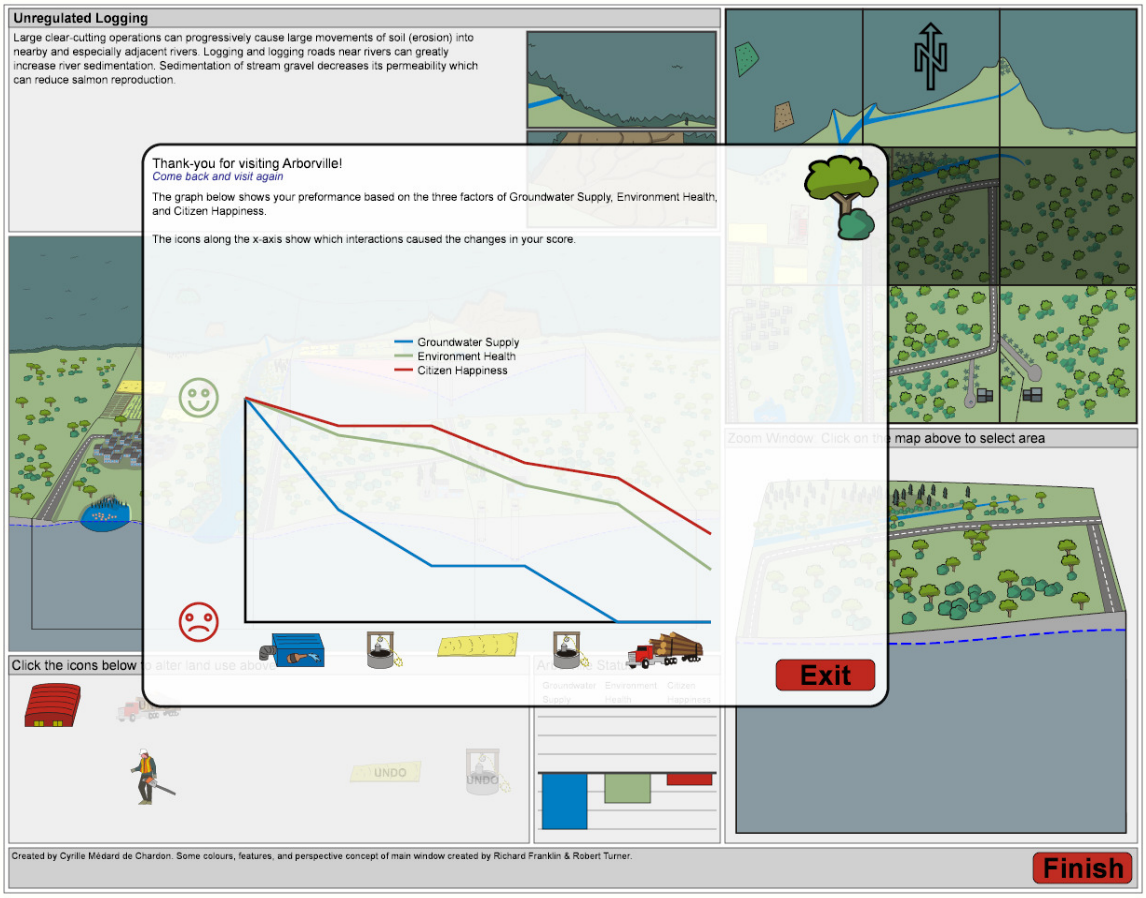
Created by Cyrille Medard de Chardon. Some colours, features, and perspective concept of main window created by Richard Franklin & Robert Turner.

Figure 3-22: Version 6 includes the zoom window and land use details to the map.

Arborville Version 7 (Status bar and graph)

In addition to the changes to version 6, Arborville Version 7 adds feedback in the form of bar and line graphs depicting the relative health of Arborville's groundwater supply, environment health, and citizen happiness. The bar graph is visible throughout interaction and changes dynamically with land use changes.

The line graph is displayed when the user has finished exploring Arborville and shows how their land use choices altered groundwater, environment, and citizen scores over the time of their experience. While the y-axis shows quantity the x-axis depicts icons representing the interactions performed (Figure 3-23). This version of Arborville was created to measure the effect of feedback.



Unregulated Logging

Large clear-cutting operations can progressively cause large movements of soil (erosion) into nearby and especially adjacent rivers. Logging and logging roads near rivers can greatly increase river sedimentation. Sedimentation of stream gravel decreases its permeability which can reduce salmon reproduction.

Thank-you for visiting Arborville!

Come back and visit again

The graph below shows your preformance based on the three factors of Groundwater Supply, Environment Health, and Citizen Happiness.

The icons along the x-axis show which interactions caused the changes in your score.

Created by Cyrille Médard de Chardon. Some colours, features, and perspective concept of main window created by Richard Franklin & Robert Turner.

Figure 3-23: Version 7 includes bar and line graph feedback of citizen happiness, groundwater supply, and environmental health.

Arborville Version 8 (Drag and drop)

Arborville Version 8, as described in section 3.3.2, includes all the features of version 7 with the addition of the ability to drag and drop icons onto the terrain rather than simply click on them for the land use change to occur (Figure 3-24).

Figure 3-24: Arborville Version 8 contains the ability to drag and drop land use icons onto the terrain directly. Industrial groundwater pumping (left) and well (right).

Differences between Arborville Versions

The differences between the eight different versions or Arborville described above are summarized in Table 3-2.

Table 3-2: The main differences between the eight versions of Arborville.

Version	*Differences from previous version*	*Independent Variable Tested*
Version 1	Static, contains glyphs, general text	–
Version 2	Interactive, specific text, multiple land uses	Interaction*, representation (glyphs), text
Version 3	Different Graphic style	Representation*
Version 4	Cubes can be toggled, transitions animated	Interaction*, representation, frame of reference
Version 5	Added content	Content*
Version 6	Zoom window and map	Representation*, frame of reference
Version 7	Status bar and graph feedback	Feedback*
Version 8	Drag and drop	Interaction*

* Indicates main independent variable

In addition to interface variations between the versions there are more subtle changes which cause difficulties for the users with lower resolution displays. The eight versions of Arborville fall into three sizes. Versions 1 is the smallest, Versions 2 and 3 are longer than Version 1, and Versions 4 to 8 are wider than Versions 2 and 3. Keeping the Arborville model the same size across all versions required making the interfaces with additional features, such as interaction, the mini-map, and zoom window, larger. As a result Versions 2 through 8 all require a display device with a minimum of SXGA resolution (1280 width by 1024 height). Version 1 is visible with XGA resolution (1024 width by 768 height) or greater. Because SVG is vector-based, it is possible to easily reduce the dimensions of the interface. This was not done in order to consistently present the same interface quality and size. The relative sizes of the interfaces are visible in Figure 3-25.

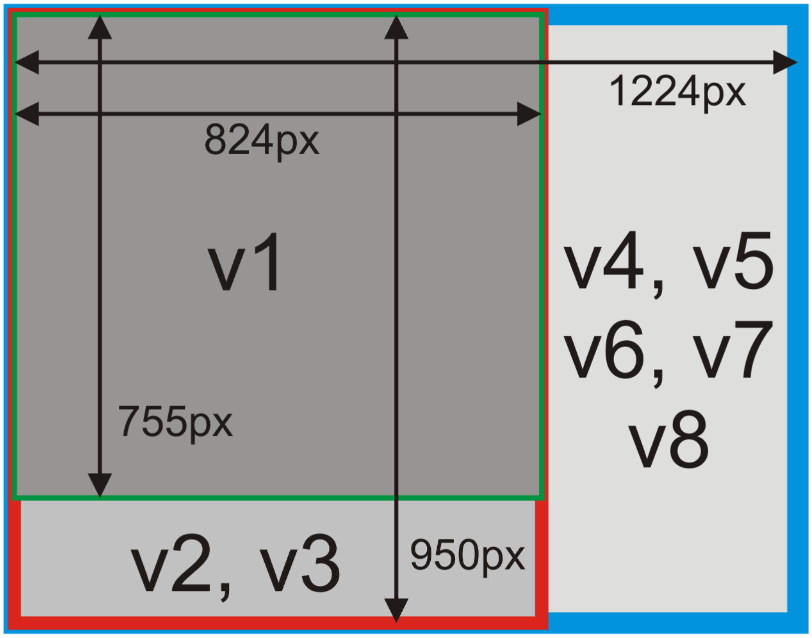


Figure 3-25: The three different dimensions of the Arborville versions. Note that while versions 2-3 and 4-8 are significantly different they still require a similar display due to the rectangular nature of display devices.

3.3.4 Testing of Arborville Variations

The testing aimed to determine the differences, if any, in perception or knowledge between users of the various versions of Arborville. In order to determine these variations a scale was created (Table 3-3) to measure knowledge. In addition to measuring explicit values additional data were recorded regarding the timing and kind of interactions performed when using the various Arborville versions.

The testing framework for Arborville, like DRASTIC, is online and randomly assigns users to one of the eight versions of Arborville. There is an exception to users with low resolution displays however. If their monitor displays less than 1024 vertical pixels they will automatically be given Version 1 which has lower resolution requirements.

As in the DRASTIC testing section discussed, having users interact through their PCs in a setting they feel comfortable minimizes distortion of results. Since these educational tools would be distributed online this provides a realistic field test of the software.

Arborville testing consists of six web pages (Figure 3-26). Like DRASTIC they all contain a status bar at the bottom of the page showing the user at which stage in the process of completing the online survey they are at in an attempt to promote survey completion.

The first page provides a simple and brief introduction inviting the visitor to participate in the use of Arborville and complete the survey. The second page contains the legal ethics form. Users who do not agree are sent back to the introductory page. Page 3 asks some demographic questions as well as whether the user has filled out the survey before. The Arborville pre-test (Table 3-3) is presented on the bottom of the page in a randomly generated order.

Table 3-3: Arborville Human Impacts on Groundwater Comprehension (AHIG-C) Scale Questions.

In general…	*Strongly Disagree*	*Dis-agree*	*Un-decided*	*Agree*	*Strongly Agree*
1. Logging near streams is more likely to harm fish.	1	2	3	4	5
2. Large urban areas do not affect groundwater levels.	5	4	3	2	1
3. Larger urban areas can cause higher than usual river flows during and after rainfall.	1	2	3	4	5
4. Natural groundwater levels recharge streams.	1	2	3	4	5
5. Larger urban areas can decrease water levels of nearby streams (base flow).	1	2	3	4	5
6. Cattle by streams are unlikely to contaminate the water.	5	4	3	2	1
7. Stream side cattle reduce filtration of surface runoff.	1	2	3	4	5
8. Paved surfaces prevent unfiltered rainwater to quickly flow to streams.	5	4	3	2	1
9. Streamside cattle do not affect fish and other organisms in the stream.	5	4	3	2	1
10. Lower than usual groundwater levels do not affect streams.	5	4	3	2	1

There are ten questions in the Arborville Human Impacts on Groundwater Comprehension (AHIG-C) scale (Table 3-3). The questions all focus on the concepts communicated by the original GSC Waterscape poster. They attempt to measure what individual concepts the user has learned from using any of the Arborville interface versions. Similarly to the DRASTIC scale questions, limitations to the AHIG-C scale were later revealed from testing by a hydrogeologic expert who did not agree with all the scale’s designated correct answers. Future research will test survey scales with their respective expert prior to testing.

Page 4 of the Arborville online survey (Figure 3-26) contains code to check whether the user has SVG installed. If SVG is not installed, the participant cannot proceed or use Arborville. Users must launch the version of Arborville chosen randomly (except for low resolution displays) before the option to proceed to the next page becomes available. After using the Arborville interface, users are asked to answer the same AHIG-C scale questions as page 3 of the online survey for the post-test, but presented in a newly randomized order. Page 5 thanks the users for completing the survey and provides them with links to all eight versions as well as a comment box and an option to email the website to friends.

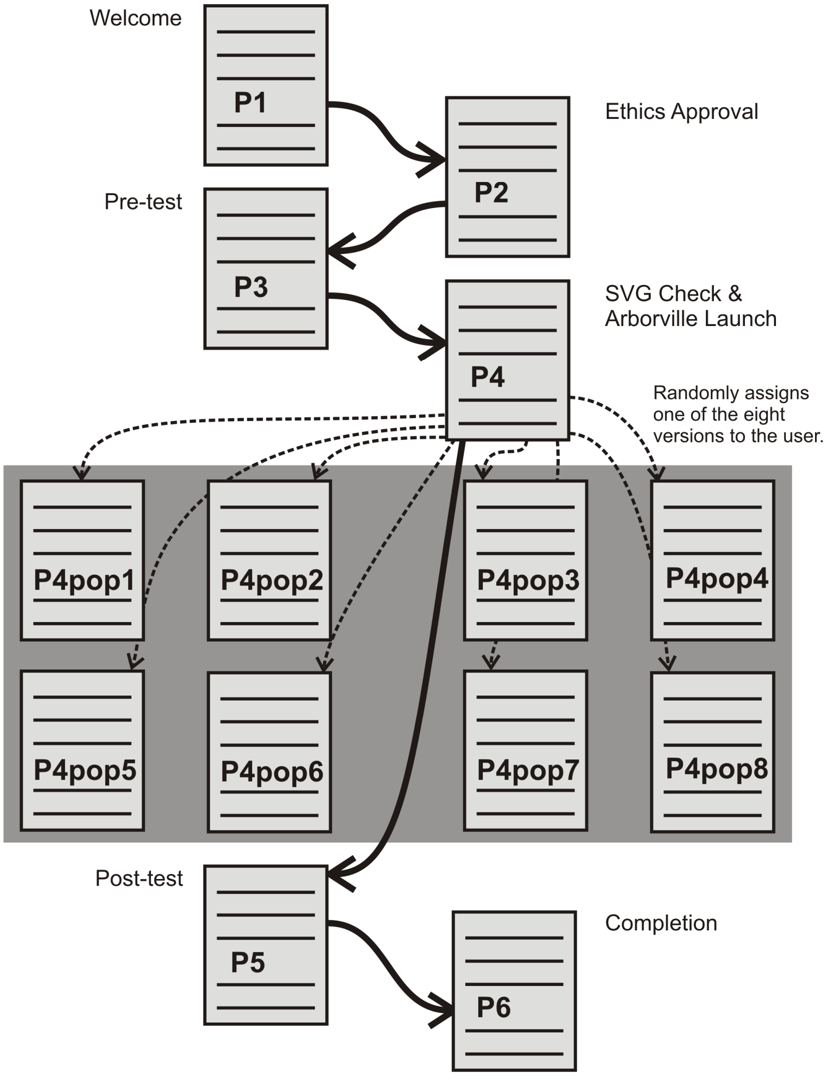


Figure 3-26: Arborville online survey sequence structure. Users will receive one of the eight versions randomly assigned to them.

While data were collected explicitly for the demographic and AHIG-C scale questions they were also gathered covertly. The time to complete the pre-test, Arborville, and the post-test are captured. Mouse movement across Arborville and any interaction events are recorded and timed. These data will help determine user behaviour.

Manually designing of the online testing framework came at the cost of a few logic errors however. Some data were destroyed and lost after gathering due to a bug in the user error handling procedures. Users who did not have SVG installed until viewing Arborville and followed the instructions to refresh their browser page lost their database id in the process. This caused later results to be stored as id “0” rather than their respective id. This was somewhat easily repaired since the records are consecutive, their last survey records with id “0” being stored adjacent to the one with a correct id. The other logic error occurred when users who had missed a question were returned to the post-test questions to complete the question they had not answered. This caused mouse and interaction tracking data that had been previously added to the database to be replaced with blank values. There is no method of retrieving these data.

In addition to introductory geography students participating in experiments for one percent credit, as frequently done by other departments, facebook.com ads were also used to recruit participants. In terms of money spent and valid survey responses, using facebook.com was very inefficient.

3.4 CABI (Cellular Automata Basin Interface)

The CABI interface is named after its CA groundwater modelling engine and basin content. CABI allows participants to visualize a 3D model of a basin, containing bedrock, groundwater, and sediment layers, and interact with it through the placement of wells. Interaction and visualization is with a 3D model of a basin. CABI evolved from a proof of concept and is relatively unrefined compared to DRASTIC and Arborville.

CABI has two aims, exploring what is possible using CA to drive a groundwater model and allow users to explore the volumetric dimensionality and relationships of surface and subsurface groundwater processes. CABI evolved from the need to create a more flexible environment than Arborville yet less time consuming to create. By using CA to control water behaviour dynamically, wells could be placed at any location and water levels would adjust. This would be easier than scripting every possible outcome as was required in Arborville and also gives the user greater choices making each user's experience unique. There are only two versions of CABI, CABI1 is discussed below.

3.4.1 CABI Design

CABI was designed to communicate how pumping groundwater alters groundwater and stream levels. More advanced interaction was desired after the completion of Arborville and its rigid design. Arborville allows a well to be placed only in one location. The goal was to allow the user to place as many wells as desired in any locations within a basin environment containing a stream. However, using a more powerful graphics library, programming language, and programming paradigm requires the software to be installed on the user's machine rather than using a browser to access the educational tool.

The model was designed to contain a simple rotatable terrain on which the user could place wells. It was meant to contain minimal textual instructions and menus. The user should be able to perform simple interactions and have the environment adapt to their well placements. This interface is aimed at prototyping a proof of concept rather than focusing on interface design and usability.

The design of CABI responds to the limitations of many spatial analysis tools to represent 3D volumetric phenomena with 2D representations such as Arborville. The goal for this interface was to represent groundwater flow sufficiently well so that it could be used as a conceptual education tool for decision-makers, stake holders, and educational groups.

3.4.2 CABI Development

Developing such an interface required choosing both a programming language and graphics library. C++ was chosen as the former and OpenGL as the latter. OpenGL is a library of functions that simplify the creation of 3D content. OpenGL also has simple configurational properties and an active online community consisting of many tutorials and forums.

In order to provide an environment that dynamically controls water levels across space required a special program architecture. CA provides an alternative to complex physics and intense computation with its simple rules that allow the emergence of complex behaviours.

Cellular Automata

A bottom-up approach to modeling complex systems, CA became popular in the 1990s (Wolfram 2002). The fundamentals of CA rely on *a)* the use of a lattice of discrete spaces (cells) usually rectangular in shape, *b)* each cell having identical dimensions, *c)* each cell having a neighbourhood (Figure 3-27), *d)* each cell being in a finite set of states based on transition rules applied to the neighbourhood, and *e)* and each iteration of time is discrete and equal (Wolfram 2002).

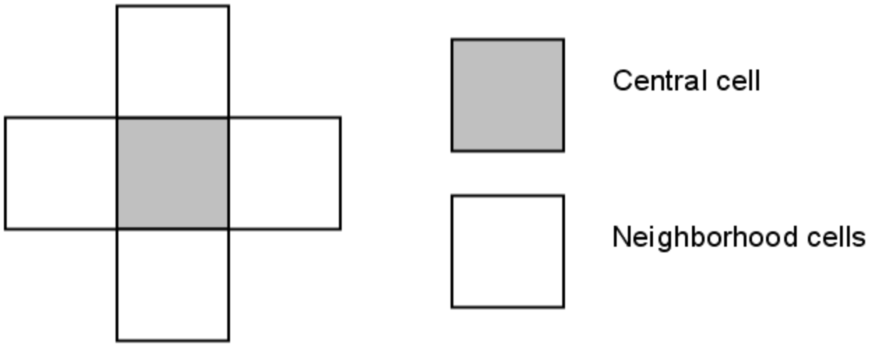


Figure 3-27: CA neighbourhood example.

CA transition rules are created by taking into account a defined change in time, appropriate reactions to the states of the neighbourhood cells, and the state of the cell itself. An important rule about CA is that the state of each cell does not change in the order they have the transition rules applied to them, but rather at the same time once all the future states are known.

Scale in CA plays an important role in the model outcome. The resolution of a cell, how many metres it represents in reality, for example, is firmly tied to the temporal scale of the model.

Fuzzy Set Theory

When modeling in CA the use of crisp values such as 1 or 0 (grass or fire) may be sufficient for many applications where the spaces represented by the cells change rapidly and completely from one state to the next. Rapidity is of course subjective to its application and spatio-temporal scale. When modeling, the time taken for a cell to change in reality from one state to another may be an appropriate time step for CA. The use of crisp values on raster spaces is “not the most appropriate for representing geographic data” which are “inherently characterized by vagueness or fuzziness” (Dragicevic 2004, 13).

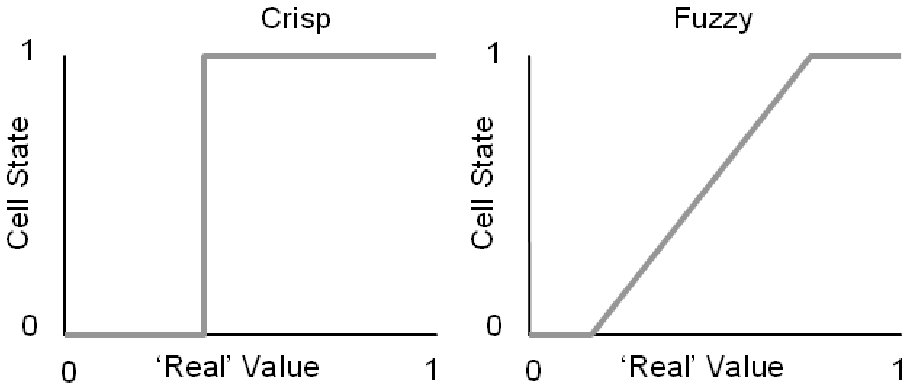


Figure 3-28: Using fuzzy sets allows modeling object states more realistically.

When implementing fuzzy sets, a cell’s state can be *between* 1 and 0. Using groundwater as an example, this allows for cells to be partially full of water rather than being either full or empty (Figure 3-28). This permits more flexibility in the model since time and space are no longer as rigidly tied to crisp values. This may also simplify calibration of the model. Using fuzzy sets increases programming complexity. A prototype implementing fuzzy sets with CA is called GOCAM.

GOCAM (Groundwater OpenGL Cellular Automata Model)

GOCAM was built to model water in a basin containing a confined aquifer. The model simulates daily rainfall, groundwater pumping from a confined aquifer, and irrigation. GOCAM was not meant to be used by non-experts, but by the modeller for calibration and validation to determine the effectiveness of using CA to model groundwater.

Unlike traditional CA which is two dimensional, GOCAM uses CA to power the 3D behaviour of water requiring 3D CA. This requires a 3D neighbourhood rather than a 2D one as conventionally used. Figure 3-29 shows the neighbourhood introduced by von Neumann (1966) (left) and the 3D version used for this model (right).

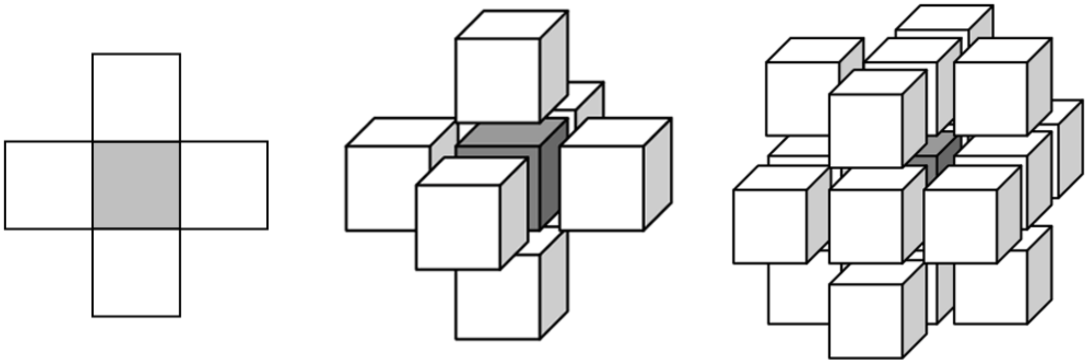


Figure 3-29: GOCAM uses a simple 3D neighbourhood (middle) rather than the traditional 2D one (left) or a more complex one (right) with 18 neighbours as initially intended.

Development started with few voxels, the volumetric equivalent of a pixel, representing soil, bedrock, and air cells for testing. Each voxel represents a cellular unit of identical size with their own fuzzy state, position, and neighbours within the 3D lattice. The first working model was 3×3×3 voxels in size consisting of a total of 27 cells. Displaying the lattice of cubes as wireframes allowed displaying the interstices' percentage as an empty rectangular prism within the cube, leaving an adjacent prism to be filled by another coloured (ex. Yellow, orange, and green) rectangular prism representing the material type of the cube (Figure 3-30). The saturation of the pore space, the air between discrete sediment pieces, is represented by the percentage a blue prism fills the empty space adjacent to the material rectangular prism. As a result each voxel communicates its porosity, saturation, and material. Once the model functioned correctly it was expanded to $10 \times 13 \times 11$ voxels for a total of 1430 cells.

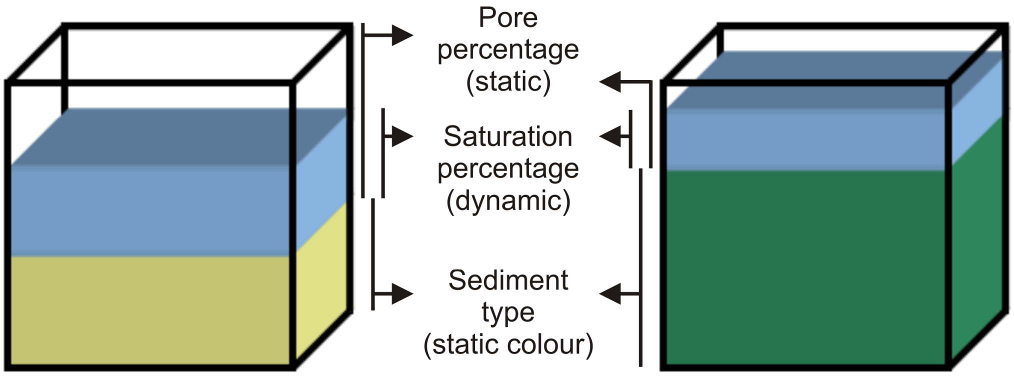


Figure 3-30: Two examples of sediment type voxels in GOCAM displaying their porosity, saturation, and material.

While each type of material was given a different colour legend, when viewed from most angles many of the voxels were indistinct against other voxels of the same colour (and type). A diffuse lighting model was built into GOCAM to ease visualization of the separate voxels. Because the objects are prism-shaped they only require one extra calculation per face to add lighting to the model. This is relatively inexpensive computationally.

To facilitate visualization, mouse controls were built into the interface to rotate the model. Constraints were added so that the model can only rotate 180º vertically to avoid disorientation in regards to which direction is up. The ability to zoom-in and out were also added so that some of the slower minute changes could be visualized more clearly. GOCAM still did not allow a clear view of the inside of the model where important interactions take place. To make the model significantly easier to visualize, clipping of the voxels on the left side, front, and top of the model was added. When voxels are invisible they are still included in CA calculations and interactions. The display of the voxels was completed first to facilitate future testing of the model when implementing and calibrating the CA rules. The neighbourhood was originally planned to have 18 neighbours to include all cells that share an edge, but was reduced to six (Figure 3-29) due to unnecessary complexity for a prototype. The neighbourhoods were virtualized by creating links within the cell data structure that pointed to other cells within the neighbourhood. The neighbours are detected during the initialization of the model in a flexible manner and could relatively easily be altered to create a larger set of neighbours in the future.

The data input for the cells is in numerical format, and was manually entered within the compiled code, and therefore cannot be changed without a copy of the source code. An early attempt at making the data external in a text file was abandoned due to time constraints and file parsing difficulties.

Once the data structure was created, cells were strung together in a linked list resembling a 3D mesh. Linked lists are based on the concepts of anchoring objects to each other in sequential order. Each cell has the sole knowledge of where the next one is. This possible weakness is the system’s strength in terms of flexibility and suits CA naturally since each cell must be visited once, the program can simply follow along the chain. Each iteration of the model passes through the list of cells twice, the first time to perform the transition rules and the second to apply the changes.

Unlike traditional CA where the total number of cells of different types may change over iterations, this groundwater model maintains accurate quantities of water across iterations. Water is not created nor destroyed unknowingly; it is added to the model or removed in measurable amounts. Due to variations in permeability and porosity between neighbouring cells it is necessary for portions of cell water to be moved rather than their entirety. This required implementing fuzzy sets to represent water content (Figure 3-31).

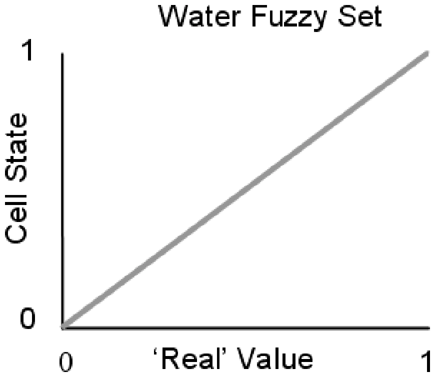


Figure 3-31: Linear fuzzy set implemented for water within the model.

The GOCAM model is generated upon initialization from an array in the source code. The three dimensional array of numbers are proxies for different cell types, such as 6 being saturated gravel, 99 being bedrock, and 0 being air. During initialization of the data model each cell will be given porosity, permeability, and water content values based on their cell type. Once initialization is complete and the transition rules commence the water content value is the only one which can change.

While the GOCAM CA model is running, cell states (water content) are determined by their neighbourhood. Cells can receive water from above or one of its four equal level neighbours in order to determine its own future state. Although the bottom cell is linked it is not used due to the added complexity of calculating when a cell will push water ‘up’ to another cell based on Darcy’s Law calculations.

The following transition rules were applied to each cell:

1. If the cell is full of water ignore its neighbourhood and move to next cell.
2. If the cell above has water transfer the maximum possible based on the more limiting permeability of the two cells and porosity of the receiving cell.
3. Of the neighbouring cells (north, east, south, and west) with a higher percentage of water, rank them in order of highest percentage full. Then allow each cell in order of highest to lowest to give water to the host cell.

In addition to these transition rules, there are checks inserted to make sure that a cell cannot overflow or hold more water than its pore space allows. Due to the cells being ranked, not all the neighbouring cells will necessarily transmit water to the host even if they are initially higher. This is another limitation as permeability comes into play in determining the direction of water flow. The uneven transfer of water between neighbouring cells somewhat violates the CA law stating cell states should not change until all cells have had the transition rules applied to them. Perhaps more damaging to the strict CA law is the removal of water from cells. When a cell has a small amount of remaining water and is taken in its entirety by its neighbour, it deprives other cells that would have taken it had they been first in the procession of the transition rules. This break from CA law is acceptable due to complications that would occur from programming a deficit system allowing multiple cells to claim the same parcel of water. The minute amount of water transferred each iteration in such a scenario minimally impacts the overall model.

Model parameterization was done using the values presented in Table 3-4 on material porosity and permeability for different materials derived from Fetter (1994) and Ward and Robinson (2000). The values, however, were adjusted to suit the model balance. The porosity and permeability of a specific gravel type can vary greatly based on its uniformity of size, structure, and shape. While granite technically does have porosity and permeability it was given zero values to contain the model water and due to the small impacts of groundwater in fractured media over short durations.

Table 3-4: Parameterization of material porosity and permeability in model. (Source: Fetter 1994, Ward and Robinson 2000)

Material	*Porosity (%)*	*Permeability (m/s)*
Gravel	30	10^0
Sand	40	10^{-2}
Clay	47	10^{-5}
Granite	0	0

The scale of the porosity and permeability were chosen to match cells of a cubic decametre scale (10 metres × 10 metres × 10 metres). The temporal scale was set to 100 seconds between iterations. After each 100 second scale iteration the model

1. applies transition rules to each cell,
2. discharges river mouth water from the model,
3. and pumps water from the aquifer at the rate defined by the user.

At the daily scale of 864 iterations of 100 seconds (86,400 seconds equals 24 hours) the model

1. distributes 130 cubic meters of rain across the area (corresponding to 10 millimetres of rain a day, 3650 millimetres per year, close to Canada’s Pacific Coast that receives up to 4000 millimetres a year)

2. and removes and redistributes the water pumped from the aquifer in the previous 24 hours by the groundwater well, evenly across the surface of the model to simulate irrigation.

To make the groundwater model realistic it had to be made dynamic with a series of inputs (precipitation and irrigation) and outputs (river discharge), otherwise the model would have quickly become stagnant as all the water would have settled flat. Further pumps can be added by the programmer to the model with ease.

Reducing permeability during calibration of the model increased the flood effect in the simulation. Flooding is caused by little water being absorbed by the different sediment types due to the permeability parameters. Increasing permeability had the opposite effect. Calibration of the model was mathematically complex in terms of converting from volumes of different units to speeds of water flows.

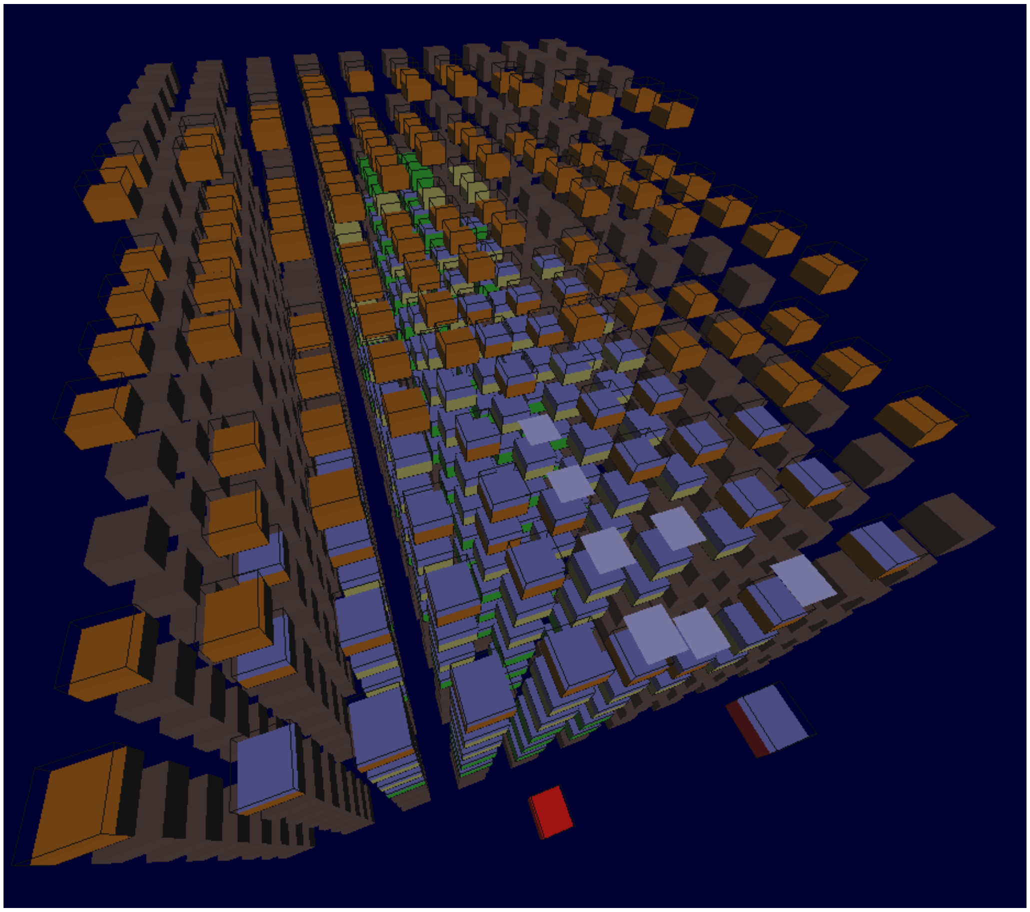


Figure 3-32: GOCAM model displaying voxels of various materials. A river has formed in the ravine (lighter coloured cells).

The combining of cellular automata, fuzzy sets, hydrogeology, and spatial modeling combined through programming created a rudimentary yet complex prototype (Figure 3-32). Upon feedback it was discovered that the fundamental CA rules do not mimic the behaviour of confined aquifers adequately. Figure 3-33 shows the gravel confined aquifer (green), clay aquitard (beige), and sand aquifer (orange). The desaturated gravel cells below the clay aquitard should not occur. The model does, however, adequately represent unconfined aquifers.

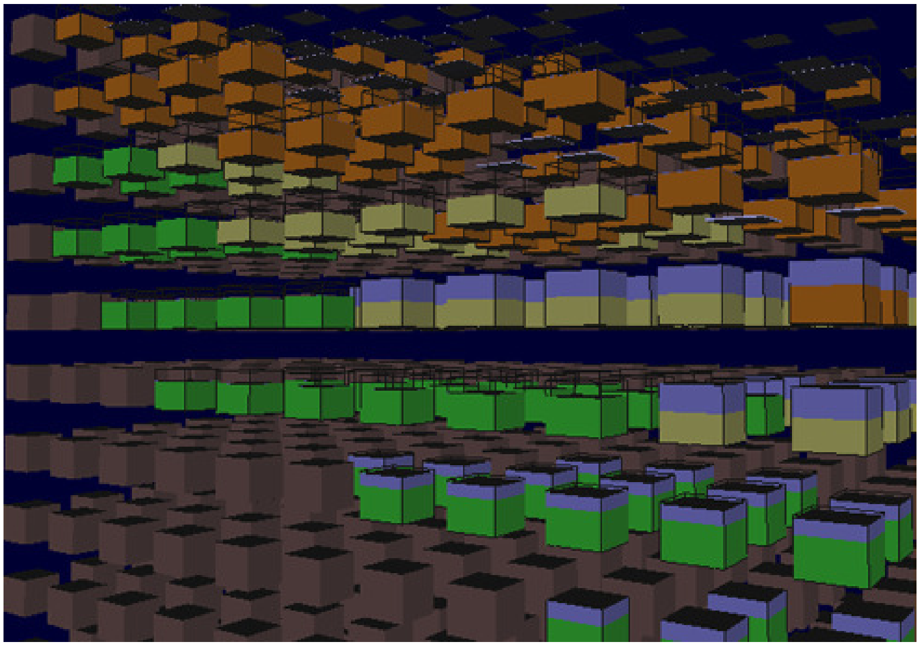


Figure 3-33: GOCAM cellular automata transition rules do not model confined aquifers appropriately.

GOCAM provides a command line menu, but as a proof of concept is rather cryptic for any user to operate and learn concepts from. GOCAM serves as an operational view of how the CA is behaving rather than as an educational tool.

CABI (Cellular Automata Basin Interface)

GOCAM does not allow users to place wells and clearly see how this would alter water table levels. GOCAM shows that CA can be used successfully to control water in an environment consisting of air, soil, and bedrock cells. By coding from scratch, yet using the lessons and structure from GOCAM, CABI was built more rapidly with added features. While still having the same underlying CA theory, CABI included user customization of the terrain, a completely new and simplified visualization scheme, the ability to add wells, and simplified controls.

GOCAM is too abstract for users to easily understand what they are viewing. The new visualization technique of CABI relies on converting cells into layers by finding the top most cells of bedrock, soil/sediment, and water for each XY coordinate to form a mesh (Figure 3-34). While the program parses the data once for the soil and bedrock elevations, they are continually revaluated for the water levels since they are dynamic. This much simpler display removes clutter and conforms more closely with the users expectations.

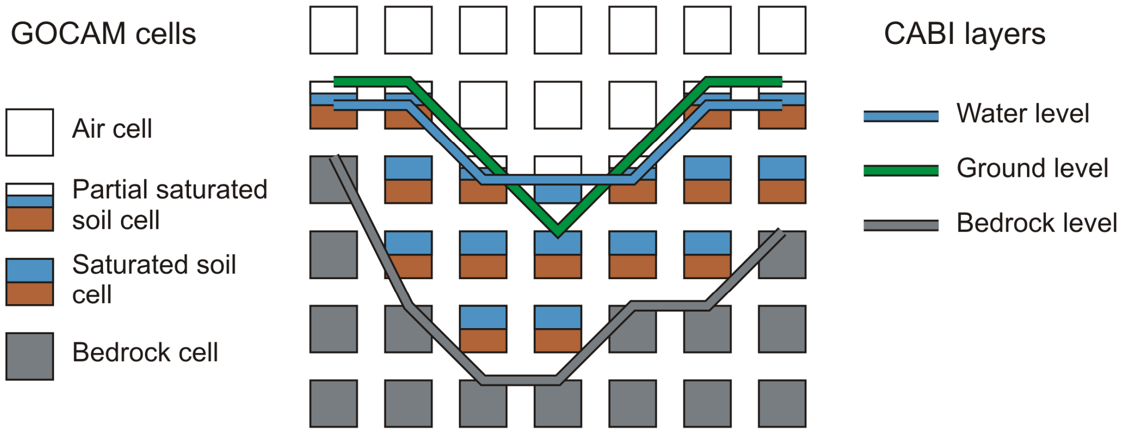


Figure 3-34: A side view cut plane of the transformation from GOCAM to CABI showing the different cells represented by the three layers.

The reduced number of elements to display in CABI, due to its visual simplicity, allowed a greater number of cells to be added to the model. The GOCAM prototype processed nearly 1,500 cells, more would have been overwhelming for the user. During testing CABI had over 42,000 hidden cells underlying the three layers (Figure 3-35). While displaying surfaces rather than voxels reduced the graphical processing costs, it increased the processing power required to execute the same number of iterations per second. This was easily dealt with by changing the parameters so the model appeared to respond at same pace. However, user’s ability to customize their terrain by using a text editor has increased the program initialization time from under a second to approximately two minutes for models containing roughly 40,000 cells.

Upon loading, CABI does not provide instructions to the user. It encourages the user to discover the relatively simple mouse controls to manipulate the model. A menu in the top right corner of the window contains three buttons to toggle the visibility of the soil, water, and bedrock surfaces as well as a static mini-map where the user can place wells by clicking on it (Figure 3-35).

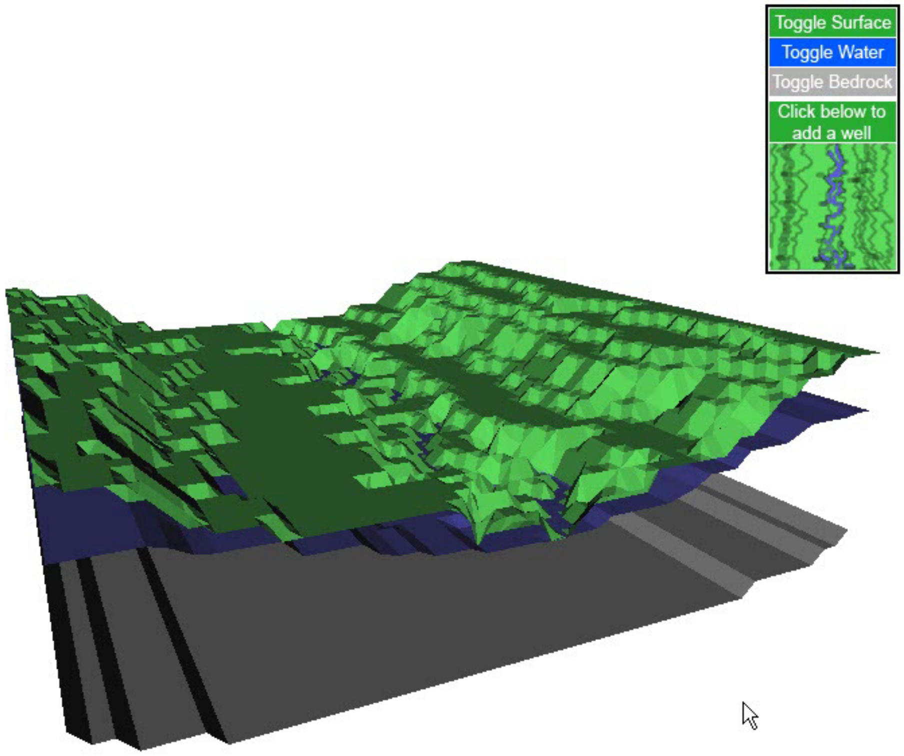


Figure 3-35: CABI displays three layers but processes thousands of hidden cells to determine water levels.

In GOCAM the user has the ability to control the rate of pumping manually over time. This was removed in exchange for the flexibility of placing multiple wells at multiple locations that simultaneously draw water at a constant rate over time. While it seems more intuitive to place wells on the environment directly this is technically complex to program and would also require devising alternative controls for model rotation.

The main program cycle of the CABI model executes in four steps. The first step is to have all pumps remove water from their draw point into a ‘cloud’ which stores numerically the total amount of water drawn by all wells. The second stage directs water flow from neighbouring cells into the cell currently being processed. Newly received water by cells is held in stasis so the water cannot be used a second time during the same cycle. The third stage unlocks the water in stasis after all the cells have determined where their incoming water flow will arrive from. The fourth and final stage is the recharge in the form rain. CABI is a closed system all water pumped from wells and exiting the system at the river mouth flow into the cloud variable. This cloud, upon reaching a threshold based on the product of the model’s width and length will ‘rain’ water equivalently across the top air cells of the model.

The parameters used in GOCAM were based on real values and have been altered in CABI to best simulate an accelerated reality. The goal of this model is not to replicate reality.

The final CABI program behaviour has several satisfying results. When the model runs it will correctly replicate rivers, base flow, and cones of depression around wells placed on the terrain. While far from realistic behaviour in terms of temporal fluctuations, the ground water level provides a satisfactory playground for users to explore the concepts.

3.4.3 CABI Variations

CABI2 is a variation of CABI(1) with an added constraint of viewing angle. CABI2 constrains the user to the viewing angle of 45º above horizontal while CABI1 allows the user to look under and down onto the model (Figure 3-36). Both versions can rotate the model 360º on the z-axis.

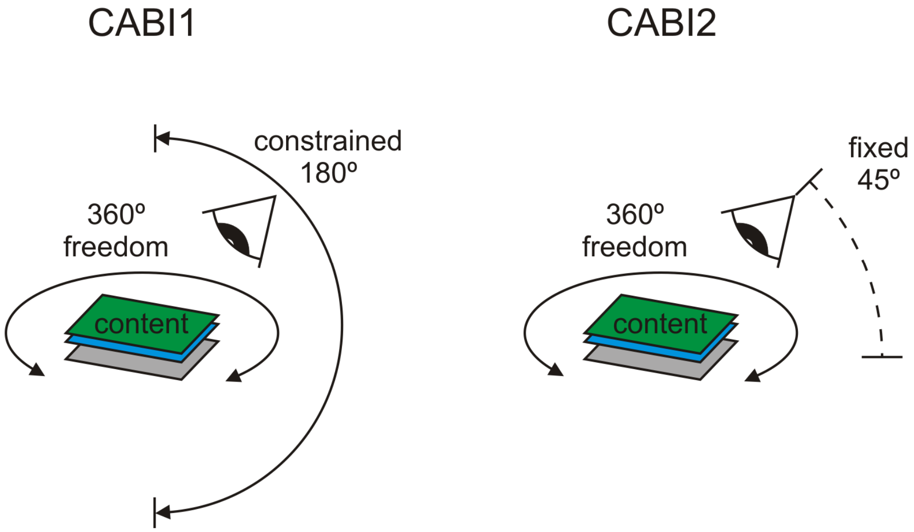


Figure 3-36: CABI1 (left) allows constrained movement from -90º to 90º while CABI fixes the camera at 45º (right).

3.4.4 CABI Testing

Unlike DRASTIC and Arborville testing that were embedded in a narrative introducing the interface setting, testing for CABI provided no introduction and data was gathering using paper survey booklets (Appendix A).

The survey contains qualitative and quantitative questions focusing on groundwater, surface water, and well interactions. The survey attempts to measure what individual concepts the user has learnt from using either of CABI versions. Due to the lack of narrative for CABI the qualitative questions where mainly trying to gain an impression of what the users thought they were viewing and how they were impacting the model. The qualitative questions focused on surface water, groundwater, and well interaction concepts that were modeled in CABI. Similarly to the DRASTIC and Arborville scale questions, limitations to the CABI survey questions were later revealed from testing by a hydrogeologic expert who did not agree with some of the Likert scale questions’ designated correct answers.

The test setting was a geography computer lab supervised by the TAs of the classes involved. The participants were all in an introductory geography course. Testing consisted of a series of tasks with users recording their thoughts and answers to questions. Each student within a row had alternating versions of CABI and was unaware of the multiple versions. Participants used CABI while following the directions booklet. CABI testing began by participants describing what they saw on the screen before using the mouse to manipulate the model. Participants were directed to toggle layers, add wells, and record any thought after each task. After a few minutes of interface use participants completed Likert questions regarding groundwater concepts while still using CABI. The final questions ask general questions about their CABI experience and suggestions for improvement.

3.5 Summary

Three series of tools were constructed as well as multiple versions of each that altered interaction design, feedback, content, and controls. DRASTIC's three versions allow users to view the different factors that can determine an area's pollution potential. The eight versions of Arborville allow users to see how land use decisions can alter their environment, and CABI's two versions let users place wells in a 3D rotatable and dynamic environment. While DRASTIC and Arborville were tested online CABI's testing was done through paper surveys completed while using one of the two versions on workstation in a computer lab.

The three interfaces visually communicate groundwater concepts to OB stakeholders but are relevant for different reasons. DRASTIC tests interface variations of 2D maps containing real data. Arborville also tests variations in interface design, but using a fictional location displayed from a perspective view. CABI, while testing interface controls, contains a manipulable 3D basin model. These interfaces are relevant to public education, 2D and 3D groundwater visualization, and conceptual and model visualization. To serve as efficient alternatives or collaborative educational tools testing needs to determine their worth. Testing analysis and results of the interfaces are presented in the following chapter.

CHAPTER 4: ANALYSIS AND RESULTS

4.1 Introduction

The preceding chapter outlined the methods taken to create the DRASTIC interface, Arborville, CABI, and their variations in an attempt to determine whether differences in learning outcomes exist between these educational tools. This chapter analyzes qualitative and quantitative measures to determine the differences and similarities between the interface versions in respect to their effectiveness to communicate the same facts and concepts.

For each testing protocol a variety of qualitative, quantitative or cartographic data were collected. Much of the data gathered in this research were through Likert scale questions. There is significant controversy regarding whether Likert scales are ordinal or interval (Goddard and Villanova 2006, 118). Considering the scales as ordinal data is more robust to criticism and will therefore be analyzed using non-parametric statistical tests as done in similar studies (Harrower and Sheesley 2007, 24). Analysis results of an alpha level of lower than $p = 0.05$ will be considered statistically significant.

This chapter begins by presenting the quantitative and behavioural analysis performed on the DRASTIC data gathered. Data collected from Arborville testing is similarly quantitatively and behaviourally analysed, but at more length due to the greater number of versions. Unlike DRASTIC and Arborville that used online Likert scale questions, the testing of CABI was mainly done through open-ended questions on paper surveys. CABI's qualitative data are coded to detect trends and the few CABI Likert scale questions are analyzed. The chapter's conclusion summarizes the analysis process and results, while the discussions of some of the findings are covered in the following chapter.

4.2 DRASTIC

The DRASTIC online survey gathered demographic information about the participants (gender, age, level of education, and area of work/study), page view times, interaction (mouse clicks, mouse movement), task questions, and two measures of the DRASTIC Groundwater Susceptibility Factors Comprehension (DGSFC) scale (Table 3-1). The DGSFC scale contains eight Likert scale questions. When starting the survey, the DGSFC scale questions were asked below demographic questions as part of the pre-test, and asked again below the task questions after using a version of the DRASTIC interface as part of the post-test. Testing occurred in the Fall of 2007 mainly using Simon Fraser University (SFU) undergraduate students in an introductory geography course. Inquiries to contact the OB Water Board and CWN websites to provide links to DRASTIC and Arborville testing websites went unanswered. All data were gathered to determine whether the three versions of DRASTIC equally communicate groundwater susceptibility. The null hypothesis is that the three versions of DRASTIC interfaces perform equally well.

DRASTIC participants were mostly those recruited from an introductory undergraduate geography course. A total of 92 online surveys were collected. Of these, 65 were completed fully, but only 38 were found to be valid records for use in most of the analyses. Validity was based on (1) completion, (2) it being the user's first visit to the survey, and (3) interface use greater than a minute in duration. Of the 54 discarded surveys 27 were excluded due to interface use less than a minute (Figure 4-1) and users not being able to load the SVG plug-in. Due to the lack of a better control group, the 27 responses are considered and analyzed as a control group.

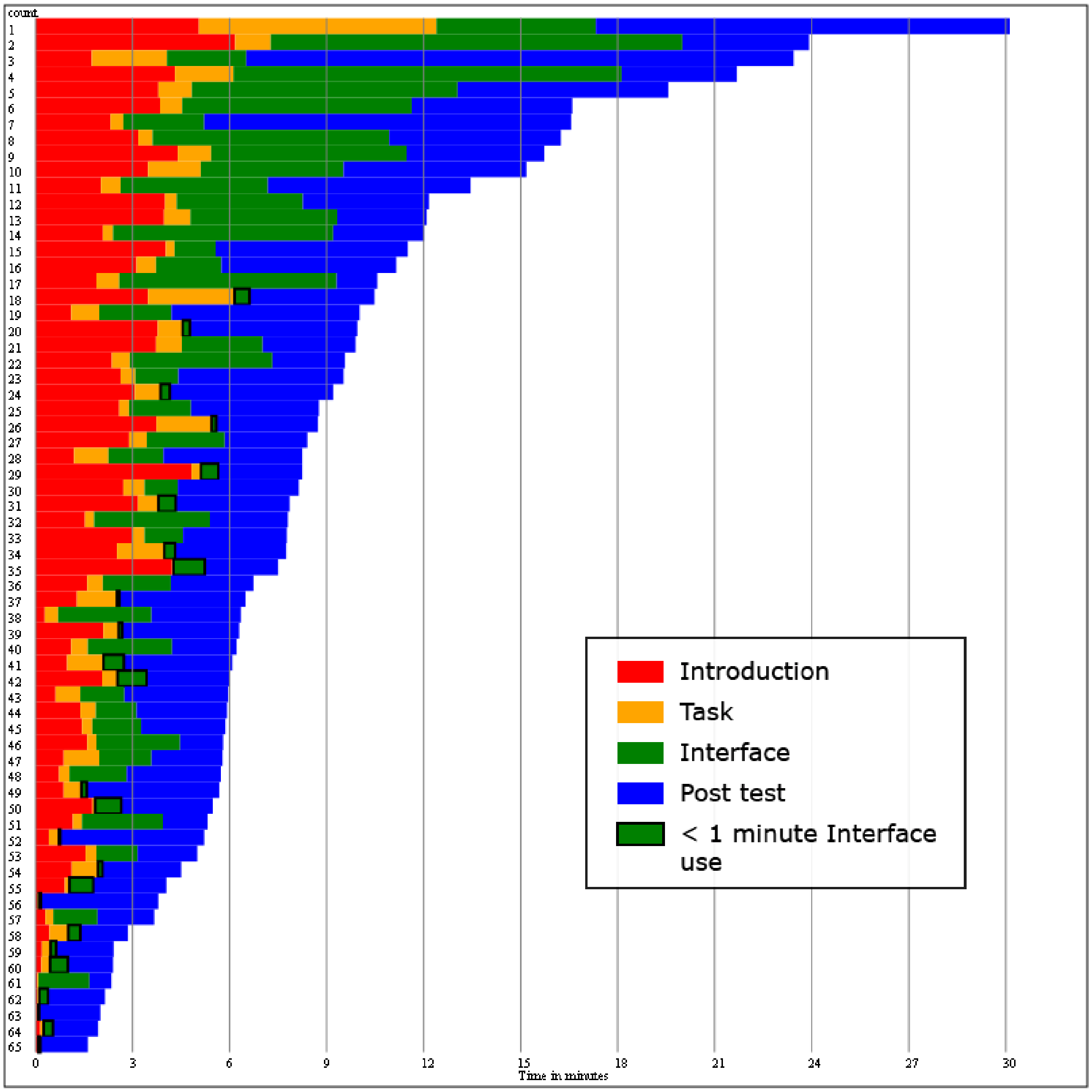


Figure 4-1: DRASTIC survey completion times of the introduction, task, interface use, and post-test. Of the 65 completed surveys, 27 had interface use less than 1 minute and were added to the control group. Note that only 25 are highlighted as 2 participants spent over a minute on the interface page but did not have SVG installed and could not see the DRASTIC interface.

4.2.1 DRASTIC Quantitative Analysis

The demographic breakdown of the 38 participants consists of 20 females and 18 males of which 75% are between the ages of 19 and 32. All participants but one have some college, university or higher education. Of the 38 valid participants 13 used the conventional HTML version, 11 the Basic SVG version, and 14 the advanced SVG version. The control group has 19 women and 13 men, 66% are 19 and older and over 80% have some college, university or higher education. These numbers may not be enough for strong statistical significance.

To understand how respondents performed across time on the pre- and post-tests, a test-retest reliability analysis was completed. This analysis is typically employed to determine how similarly respondents answered across repeated measurements. The analysis shows there is little change between respondent's pre-test and post-test responses (Table 4-1). The largest variation of responses is in the control group. This may be due to control group participants being less interested in the exercise or simply because they guessed differently both times when answering. While the lack of lengthy exposure to the interfaces makes these participants a useful control population, their response quality puts into question their validity as a control group.

Table 4-1: A DRASTIC test-retest reliability analysis shows little change in participant responses between the interventions.

Intervention	*Participants*	*Reliability*
Conventional HTML	13	0.918
Basic SVG	11	0.900
Advanced SVG	14	0.955
Control Group	27	0.867

Analysis of performance based on gender and education showed no significant differences in scores. This is not unexpected since the majority of the participants had the same level of education.

In order to determine whether individuals improved on their survey scores a Wilcoxon matched pairs test was performed for pre-test and post-test responses on each group of interface users and the control. Table 4-2 summarizes the statistical significance of changes to scores for each question for each interface. The test shows significant improvements in scores for different questions for DRASTIC interfaces Version 1 and 3. The HTML DRASTIC Version 1 significantly improves scores for question three, and not significantly, but possibly, for questions two and five. Version 2 (Basic SVG) is near being significant for improving scores for question seven ($p = .053$) and possibly question one. With very strong significance, the Advanced SVG DRASTIC Version 3 shows improved scores for question four, with question three and seven slightly over the alpha. The three DRASTIC versions nearly all made significant improvements in scores on different questions. The different learning outcome between versions weakly contradicts the null hypothesis that the interfaces communicate concepts in the same manner.

As expected, the control group has no significant changes in score. Little can be learnt with interface use less than 60 seconds. A larger sample size is needed to identify stronger trends between DRASTIC interface versions. All three DRASTIC interface versions pay equal attention to all seven DRASTIC factors on which the test questions are based on. The cause of different questions improving between the DRASTIC versions is unknown. Potential explanations are the small sample size, imbalances in sample sizes, and chance.

Table 4-2: Wilcoxon Matched Pairs Test (2-tailed significance) shows that HTML and Advanced SVG versions of DRASTIC have significant improvement in one score each.

Pre-test – Post-test	*Q1*	*Q2*	*Q3*	*Q4*	*Q5*	*Q6*	*Q7*	*Q8*
HTML Version (N=13)	1.000	.101	**.024**	.196	.107	.343	.174	.257
Basic SVG Version (N=11)	.096	.206	.480	.476	.227	.739	.053	.394
Advanced SVG (N=14)	.660	.334	.084	**.006**	.794	.180	.064	.730
Control (N=27)	.805	.422	.183	.904	.719	.426	.977	.398

Comparisons of individual questions shed little light on whether interfaces differ in communicating the DRASTIC concepts. Aggregating scores of the eight scale questions may amplify or dampen the differences in scores depending on how consistently the participants perform. Table 4-3 shows that the conventional HTML and Advanced SVG version scores have significantly improved performances. The non significant p-value of the Basic SVG Version is due to the decrease in performance of four of the 11 Basic SVG participants of which one has drastically decreased in score (-10). When this participant is excluded the performance of the Basic SVG interface improves significantly (p = .041).

Table 4-3: Wilcoxon Matched Pairs Test (2-tailed significances, p = .05) of pre-test against post-test scores shows that the conventional HTML and Advanced SVG version scores have significantly improved.

Interface Version	*significance*
HTML Version (N=13)	**.018**
Basic SVG Version (N=11)	.142
Basic SVG Version (without outlier N=10)	**.041**
Advanced SVG (N=14)	**.017**
Control (N=27)	.233

Graphic representations of performance for the four populations show that all three DRASTIC interfaces increase scores when utilized longer than a minute (Figure 4-2). In each DRASTIC interface version one participant is strongly anomalous compared to the others, except the Basic SVG version where there are four strongly negative performances. Some participants may have had language difficulties, carelessly completed the post test due to survey fatigue or low motivation, or simply difficulty operating this DRASTIC version.

The reason the Basic SVG DRASTIC does not significantly increase performance scores can be attributed to the four negative score slopes in the top right quadrant of Figure 4-2. The negative scores may be an anomaly since there is not a normal distribution in results. There are clearly improving and worsening scores, but none in between. Expecting a normal distribution with such small samples is perhaps unreasonable. Three of the Basic SVG version users with decreased performance had interface use durations of less than two minutes. However, so did two other participants in the same sample that improved their scores. No additional data are available to explain why this performance dive occurred for a third of the users. The users do not show any other remarkable differences in the data besides their decreased scores. While the difference in pre-test and post-test scores for all BASIC SVG users is not significant, the average improvement of Basic SVG sample scores is greater than that of the Advanced SVG version where participant scores improved statistically significantly.

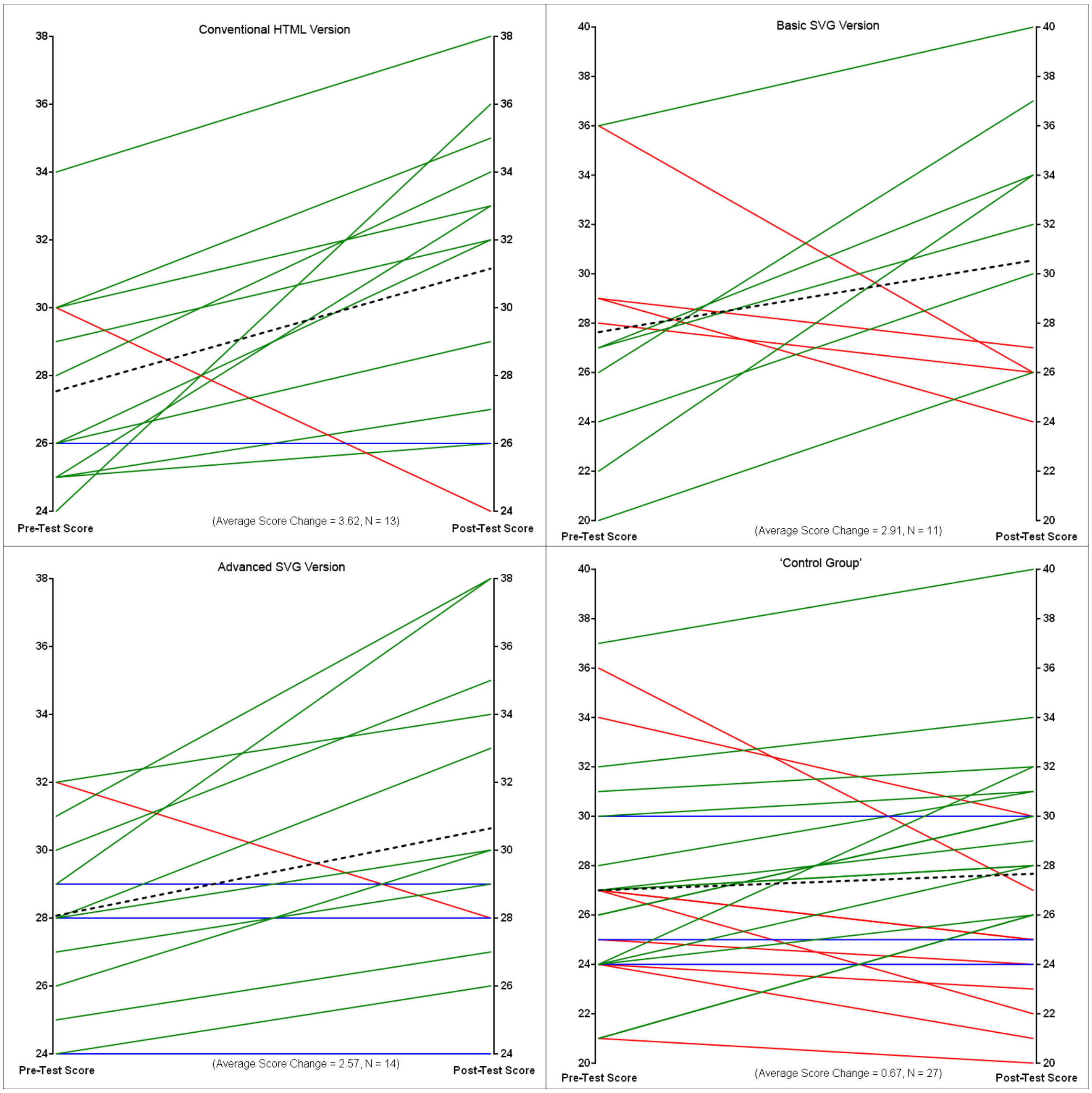


Figure 4-2: Changes in performance between pre-test and post-test by participants for the four DRASTIC samples.

Looking across all samples at participant viewing duration for the different segments/pages of the survey and score improvement, no correlation was found with the exception of interface use duration. This was only significant for the Advanced SVG version (p = .027) (Table 4-4). The correlation suggests that longer interface use relates to higher scoring. Surprisingly the control group had a negative but not significant correlation, meaning the longer the participant used the interface the lower their score was expected to be. One explanation could be that users focused more on the interface than groundwater susceptibility, supporting the argument that the control group may be careless in its completion of the survey.

Table 4-4: Spearman correlation (p = .05) between Interface use duration and difference between pre-test and post test scores for DRASTIC interfaces.

Interface Version	*Spearman Correlation*	*Significance*
HTML Version (N=13)	.509	.076
Basic SVG Version (N=11)	.453	.162
Advanced SVG (N=14)	.588	**.027**
Control (N=27)	-.288	.145

In addition to scale questions, task questions were asked before the post-test scale questions. While scale questions can be answered correctly by reading the text provided on the introductory page, the task questions answers require the use of any one of the three DRASTIC interface versions. No relationship between scores of task questions and interface versions were noted, supporting the null hypothesis. Surprisingly, all versions performed equally poorly with means near 14 points, where random answers would score 12 points, of the possible maximum of 20. The questions may have been too challenging or participants may not have observed the task locations while using the interface as directed. Participants received the following directions: “When viewing the maps on the following page please try and understand why the three locations below have received the final vulnerability ratings they have.” After interface use, the task questions ask participants to rank the vulnerability of the three areas through Likert scale questions (Table 4-5). Low score results might be related to participants focusing too much on the individual factors for the three locations rather than the overall vulnerability.

Table 4-5: DRASTIC task questions asked after interface use.

Likert Questions
Area 1 (Western river bend) has a higher pollution potential than area 2 (Downtown Oliver intersection).
Area 1 (Western river bend) has a higher pollution potential than area 3 (Benchlands road switchback).
Area 2 (Downtown Oliver intersection) has a higher pollution potential than area 3 (Benchlands road switchback).
Area 3 (Benchlands road switchback) has less than half the pollution potential of area 2 (Downtown Oliver intersection).

Whether users clicked on links displaying additional information in pop-up windows was also tracked to determine if inquisitiveness, based on clicks on pop-up windows, relates to better performance. No relationships were found between inquisitiveness and performance.

Data collected from the pre-test, post-test, task questions, duration of page viewings, and pop-up window use has yielded little reason to contradict the null hypothesis. Some data do however show a weak relationship between the HTML and Advanced SVG versions mildly improving performance. The robustness of this claim wavers due to the low number of participants in all interface groups and the ‘weak’ control group. While qualitative measures provide a means to determine changes in user learning it is also possible to study qualitative measures such as mouse movement and interaction to gain insights into interface use.

4.2.2 DRASTIC Behavioural Analysis

Interface and usability research mainly observes participant behaviour through responses to questions that do not necessarily reveal the users' process of discovery. DRASTIC participant behaviour was tracked for all three interface versions. Interaction and mouse movement were recorded. The conventional HTML version tracked mouse movement across the nine maps, while the Basic and Advanced SVG versions tracked interaction sequence as well (e.g., use of buttons). Mouse tracking can serve as a proxy to eye tracking with the exception that it only captures conscious and not unconscious attention (Norman and Panizzi 2006, 263).

The order in which information for the Conventional HTML DRASTIC version is presented determines heavily which maps received the most attention. Table 4-6 shows the maps in the order that they were browsed by the 28 participants and mouse tracking hit numbers. The hits consistently decrease the farther down the users progressed with a few explainable exceptions.

Table 4-6: The maps in order presented when using Conventional HTML DRASTIC show a steady decline in mouse tracking hits.

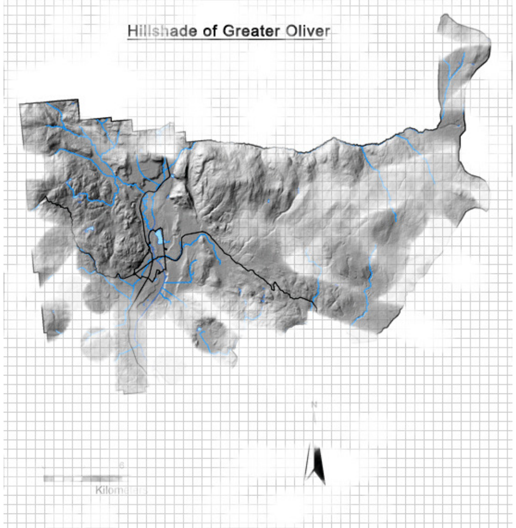
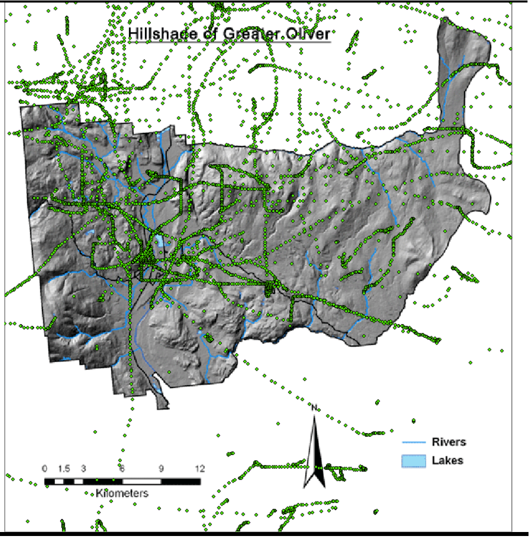
Order of Appearance	*Maps of Greater Oliver*	*Mouse Tracking Hits*
1	Hillshade	4,475
2	**D**epth to Water	3,280
3	**R**echarge	1,493
4	**A**quifer Media	1,306
5	**S**oil Media	2,336
6	**T**opography	745
7	**I**mpact of the Vadose Zone	829
8	hydraulic **C**onductivity	488
9	DRASTIC Vulnerability Rating	1,340

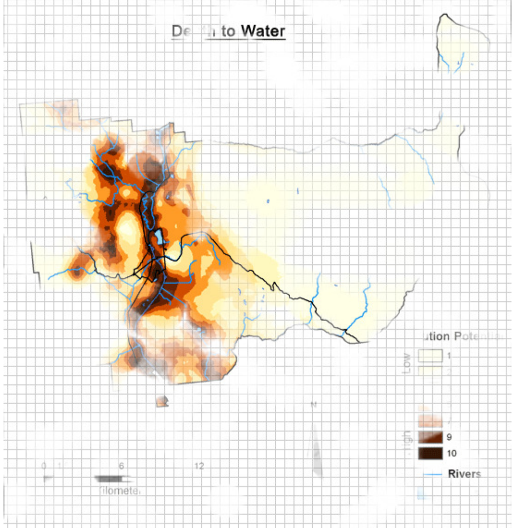
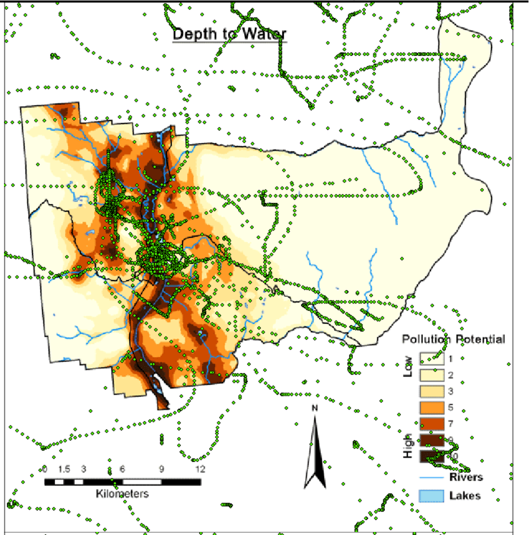
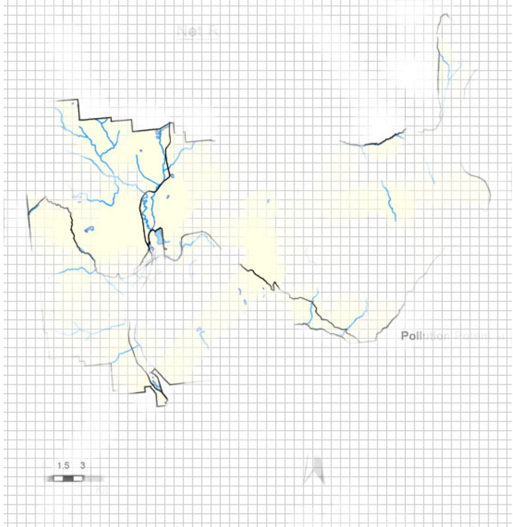
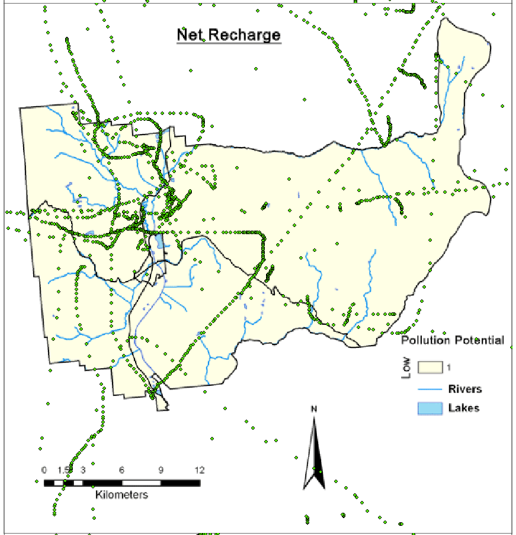
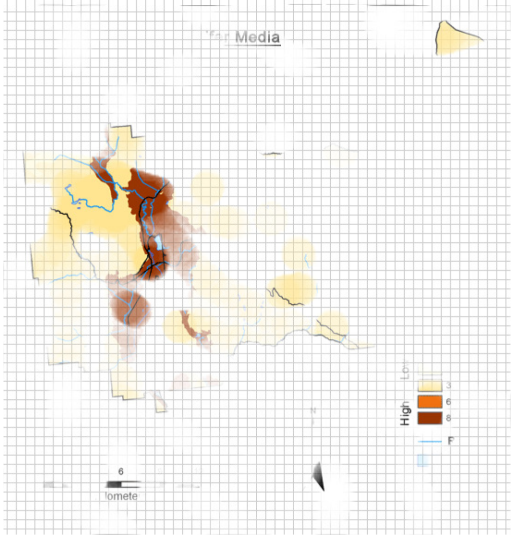
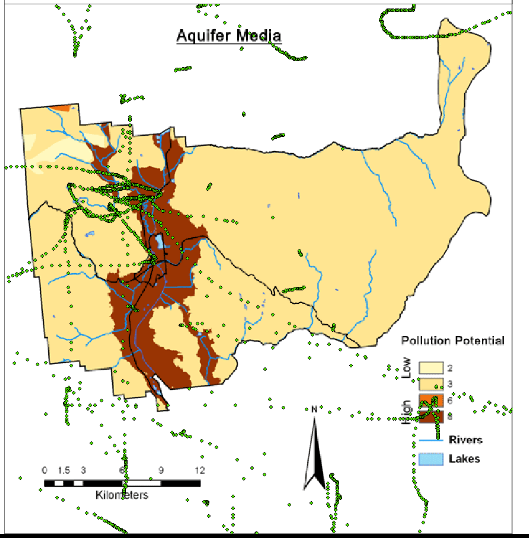
The high value for the Hillshade map is partly due to the submit button on the previous webpage being located near the top left of the Hillshade map on the interface webpage. While it is possible that participants simply find this map the most interesting the concentration of mouse points near the submit button supports the previous statement. The high soil media hits are most likely due to it being the most vibrant and visually striking map of the series. Finally the higher than expected mouse hits on the last map, the cumulative DRASTIC vulnerability map can be explained with users passing their mouse cursor over the map to reach the submit button on the webpage to proceed to the next step in the experiment. Besides these exceptions it seems users lost interest the farther they moved down the website even though the most important map in regards to the task is the last one. This conclusion may be misleading however since individual participants can skew the total mouse tracking hits per map. The decision to use all 28 data records available rather than the 13 participants screened earlier is the result of limited mouse tracking data available for the DRASTIC HTML version.

By creating point density maps of mouse tracking hit locations and using them as masks over the DRASTIC factor map areas with high mouse presence or user attention can be clearly identified. Table 4-7 shows the nine maps in the order they were presented on the HTML DRASTIC interface webpage twice, once using point density masks and the second showing mouse tracking hit locations. Areas displaying a grid on the left map are areas with no mouse tracks. The first map, the hillshade point density map, at the top left of Table 4-7, shows a white space near the top left corner. This is due to the submit button on the previous page being located there, making the mouse appear at this point when the new webpage appears. The general decrease in mouse tracking points across the seven following sequential maps can be clearly seen. The final DRASTIC vulnerability map, perhaps the most important, seems to have increased attention. Looking at mouse tracking paths for the final map it becomes obvious that users were passing the mouse cursor over the DRASTIC Vulnerability Rating map to reach the submit button directly below it.

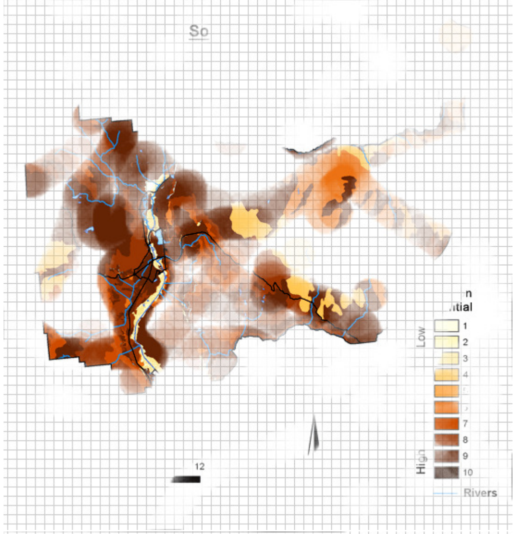
By studying the point density mask figures in Table 4-7 it appears that users quickly lost interest in focusing on the task locations. These are only visible in the first three maps as well as the soil media map in Table 4-7. Participants may have lost interest in the maps or forgotten their task.

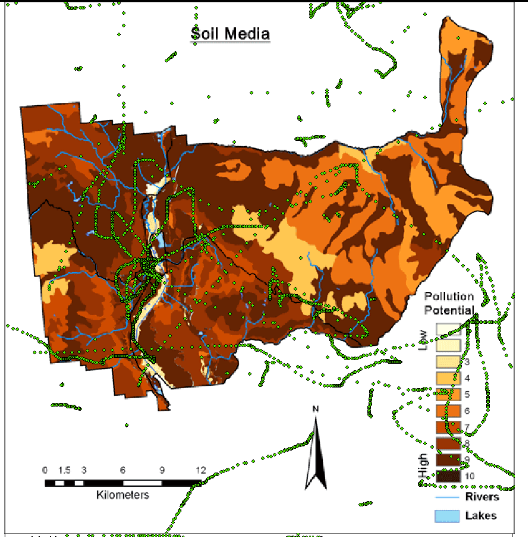
Table 4-7: Mouse tracking hit locations for the nine Conventional HTML DRASTIC maps. The grid background shows which areas were of little interest to participants.

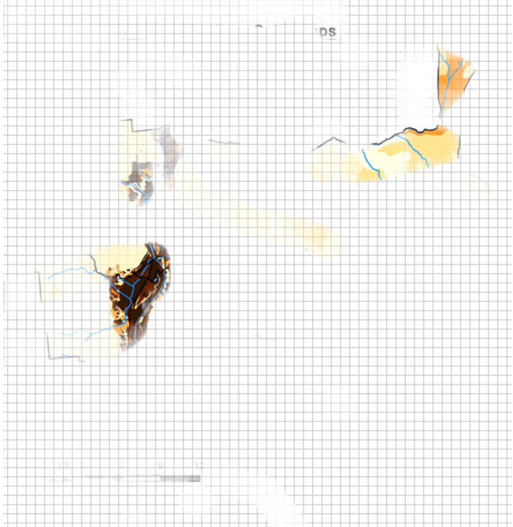
Mouse Point Density Masked Maps	*Mouse Tracking Trails Overlaying Maps*
	

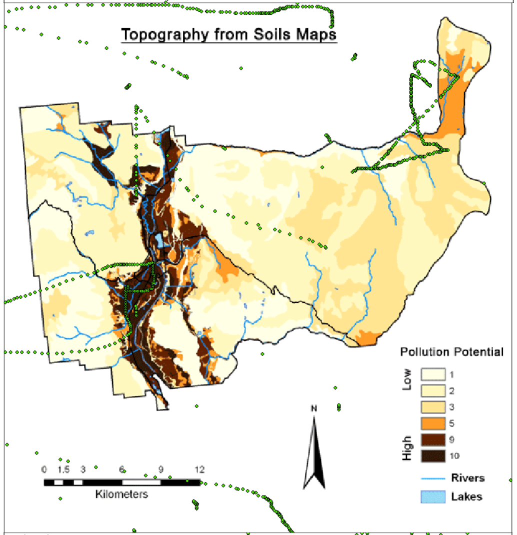
Mouse Point Density Masked Maps	*Mouse Tracking Trails Overlaying Maps*
	
	
	

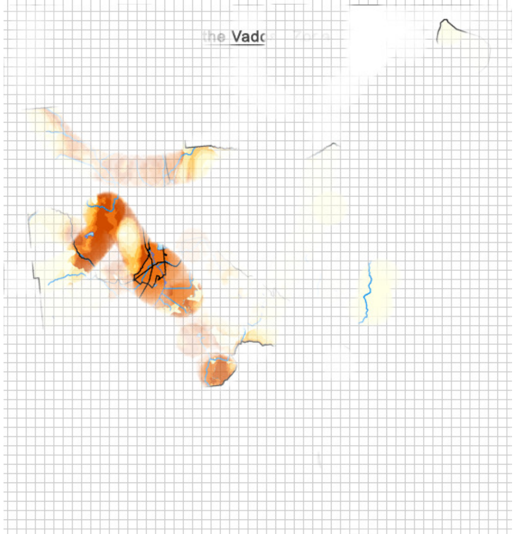
Mouse Point Density Masked Maps	*Mouse Tracking Trails Overlaying Maps*

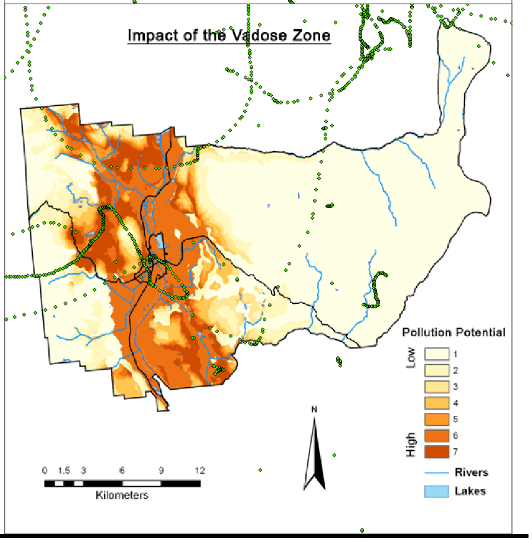


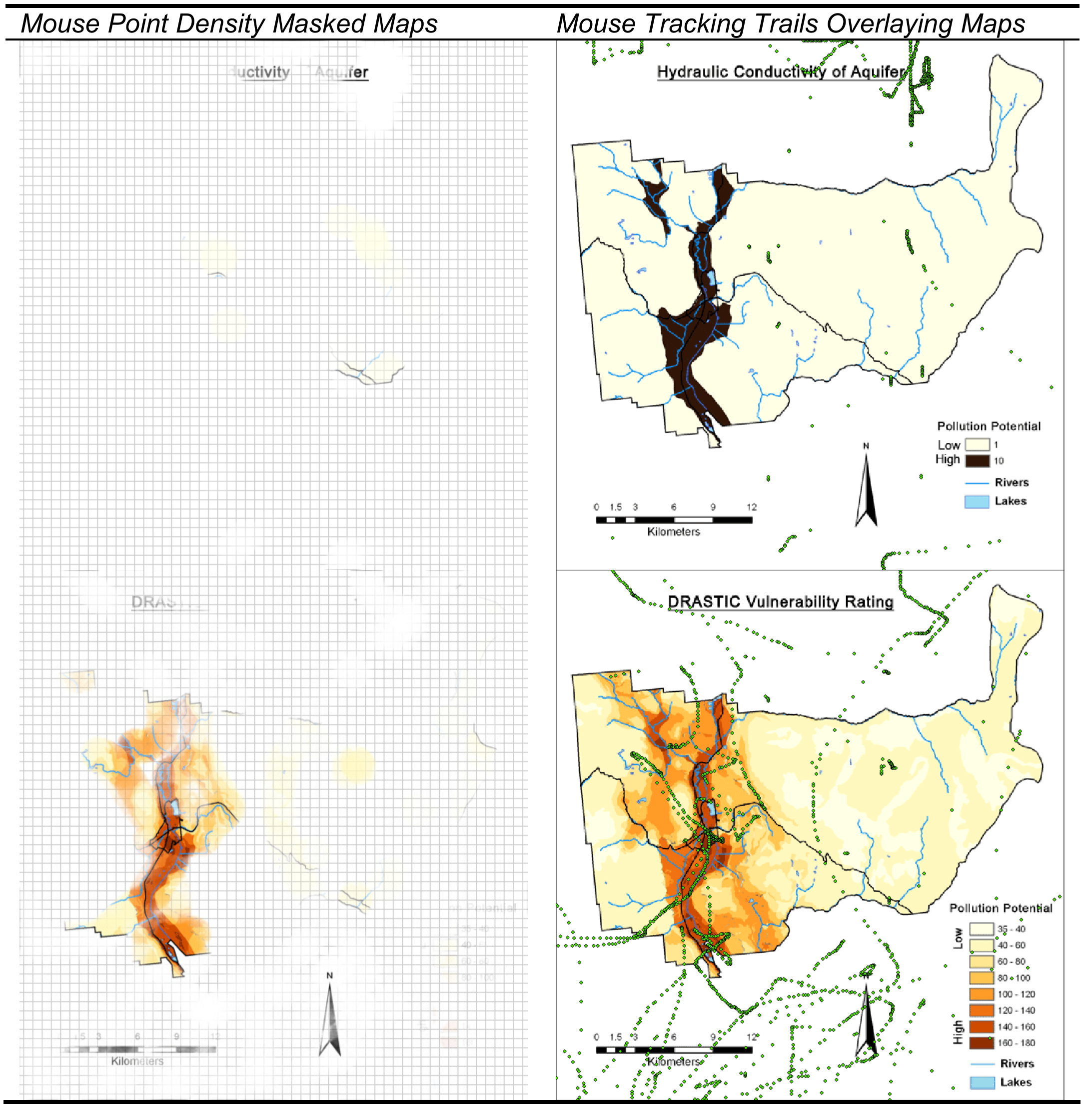












As mentioned before individual users can have far greater impact on the mouse density maps by simply having stronger tendencies of passing their mouse over the maps or moving their mouse across the map more slowly. Mouse tracking data of the nine DRASTIC maps for the HTML version show a decreased interest in maps over time and also help provide answers to artefacts of mouse tracking. While mouse tracking can show conscious mouse movement it also shows functional movement such as clicking on buttons. In this instance mouse tracking analysis may be more effective at determining participant behaviour than serving as a tool to compare interfaces.

Mouse tracking may have greater meaning when participants need to interact using their mouse. Users of the Basic and Advanced SVG interfaces are required to click and move the mouse across the interface to interact. The mouse behaviour may be different due to this.

By studying individual Basic SVG user mouse trails and click locations it seems many of the users performed a cursory analysis of the different layers. Most participants clicked buttons ten to 20 times, that translates to viewing each map once or twice. One user, who took the longest of all the participants to complete the experiment, did not click at all and therefore saw no maps but waved their cursor across the map. Their score decreased by two points in the post test. This may be a case of the participant perceiving the interface's affordances differently than most other participants and not recognizing what were meant to appear as interactive button. Another Basic SVG user clicked 53 times on the DRASTIC buttons but never on the hill shade or combined factors button as would have been required to respond to the task questions correctly. The remaining users all clicked on the nine DRASTIC factor map buttons and nearly all on the hill shade and combined factors buttons. Aside from using the mouse cursor to click on the buttons there is minor mouse movement across the maps. Some mouse trails follow text at the top of the page and the left edge of the map but rarely beyond this. A few users did nonsensical yet extensive mouse movements around the map. These may be unconscious, out of frustration, boredom, or simply a habit.

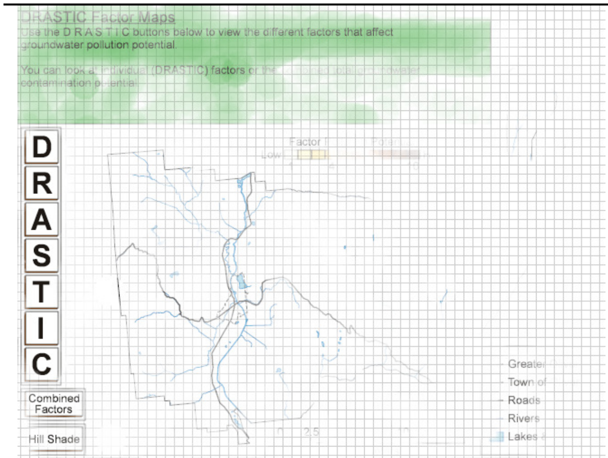
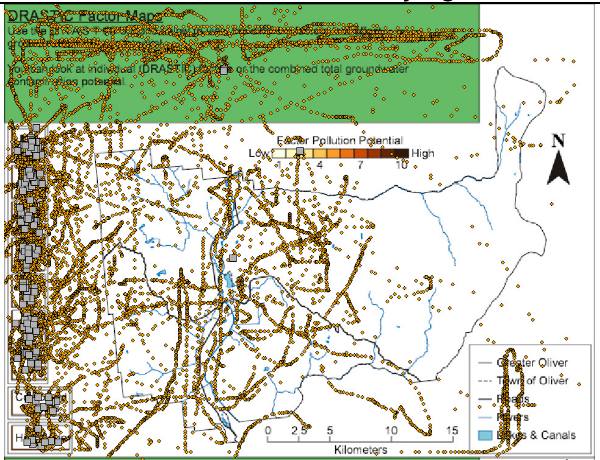
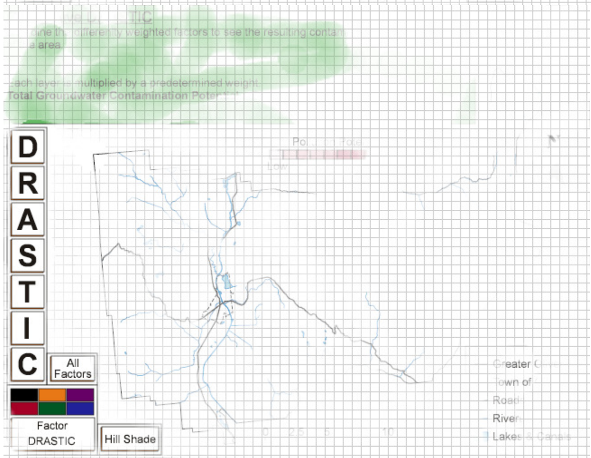
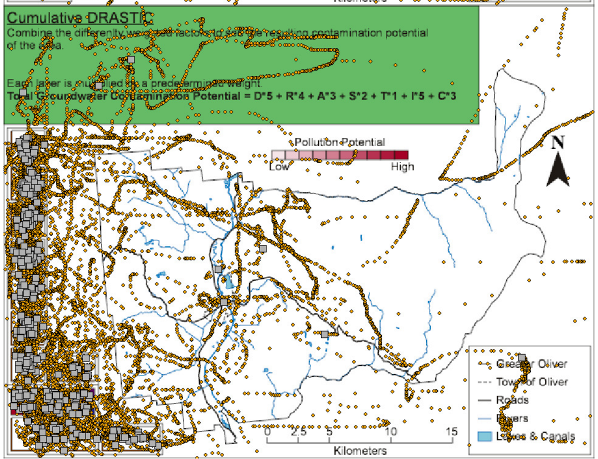
A Basic SVG participant with a drastically lower post test score (-10) seemed to have only interacted in a cursory manner which may explain their score. This however is not necessarily true since there was no significant correlation found between interaction amount (mouse hits and clicks) and change in score. Conversely there is almost a positive significant correlation (p = .082) between time spent on the introductory webpage and post-test scores for all three interface versions combined. This was to be expected as the interfaces simply reinforce what has been explained in the introduction. The task question scores however should reveal how useful the different interface versions were for understanding groundwater vulnerability at specific locations. As mentioned earlier no significant differences in task score were found between the DRASTIC versions.

Advanced SVG participants showed very similar behaviour to the Basic SVG participants. They clicked on the interface roughly the same number of times. Some of the Advanced SVG participants did not interact with the Cumulative Mode and Hill Shade button. In both versions participants are drawn to the DRASTIC buttons and almost all users clicked on each DRASTIC button at least once. Perhaps the smaller font sizes of the ‘Combined Factors’ and ‘Hill Shade’ buttons below the seven DRASTIC buttons communicates a visual hierarchy of importance. Participants of DRASTIC versions 2 and 3 performed similarly in scale tests, interaction time, task scores, and interface use duration. No significant differences were found.

Table 4-8 shows mouse movements of all participants combined for both SVG versions of DRASTIC. Low concentrations of mouse movements near the task zones may indicate that users forgot to focus on their tasks or simply did not use their mouse to do so. High concentrations of mouse hits near the buttons may also indicate participants focused on interaction and not content. The low task scores support this.

Comparing the two SVG versions is difficult due to similarly low task scores. Since the scale tests are largely influenced by the introduction that all users visit, the variation between interfaces are expected to be minimal. The interfaces serve as reinforcement of the introduced concepts only. They are meant to be exploratory tools used to determine the vulnerability of specific locations within Greater Oliver. Only the task questions could serve as true measurements of the abilities of the different DRASTIC versions to allow exploration.

Table 4-8: Mouse tracking hit locations for the two SVG DRASTIC interface versions. The grid background shows areas of little interest to participants. The Basic SVG version (N=11) maps are at the top, Advanced SVG (N=14) at the bottom. Squares show mouse clicks and circles mouse paths.

Mouse Point Density Masked Maps	*Mouse Trails and Clicks overlaying interfaces*
	
	

Using mouse tracking provides little explanation as to how participants are gathering the task knowledge required. Poor task question performance may be due to users having forgotten about or disregarded the task and are simply giving the interfaces a cursory use. Mouse tracking helps little to show where users were focusing. Perhaps with a larger sample size and a more motivated sample population mouse tracking could have more to offer in understanding user behaviour in a natural setting. The HTML version of DRASTIC seems to show mostly incidental mouse hits where as mouse movement for both SVG versions of DRASTIC show mainly toggling of the seven DRASTIC buttons once or twice by each user. Mouse tracking does seem to show participant attention quickly waning for Version 1 users. This however does not produce significantly lower task scores for the participants.

4.2.3 DRASTIC Results

There is no evidence available to refute the null hypothesis. The data available for this analysis support that all three versions of DRASTIC perform equally well. While some significant improvements in scale score for certain questions were discovered for the HTML and Advanced SVG versions it does not discount the possibility of the Basic SVG version also causing significant improvement if a greater number of participants were available. The low number of valid participants was the result of over half of the original participants not completing the survey, completing it a second time, or completing it too rapidly. The generally low motivation of the participants coupled with the low sample sizes make it difficult to determine much of significance.

The very similar task performance scores across the three interface versions, even the low motivation control group, support the argument that the task questions were either too difficult or the task was not consciously being considered during interface use. Placing circles on the maps and interfaces at task locations in an effort to increase task focus could have altered the manner in which the interfaces/maps were used and caused an unfair evaluation of the interfaces. Interestingly those who did use the task locations pop-up map on the interface page performed no better. Perhaps the task required too much active memory for too long to respond to the task question.

The three interface populations significantly improve their scores, when omitting anomalous scores, as seen in Table 4-3. These performance improvements however are likely due to the introduction page which provides the content to respond correctly to the scale questions. A significant Spearman correlation of the four samples shows that the more time is spent on the introductory page the greater the score improvement between scale tests. Learning variations between the three DRASTIC versions are most likely overpowered by the stronger learning effect of viewing the introductory page that more greatly alters participant final scores.

In conclusion the experiment does not detect that any of the three interfaces communicates more. Clearly, however, the more time users spent learning the material the better they were likely to do. A larger and more motivated sample may help detect if the three tools communicate spatial concepts differently. Qualitative behavioural analysis using mouse tracking may also yield more insightful results with participants more captivated by the DRASTIC content.

4.3 Arborville

Unlike DRASTIC, Arborville contains no introductory page before interface use. This may allow for greater variation in test scores. The Arborville online survey gathered similar information to the DRASTIC survey: demographic data, page view times, interaction, and two measures (pre-test and post-test) of the Arborville Human Impacts on Groundwater Comprehension (AHIG-C) Scale (Table 3-3). Between the pre-test and post-test, a version of Arborville was randomly chosen based on the user's screen resolution. Testing was mainly completed by undergrads in an introductory geography course in the Fall of 2007. In order to recruit more participants, ads were placed on the Facebook.com website at the end of May 2008. With over $70 spent during 15 days, 322 clicks resulted. Of these Facebook users most did not start the experiment and few of those which started finished. Facebook.com ads resulted in only four additional valid surveys.

The variety of data was gathered to try and determine whether there were differences in user perception between the eight versions of Arborville. The null hypothesis is that all versions communicate concepts equally. The Arborville survey had 336 visitors completing the survey yet only 167 were valid based on pre test, post test completion, and it being their first visit to the survey.

4.3.1 Arborville Analysis

Due to the large number of variations, one version having lower screen size requirements, and the large number of invalid surveys the number of participants using each version is highly unbalanced and most have an extremely low N (Table 4-9).

Table 4-9: User display resolution requirements and large number of invalid surveys resulted in an unbalanced distribution between samples.

Arborville Interface Version	*Surveys Completed*	*Valid Surveys*	*Female – Male Valid Distribution*
V1 – Static	238	131	79 – 52
V2 – Interactive	15	6	3 – 3
V3 – Modified Graphic Style	15	6	5 – 1
V4 – Cubes Toggle	14	4	1 – 3
V5 – Added Content	14	6	2 – 4
V6 – Zoom and Map	14	6	5 – 1
V7 – Status bar and graph	13	4	4 – 0
V8 – Drag and drop	13	4	0 – 4
Total	336	167	99 – 68

The cause of the imbalance in participants between Version 1 and the other versions is due to display resolution requirements. Version 1 requires a minimum resolution of 1024 by 768 while the remaining versions require a 1280 by 1024 resolution. Of the 167 valid surveys only 36 had resolutions of 1280 by 1024 or greater, while the rest, with the exception of one, had resolutions between 1024 by 768 and 1280 by 1024 (Figure 4-3). Resulting in an imbalanced sample populations.

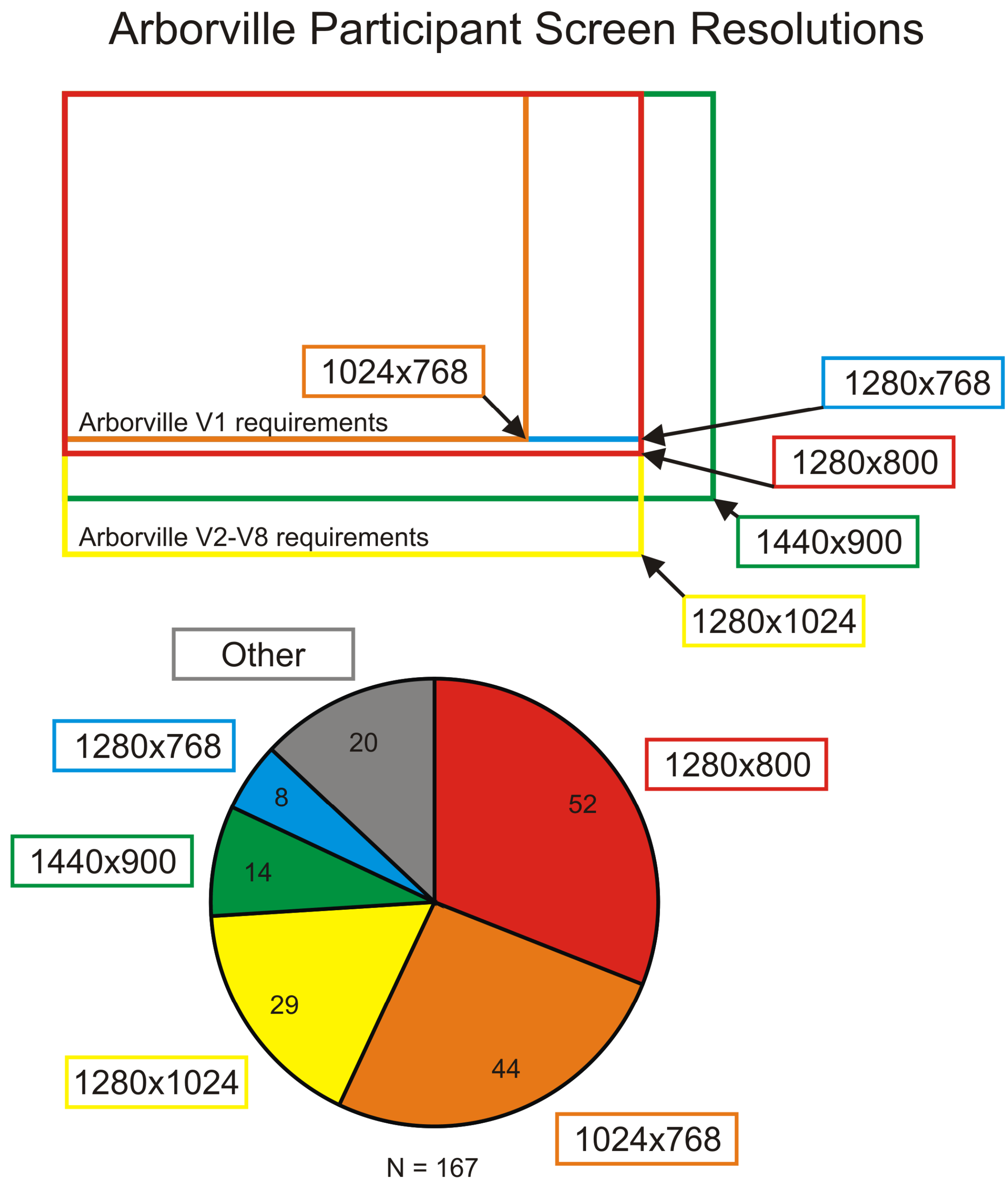


Figure 4-3: Arborville Participant Screen Resolutions. The Arborville versions 2 through 8 have higher resolution requirements than a large portion of the participant sample has access to.

The imbalance between the different versions is less restraining for data analysis than the extremely low N of versions 2 to 8. Analysis will be statistically insignificant, but may still be able to offer indicators as to if and how the versions vary. Due to the extremely low number of respondents (n = 4-6) for version 2 to 8 the gender distribution of respondents varies considerably.

In a Wilcoxon matched pair test of participant score change between measures, the low participant numbers for interface Versions 2 to 8 result in mostly insignificant or possibly lucky significant results while Version 1 shows significant change for six of the ten questions (Table 4-10). Version 1 participants achieved a strong significant improvement in their cumulative score as well. Results of version 2 to 8 are largely erratic due to the small sample sizes.

Table 4-10: Wilcoxon Matched Pairs Test (2-tailed significance, p = .05) shows whether significant improvement occurred for each question and cumulative scores for each version of Arborville. Note the low participant count for versions 2 to 8.

Pre-test – Post-test	*Q1*	*Q2*	*Q3*	*Q4*	*Q5*	*Q6*	*Q7*	*Q8*	*Q9*	*Q10*	*Cumulative Score*
V1 (N=131)	.062	**.001**	**.001**	**.000**	.558	.429	**.000**	.206	**.000**	**.000**	**.000**
V2 (N=6)	.102	.564	**.038**	**.046**	.739	.577	.564	1.000	.705	.414	.138
V3 (N=6)	.083	.317	.102	.450	1.000	.180	.785	.109	.317	.564	.674
V4 (N=4)	1.000	1.000	**.046**	.414	.317	.317	.564	1.000	1.000	.157	1.000
V5 (N=6)	.102	.317	.059	.180	.854	.564	.258	.655	.414	1.000	**.042**
V6 (N=6)	.317	1.000	.655	.102	.564	1.000	.317	1.000	1.000	1.000	.223
V7 (N=4)	.157	1.000	.157	.317	.157	.414	.157	.083	.655	.317	1.000
V8 (N=4)	.317	.317	1.000	.655	.180	.157	.157	1.000	.180	.317	.144
V1-8 (N=167)	**.003**	**.001**	**.000**	**.000**	.322	.480	**.000**	.458	**.000**	**.002**	**.000**
V2-8 (N=36)	**.003**	.666	**.000**	.064	.330	.953	**.050**	.302	.807	.103	**.012**

The low N for Version 2 through 8 makes further individual statistical analysis meaningless and any significant results most likely a chance occurrence. By grouping interface version scores it is possible to increase the numbers in samples. When all eight interface versions are grouped the effect of the much larger first group overpowers the others returning similar analysis results as for Version 1 alone (Table 4-10). By grouping Versions 2 through 8 questions 1, 3 and overall score change become significant. This means that these seven interfaces, as Version 1, statistically significantly increase survey results. Drawing a more specific conclusion however is not possible since the interfaces are all grouped together.

A visual representation of score change between pre-test and post-test for the eight Arborville versions illustrates the imbalance in sample sizes (Figure 4-4).

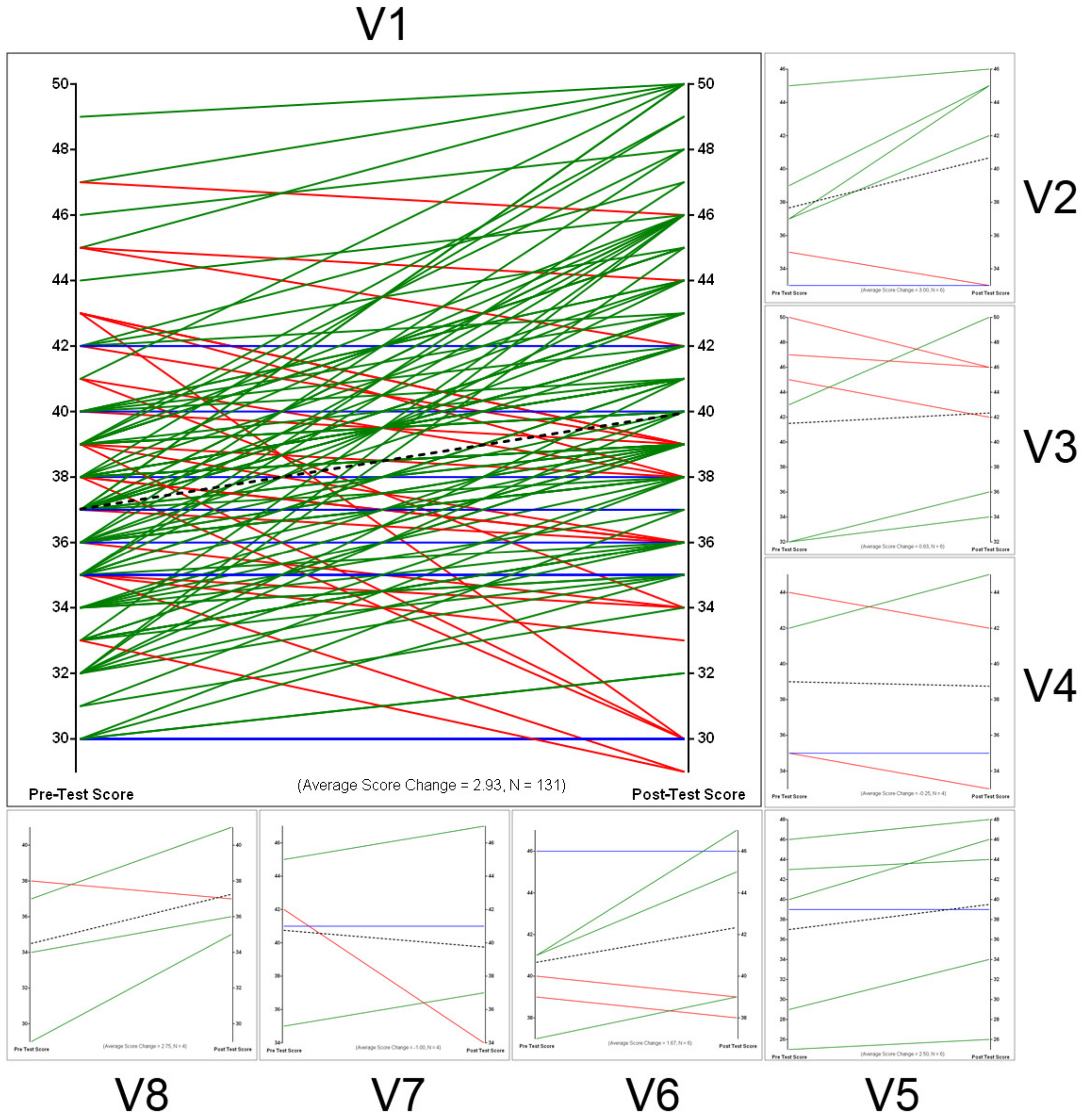


Figure 4-4: Pre-test to post-test changes in performance across the eight Arborville versions. The low number of participants for versions 2 through 8 are too few to communicate an adequate quantitative representation of the interface version.

After completing the survey participants had access to all versions of Arborville and many provided qualitative feedback of versions other than the randomly, depending on resolution, prescribed one. Participants provided their preferred versions, suggestions, and where, during interface use, confusions occured. The most common and descriptive arguments supported the GSC Arborville version 1, emphasizing that it was sufficient to communicate the concepts directly. “The concepts presented are not complex, thus it is unnecessary to create more complex versions” of interfaces (Arborville user id 245). Version 1 explicitly qualifies the behaviours within the graphic by labelling them ‘doing it wrong’ and ‘doing it right’. “The comparison of doing it right versus doing it wrong provides a clear picture of the impacts of land use as opposed to the interactive models“ (Arborville user id 360). Participants felt that Version 1 was more focused, clearer, and less confusing. The Arborville Versions 2 to 8 “are not showing the larger community picture and the interface is a bit too involved to quickly figure out what is going on” (Arborville user id 362). The only suggestion for Version 1 was providing additional information about features when the mouse is placed over them.

Criticism of the more complex versions was mainly that they were unnecessarily complex, intimidating, and/or confusing. Those that preferred the interactive Versions 7 or 8 did so with little explanation unlike supporters of Version 1. Most likely this is due to participants supporting the most sophisticated version simply because they believe it should be the best rather than have a reason for it. People respect sophistication regardless of its utility or accuracy, a danger maps commonly experience. A few participants distinguished Version 7 as being enjoyable, rather than Version 8, with the caveat that the interaction, although enjoyable, may not increase their understanding of the concepts. Another user found Version 7 more usable than Version 8. Additional descriptive suggestions included showing more obvious changes for the interactive versions and creating a more flexible interface that offers features as accessories to the main display, perhaps as slide-out panels. While the majority of participants believed Version 1 to be superior, the data gathered does not indicate performance differences between interface versions. Further, as MacEachren et al. (2005, 152) points out, users do not necessarily do better with versions they prefer or believe to be better.

The inflexible nature of the interfaces in regards to resolution has made a thorough analysis difficult. This is primarily due to the low participant numbers but also limitations of qualitative feedback of interfaces after survey use. Many users simply did not have the correct resolution to judge correctly the more advanced Arborville versions that would have appeared too large for their screens resulting in improper usage and poor evaluations. Some of the buttons may not have been visible and the interface may have seemed aesthetically congested. Although the qualitative evaluations above strongly support Arborville Version 1 to be more effective in communicating the target concepts, the feedback is most likely biased due to incorrect and partial viewing of the interfaces and, like the statistics with low n above, unreliable. Looking at participant behaviour from mouse tracking and interaction may yield better results.

4.3.2 Arborville Behavioural Analysis

Due to a survey programming error not all interface tracking data were captured for each user. The Arborville versions 1 to 8 had 69, 5, 6, 3, 5, 4, 3, and 2 participant interactions captured, respectively. Again, the low number of participants makes it difficult to generalize differences in user behaviour when using the various versions of Arborville. Behaviour that stood out and may be artefacts of the low N is discussed below.

Arborville Version 1

After data gathering was completed a mouse tracking bug was discovered in all Arborville versions that prevented mouse tracking to occur across white space. The error is marginally noticeable for Version 2 through 8. Version 1, while having the most participants, also had the greatest white spaces near content. This tracking error over-emphasizes participant interest in areas that have content (Figure 4-5). Without having the complete mouse tracking data it is hard to determine which areas users focused on more. It seems from concentrated clicks, that participants perceived the ‘doing it right’ and ‘doing it wrong’ headings to be buttons. Also visible is the attention paid to the two text paragraphs in the top right and left.

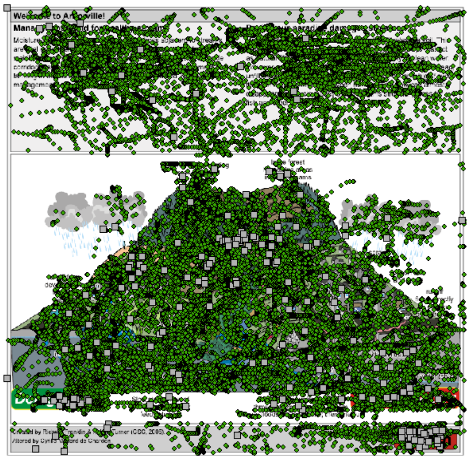
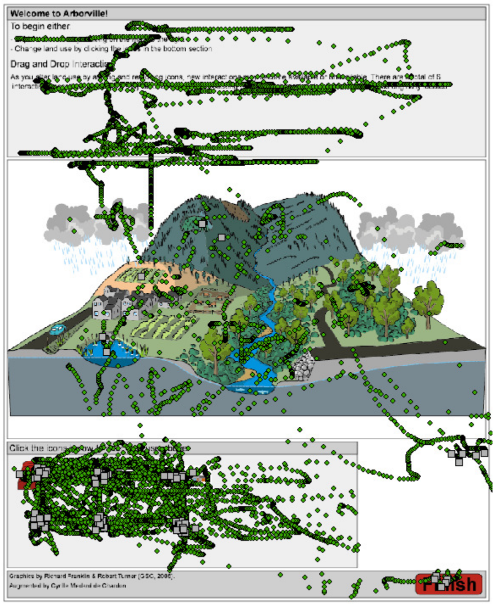


Figure 4-5: Mouse tracking of 69 users of Arborville Version 1. Due to a tracking bug, points were not recorded on white spaces.

Arborville Version 2

Version 2 of Arborville draws mouse movement from the content to the interactive buttons. The five records available show users paying attention to the instructions on the welcome screen as well as instructions and text (Figure 4-6). Every participants clicked on each land use button at least once.



To begin either

- Change land use by clicking the icons in the bottom section

Graphics by Richard Franklin & Robert Turner (GSC, 2006).
Augmented by Cyrille Medard de Chardon

Figure 4-6: Version 2 participants focused more on the interactive icons than the content with their mouse.

While Version 1 participants seemed to be searching for interaction in the content, in Version 2 mouse clicks were clearly concentrated at the icons at the bottom of the screen. Using ArcGIS, a point density analysis was done of mouse tracking points for each version of Arborville. A subtractive operation was performed on adjacent versions of Arborville to show net spatial changes in mouse location concentrations. The analysis of adjacent versions with fewer differences allows easier reasoning as to the cause of mouse point tracking variations. The comparison of version 1 and 2 shows greater attention focused on the icon set at the bottom of the screen by version 2 (Figure 4-7).

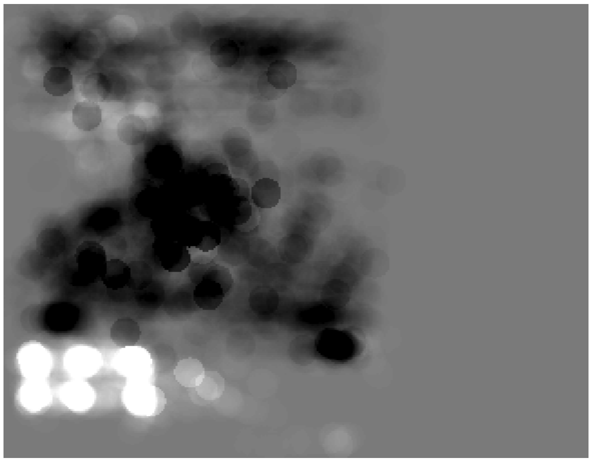


Figure 4-7: A point density comparison map shows how users have shifted attention between Arborville Version 1 and 2. White represents areas of greater Version 2 mouse hits, black of Version 1, and grey areas have equal concentrations.

Arborville Version 3

Arborville Version 3 (6 records), which has the same interaction yet a different graphical style, has a very similar distribution of mouse hits as version 2 as illustrated in Figure 4-8. Figure 4-9 shows differences between Arborville Version 2 and 3 in the form of a point density comparison map.

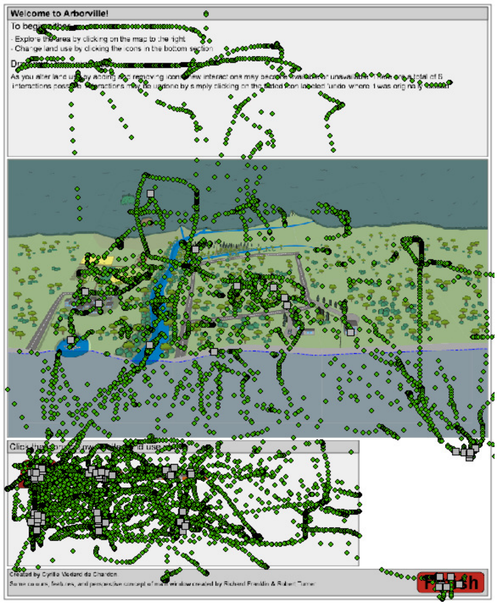


Figure 4-8: Arborville Version 3 has a very similar mouse hit distribution as Version 2.

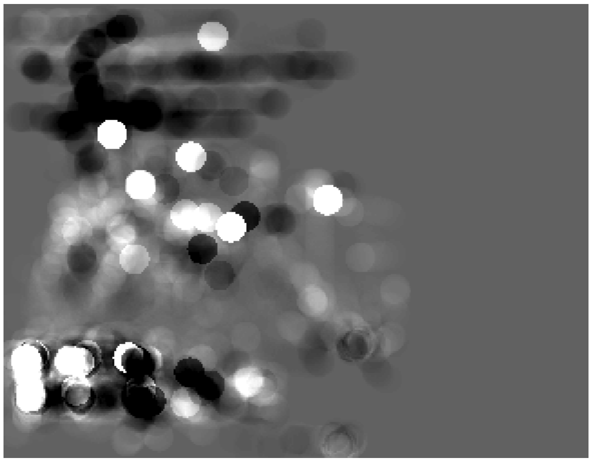


Figure 4-9: A point density comparison map shows similar behaviour between Arborville Version 2 and 3. White represents areas of greater Version 3 mouse hits, black of Version 2, and grey areas have equal concentrations..

Arborville Version 4

Version 4 of Arborville, with only three records available, shows how users rely on the mini-map in the top right hand corner to toggle the blocks which up until this version have been locked in place. Participants seem to use the blocks directly and mini-map equally to toggle the visibility of the terrain cubes (Figure

4-10). Participants easily perceived the ability of the blocks to be interacted with. Without a larger sample size it is hard to determine if toggling of blocks is useful. By toggling block visibility additional groundwater information becomes visible. A point density comparison map shows version 4 users paying greater attention to the text area and the added mini-map (Figure 4-11).

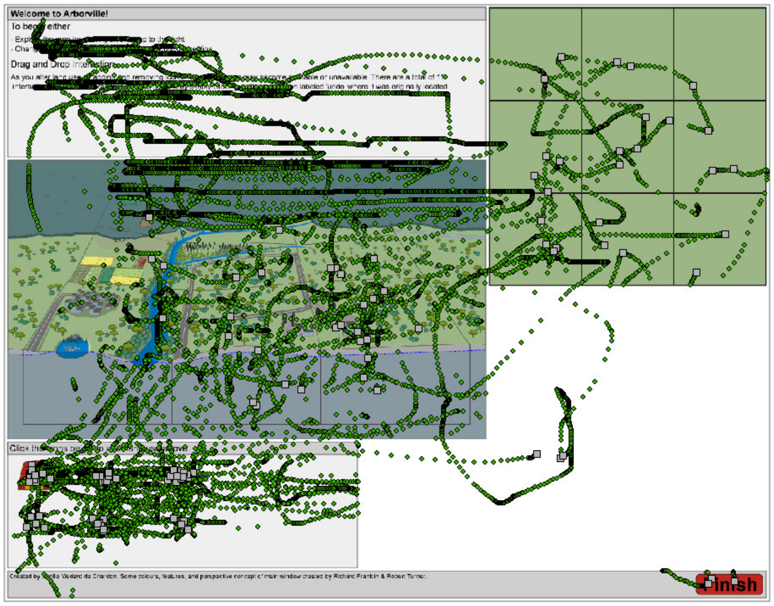


Figure 4-10: Arborville Version 4 with its larger frame and mini map toggle cubes of terrain shows an increase in users clicking on the terrain blocks and hovering above the content.

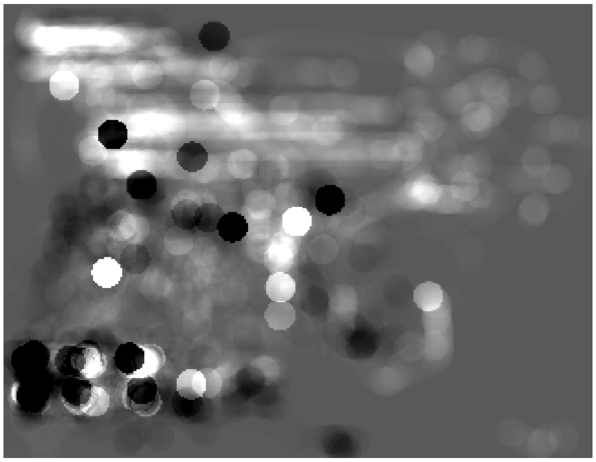


Figure 4-11: Point density comparison map of Arborville Version 3 and 4 shows a shift to the new features. White represents areas of greater version 4 mouse hits, black of version 3, and grey areas have equal concentrations.

Arborville Version 5

Version 5 of Arborville adds new interaction types and content. This should and seems to have increased mouse tracking in the areas of the new features (Figure 4-12). The mouse point density comparison map shows the added emphasis on the areas of the new interactions and largely similar coverage across the rest of the map (Figure 4-13).

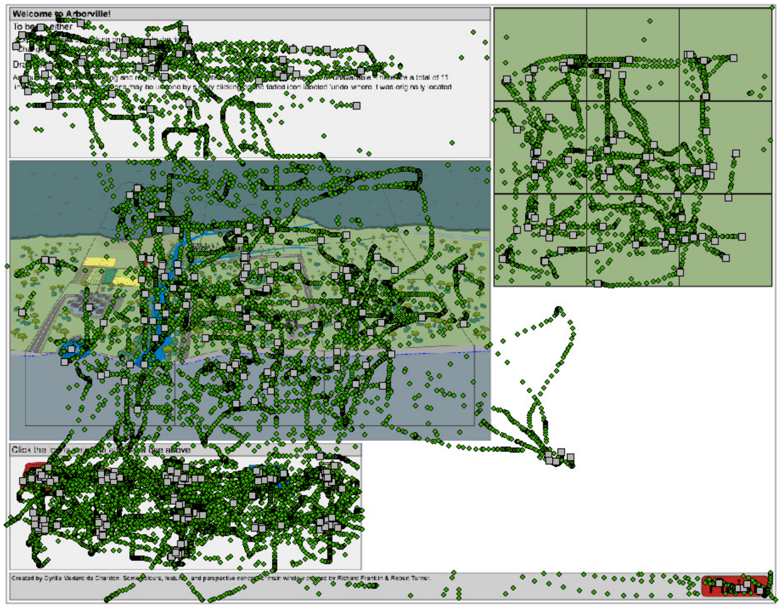


Figure 4-12: Arborville Version 5 participants behaved similarly to those of Version 4 with the exception of paying greater attention to the new interactive content.

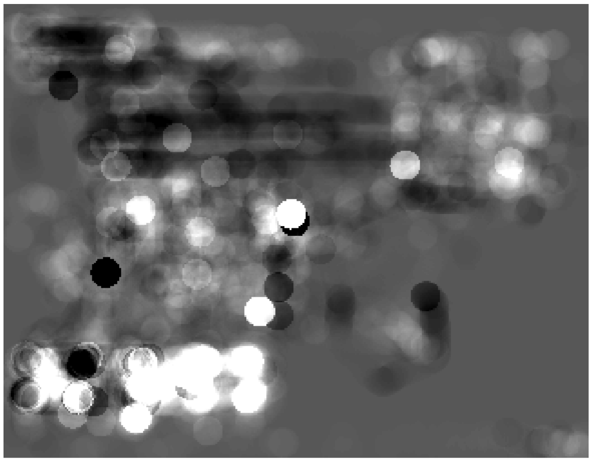
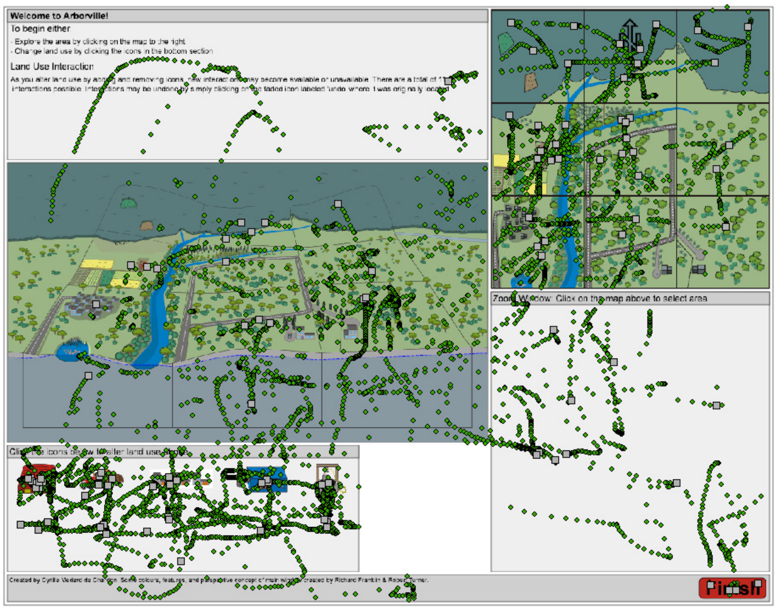


Figure 4-13: Added attention is paid to the new interaction options of Arborville Version 5 compared to Version 4. White represents areas of greater version 5 mouse hits, black of version 4, and grey areas have equal concentrations.

Arborville Version 6

Version 6 of Arborville adds the zoom box and enhances the mini-map from green squares into a representation of the terrain. The detailed mini-map and zoom box expectantly draw attention to themselves as can be seen by the moue tracks in Figure 4-14. When comparing Version 5 and 6 this, Version 5 seems to stimulate users more. This is most likely due to Version 5 having more participants than 6, with 5 users versus 4 respectively, and Version 5 participants simply being more exploratory and interactive with the interface. The small sample sizes do not allow generalization.



Welcome to Arborville!

To begin either

- Explore the area by clicking on the map to the right
- Change land use by clicking the icons in the bottom section

Land Use Interaction

As you alter land use by adding and removing icons, new interactions may become available or unavailable. There are a total of 11 interactions possible. Interactions may be undone by simply clicking on the faded icon labeled 'undo' where it was originally located.

Figure 4-14: Arborville Version 6 mouse tracking hits shows added attention to the mini-map area relative to the main content.

The point density comparison map comparing Version 5 and 6 mouse tracks is imbalanced by the overly active version 5 users (Figure 4-15). Version 6 users, relative to mouse movement for previous versions, were expected to give more attention to the enriched mini-map even though this is not obvious in Figure 4-15.

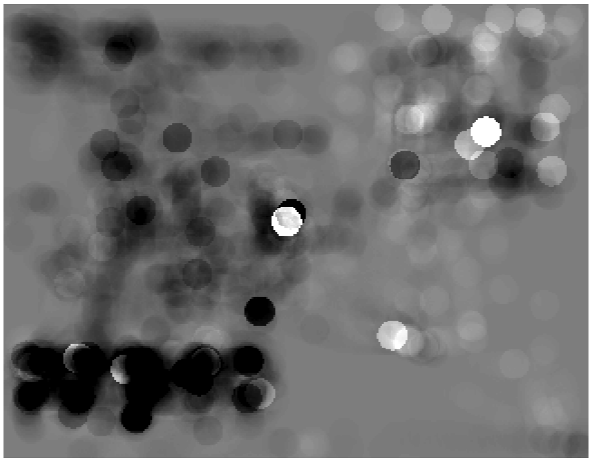


Figure 4-15: Arborville Version 5 had more active users than Version 6. White represents areas of greater Version 6 mouse hits, black of Version 5, and grey areas have equal concentrations.

Arborville Version 7

The three Version 7 records available show little attention given to the new bar graph feature using the mouse (Figure 4-16). The bar graph serves as a feedback mechanism and is not meant to be clicked on. This may mean it is correctly being perceived as not interactive. Most mouse movement attention is focused within the land use window on the icons located on the right side. The high concentration of mouse tracks on the icons on the right side of the land use window is due to 95% of the points being done by two users who repeatedly used those icons.

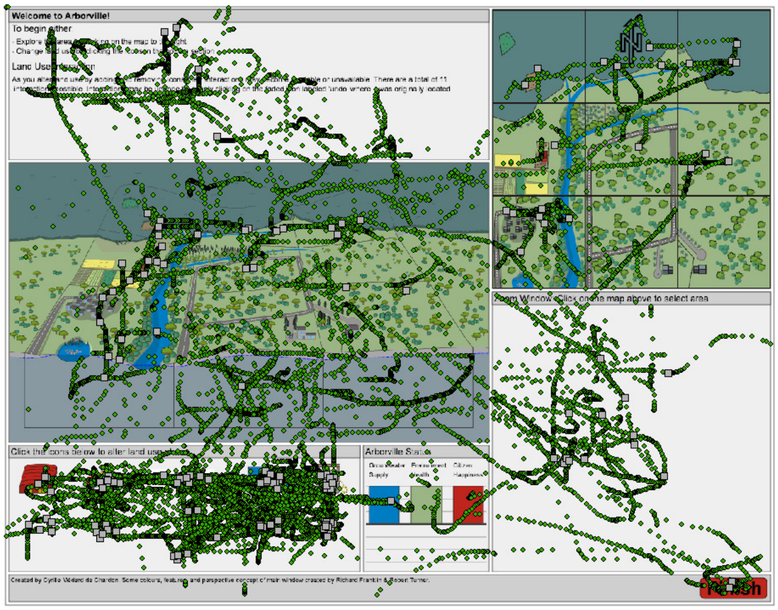


Figure 4-16: Arborville Version 7 mouse tracks show little attention focused on the new graph.

Version 7 users, even though fewer, largely overshadow Version 6 users in the point density comparison maps due to their thoroughness (Figure 4-17). The repeated use of the icons is clearly visible in the bottom left of the image. Most other areas also show higher Version 7 usage.

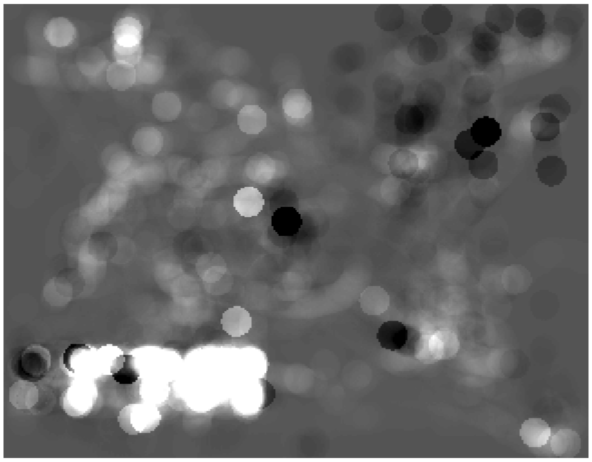


Figure 4-17: The point density comparison map shows the imbalance between the Arborville Version 6 and 7 users. White represents areas of greater Version 7 mouse hits, black of Version 6, and grey areas have equal concentrations.

Arborville Version 8

Arborville Version 8 only had two records available. A greater number of participants could have shown how the use of the drag and drop feature alters participant behaviour. While some streaks of mouse movement from icons to the perspective are visible, too few are present to make generalizations (Figure 4-18). Neither of the two users used all of the interactive icons, one trying only three, and the other seven of the ten possible options. While the behaviour of one of the users seems genuine the other seems minimalist.

Due to low numbers, the point density comparison map for Version 7 and 8 is dominated by Version 7 users (Black) as illustrated in Figure 4-19.

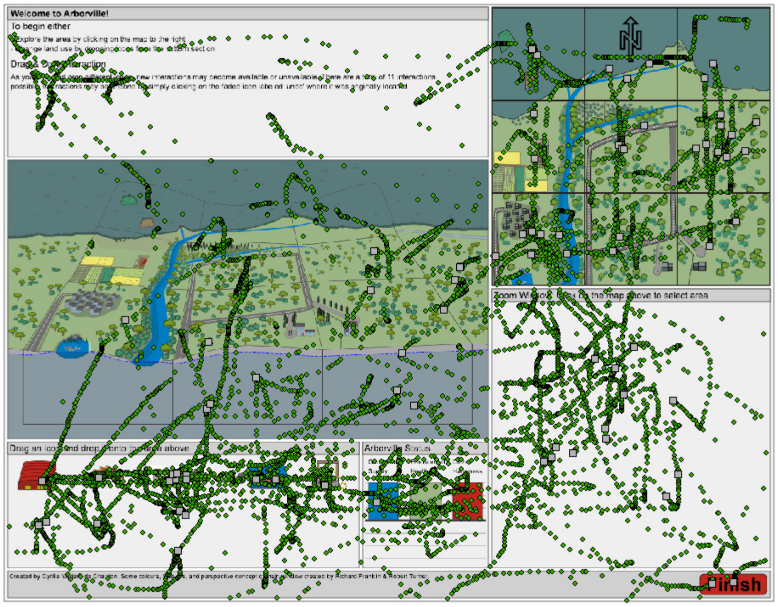


Figure 4-18: The two user records available provide a poor representation of how Version 8 participants would most likely behave.

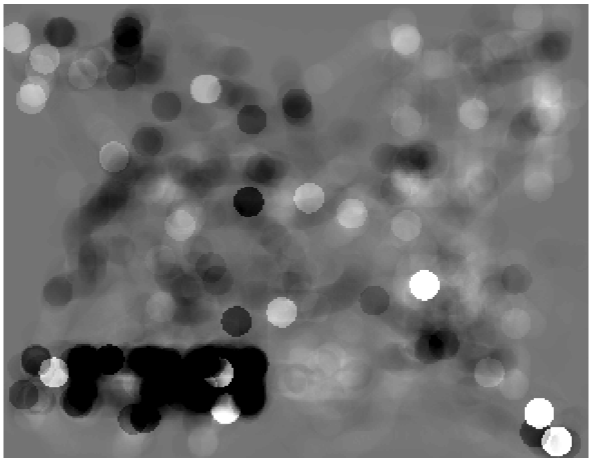


Figure 4-19: Arborville Version 7 users dominate the point density comparison map. White represents areas of greater Version 8 mouse hits, black of Version 7, and grey areas have equal concentrations.

Overall the behaviour analysis using mouse tracking has shown little unexpected difference between the eight versions of Arborville. The lack of sufficient captured participants makes conclusions difficult but serves to provide a preliminary sense of how the interfaces are used.

Due to the low participant number it is once again difficult to determine differences between the various interfaces that would alter factual and conceptual understanding. In order to make solid deductions a greater number of participants would be required as well as a data review platform. Analyzing the very large number of data points in ArcGIS does not show the order of mouse movement points and mouse clicks. Like footprints, ArcGIS only shows where the user has focused attention. In total, approximately 150,000 mouse tracking points were successfully captured and analyzed. Version 1 of Arborville, without interaction, expectedly has roughly a quarter of the number of mouse tracking points per user compared to seven interactive versions of Arborville. Constructing a simple data review platform to show the equivalent of a screen capture video would be more effective for analysis while still allowing participants to use the interfaces in their field setting. Studying the sequence in which participants explore the various versions of Arborville could allow a better understanding of the interface use.

Interface Use Duration

By using mouse tracking data it is possible to get more accurate data of interaction duration than page views. As Figure 4-20 shows, interaction times increase with the higher versions of Arborville. A greater number of participants is required to determine whether there is a significant relationship. Initial qualitative observations suggest there are differences, but larger samples are required to test this.

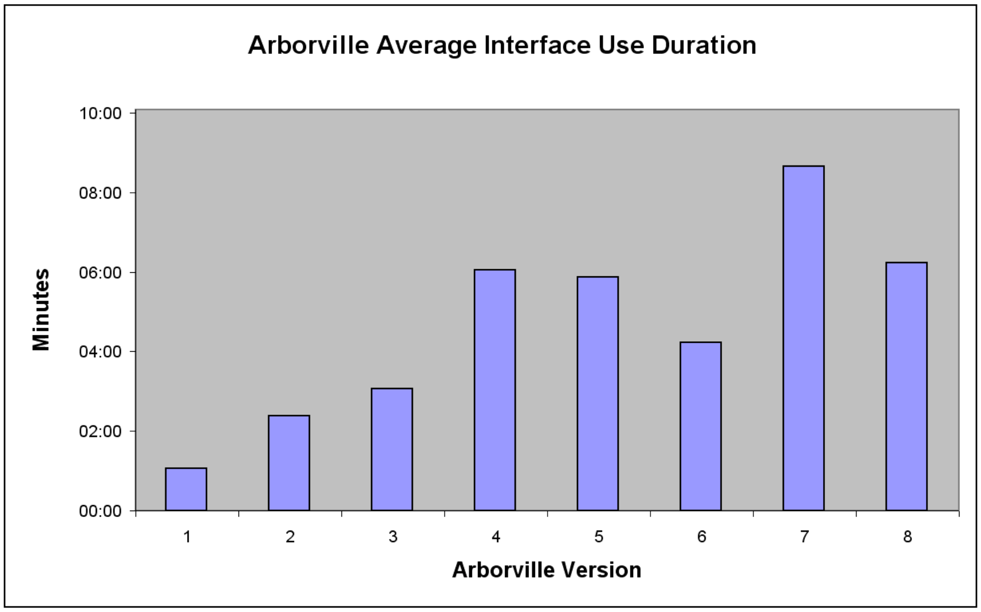


Figure 4-20: Average Arborville interface use duration for the eight versions.

The mouse tracking data captured suggests participants used the added functionality of the more complex versions of Arborville. The added functionality also seems to increase interaction time. Whether this increases conceptual and factual learning cannot be determined with the low participant count.

4.3.3 Arborville Testing Results

Greater performance variation between versions was anticipated with Arborville than DRASTIC due to Arborville having no introductory information page also communicating the target concepts. This did not occur however, possibly due to false assumptions, programming errors and many careless or cursory participants. Over 50 percent of surveys were not used due mostly to incompletion but also repetitive visits. Many participants left after using a version of the Arborville interface but before completing the post-test. At least five participants, who were undergrads at SFU, repeated the survey twice yet did not indicate that it was their second visit when asked explicitly by the survey. This was determined by comparing demographic responses, IP addresses, and survey completion times. Whether others completed the surveys multiple time without indication cannot be determined.

The small number of mouse tracking records was the result insufficient error testing being performed. When users forgot to complete all the survey questions for the post-test they would be redirected to the page. This caused mouse tracking records to be overwritten with blanks. Additional problems caused a separation of records for users who needed to install the SVG plug-in. This was manually repaired later by matching survey completion times but a few surveys were lost. While the main limitation for data analysis was the low number of participants with the appropriate resolutions completing the survey, survey programming errors additionally caused a large reduction in number of mouse tracking records.

Display & Resolution

The assumption that a large number of the population utilizes 1280 by 1024 resolutions is one factor for the imbalanced and low participant number for the Arborville versions. Screen dimensions are becoming wider rather than larger at the same ratio. Currently, about 50 percent of online users have resolutions of 1024 by 768 (Version 1 requirements) with about 40 percent having resolutions greater but not necessarily 1280 by 1024 (Version 2 – 8 requirements) (W3Schools 2008). The dimensions of all Arborville versions should have been made for 1024 by 768 resolutions but also dynamic so as to resize for higher resolutions displays. Based on vector data, SVG is designed to resize easily. This was prevented so that interfaces would not appear in drastically different sizes for different users. The same version of Arborville can appear different sizes on different displays since identical resolution displays can vary in dimension. A 15 inch and 21 inch screen can both have a 1600 by 1200 resolution, while the 21 inch monitor effectively has twice the screen area. Resolution, unlike screen dimension, can be determined when an internet browser visits a website. The unknown screen size may defeat the purpose of restricting access based on the known resolution. An alternative would be to ask participants their screen dimensions during the introductory survey questions, but most likely most would not know.

Priming and Training Effects

Arborville participants were given a pre-test with questions relating to the knowledge the interfaces are to communicate. These primed the participants so that they were more likely to notice facts and concepts relating to the questions posed to them when they used the interface. The participants then had the possibility to correct their responses during the second measure. Although Arborville Version 1 user scores statistically significantly increased, their scores only increased by three points on average. Considering each of the ten questions is on a five-point scale, with possible total scores from ten to 50, the improvement is small. Had the participants not been primed the margin of improvement may have been less. Furthermore, without a control group, it is difficult to determine if repeating the survey test questions increases scores.

User Preference

While the analysis shows a strong significant improvement in Arborville Version 1 participant scores, the increase is only by a three points on average. How Versions 2 through 8, with more participants, would alter post-test scores cannot be determined. Through informal testing and comments submitted during online, users generally preferred the visuals of Versions 1 and 2 of Arborville that were created by the GSC. The two versions are visually simpler, have fewer distractions, and may be more pleasing artistically. Version 1 was liked for its explicit flow arrows of water and pollution paths. While participants seemed to prefer Version 1 as reflected by their comments their preference does not indicate whether Version 1 is superior. Participants may simply prefer the graphical style but preference does not reflect effectiveness. The participants were most likely viewing the higher Arborville versions at incorrect resolutions resulting in portions of the interface being cropped or unusable. How Arborville versions vary in communicating factual and conceptual information cannot be resolved without larger sample sizes.

4.4 CABI

This section presents a qualitative and quantitative analysis of the CABI interface survey and results. The CABI survey (Appendix A) captures mainly qualitative information but six Likert scale questions collect ordinal data. The paper survey directs the user to complete certain actions and respond to open ended questions. The qualitative questions try to understand what CABI users perceive while interacting with the interface. A total of 43 participants from an introductory SFU geography course completed the CABI experiment and 11-page paper surveys in October of 2007. The number of participants were split 22 and 21 between the unconstrained CABI Version 1 and constrained CABI Version 2, respectively. The following sections present the qualitative and quantitative analysis in the order they were asked in the survey.

4.4.1 CABI Qualitative Analysis

All 43 surveys were transcribed into a Microsoft Excel spread sheet. Before coding, any identifying information regarding the user or what version of CABI they used was hidden to complete coding of data double-blinded. In addition, the row order of the data was randomized to further prevent bias. The rows were then nominally coded sequentially based on their response type. Transcription of surveys revealed several issues users had when completing the surveys.

The CABI model's starting condition is not in a state of equilibrium from the outset. The initial state has higher water levels than would be expected in a natural equilibrium. This causes flooding and base flow to occur on the model after several minutes of use. Certain participants revealed, through their comments, that they believed these events to be related to their interactions, specifically their placement of wells. Certain participants assumed the wells they placed dispersed the water they pumped onto the surface. This impression is reinforced when users place a well on or near the river as it begins to flood due to saturated sediment.

A few users experienced some confusion from the mini-map. They assumed that the mini-map dynamically represented the model even though it does not. Their assumption may have had an impact on what they believed was occurring. This assumption could stem from real time strategy video game use which commonly has dynamic content in mini-maps as well. In addition, the symmetric nature of this particular model caused some confusion for two users regarding how the mini-map and model were related in orientation. Certain users experienced difficulties and believed that wells were placed at a location on the model by clicking on the opposite side of the mini-map. This could be resolved by placing a north arrow on the terrain and mini-map or making the model asymmetric.

Whether wells simply pump water out of the system, onto the surface, or pump water down is not explicitly stated in the model. Participants may have perceived various behaviours. The CABI model wells pump water from the base of the wells into a cloud that redistributes it equivalently across the model as rain as described in Chapter 3. The rain is not seen, but its effects, that water is entering the system, may be deduced due to groundwater levels not continually decreasing. The distribution of water changes over time but not the quantity. The cones of depression from wells can clearly be seen and are still apparent when placed near the stream (Figure 4-21 right). Hiding the surface layer, as directed in the CABI survey, helps greatly to see the depressions around the wells.

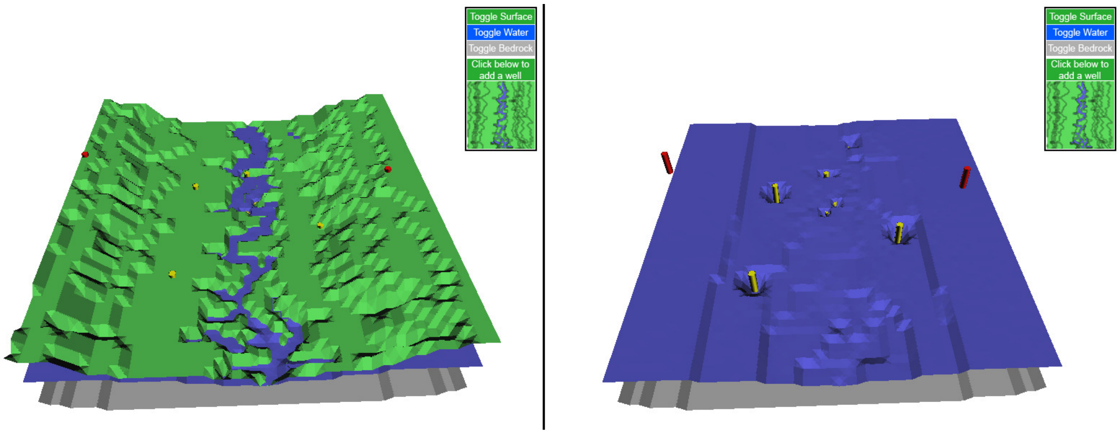


Figure 4-21: CABI interface cones of depression from wells can clearly be seen in the water table (right) by hiding the surface layer (left).

Wells can be placed anywhere on the terrain and appear a half unit above the land surface. This means when they are placed in a portion of the river deeper than a half unit, they are hidden by the water layer. This caused some users to believe the wells had no effect. All wells go a set depth of three units or cells down from the ground level. If a well is placed in a river the well may be barely visible or hidden below the water layer as its effect on the water surface is diluted due to upstream flow. Non-investigative users may have concluded that these wells have no effect on groundwater even though they visibly do reduce groundwater levels in sediment nearby. Furthermore students who did not remove the surface layer were unlikely to discover the impacts wells have on their surroundings regardless of location.

The CABI survey (Appendix A) contains mostly qualitative open-ended questions. By nominally coding survey question responses and grouping similar ones, the more common observations could be addressed. After observing the initial state of CABI most users had a good understanding of what they were looking at and what some of the possible interactions were. Once asked to manipulate the model (Question 2), some participants using CABI Version 1, which has greater control freedom, stated that the ability to view the model from a top-down and profile perspective helped them gain a better understanding of the shape of the river valley model. Many of the Version 1 participants used the greater control freedom to view the profile of the terrain to gauge the distances between the layers and describe the shape of each layer. Users described how they could “see all the parts of the river proportionally whereas some [parts] were harder to make out before” (CABI user id 38). However, users of Version 2 also described similar findings without the added control, one description noted “[t]he layer of water is closer to the surface layer than the bedrock layer” (CABI user id 26). All responses were coded using categories that described/measure the quality of user feedback. Overall Version 1 CABI participants only made a couple more insightful or satisfactory descriptions of the model than Version 2 participants (Table 4-11).

Table 4-11: CABI Question 2 coding results show little difference between Version 1 and 2.

Q2 – Using the mouse to move the model, do you notice anything new?				
		CABI Version Response Distribution		
		V1	V2	Total
Q2 - coding	Insightful / Descriptive	8	6	14
	Satisfactory	12	10	22
	Basic / Vague	2	4	6
	Incomprehensible	0	1	1
	Total	22	21	43

After the inviting users to interact with the model, toggle the layers, and place a well on the green surface, they were asked to describe what changes they saw. The goal was to have users describe a cone of depression. Similarly to question two there is little difference between the users of CABI Version 1 and 2 (Table 4-12). Clarity of descriptions were consistently poor, expressions describing the effects of wells as “the surface area gets eroded” (CABI user id 26), for example, were marked as ambiguous.

Table 4-12: CABI Question 3 coding results show little difference between Version 1 and 2.

Q3 – Observe the model and describe any changes you see and to what layers				
		CABI Version Response Distribution		
		V1	V2	Total
Q3 - coding	Correct	11	8	19
	Ambiguous	3	5	8
	Wrong	1	2	3
	No comment relating to cone of depression	7	6	13
	Total	22	21	43

Question 4a asks participants to place wells on the blue area of the mini-map and observe what occurs when the well appears near or in the river. Similarly to the previous questions, responses from both samples have similar distributions (Table 4-13). The large number of ambiguous results is due to statements similar to: "When placed on the blue, more green land showed up around the well." (CABI user id 17). While they are describing a symptom of a cone of depression in the model, they are not stating that the water level decreases. The question does not ask for anything beyond observations so while these are correct they are ambiguous observations as to whether the participant knows or sees that a cone of depression of some sort has most likely formed beneath the surface.

Table 4-13: CABI Question 4a coding results show little difference between Version 1 and 2.

Q4a – Place a well on the water by clicking on the blue areas of the map in the menu. What do you observe?

		CABI Version Response Distribution		
		V1	V2	Total
Q4a – coding	Reduce water level	5	7	12
	Ambiguous	8	8	16
	Wrong	1	0	1
	Not applicable	8	6	14
	Total	22	21	43

Question 4b specifically asks for differences relating to the effects of wells placed on land in contrast to those in or near water. This question can easily be answered by placing multiple wells in each location type with a result similar to those illustrated in Figure 4-21 that clearly shows larger cones of depression for those farther from the river. Surprisingly, but perhaps not significantly, no users of Version 1 correctly described this while four Version 2 users described the concept correctly: “The wells placed in the water have smaller depressions associated with them (on the water layer) than those placed on land” (CABI user id 2). Many responses were ambiguous, wrong, or simply did not answer the question. While of note, the four CABI Version 2 correct answers are most likely a chance occurrence (Table 4-14).

Table 4-14: CABI Question 4b Version 2 responses show a higher number of correct answers.

Q4b – Does the well placed in the water cause different changes than the well on land?

		CABI Version Response Distribution		
		V1	V2	Total
Q4b - coding	Correct	0	4	4
	Ambiguous	9	9	18
	Wrong	8	2	10
	Does not answer question	5	6	11
	Total	22	21	43

Question 5 attempts to specifically capture what participants have learnt regarding how wells alter their surroundings. Again both versions of CABI have similar distributions of responses (Table 4-15). Distinctions between ambiguous and correct answers were based on their descriptions. Responses such as “they remove water” (CABI user id 43) were considered ambiguous while “wells lower the local water level” (CABI user id 30) was considered correct.

Table 4-15: CABI Question 5 shows the distribution of descriptions of how wells alter their surroundings.

Q5 – In the model, how do wells alter their surroundings?				
		CABI Version Response Distribution		
		V1	V2	Total
Q5 - coding	Correct	7	9	16
	Ambiguous	9	7	16
	Wrong	3	2	5
	Does not answer question	3	2	5
	No response	0	1	1
	Total	22	21	43

Wells located where groundwater was deeper than they could reach (three cells) would change colour from yellow to red to signal that they were ‘dry’. Question 9a asked why certain wells may appear or become red. The social expectation of red meaning error or danger makes this question easy enough that two users explicitly stated they had not seen any red wells while running the model yet still guessed their meaning correctly. While the distributions are similar for both CABI versions it is the survey question with the largest consensus (Table 4-16). Sixty-seven percent of total users understood the meaning of a red well. Additional users may have also guessed the meaning of red wells but not stated it.

Table 4-16: CABI Question 9a shows a consensus on the meaning of red wells.

Q9a – If you placed wells in certain locations they may appear or become red – why?				
		CABI Version Response Distribution		
		V1	V2	Total
Q9a - coding	Correct	16	13	29
	Ambiguous	3	4	7
	Wrong	1	3	4
	Does not answer question	2	1	3
	Total	22	21	43

All but five participants expressed satisfaction with the mouse controls to manipulate the model. The participants that were unsatisfied “[couldn't] see underneath the model” (CABI user id 35), desired the ability to “move the model up and down” (CABI user id 15), “see a view from the direct front or side” (CABI user id 31), and “would have liked to rotate on more than one dimension” (CABI user id 40). These manipulations are all possible in CABI Version 1 but the five unsatisfied respondents were CABI Version 2 users. When asked what additional controls participants would like, eight Version 2 users described their desire for greater control. A total of twelve CABI Version 2 participants wanted a greater degree of control freedom similar to what CABI Version 1 offers. Additional control suggestions were the enlargement of the model (8 users) and greater control over wells (ability to move and remove) and a larger mini-map.

The final question in the survey asking participants for suggestions on improving CABI yielded eight users desiring better or larger graphics. A couple users desired greater analytical power such as identifying well depths and yield.

In summary, little significant difference was found between the two CABI versions based on user answers to questions. Coding and analysis of open-ended questions showed little variation between the two versions of CABI. All questions had similar distributions. Any significant difference in learning may have been masked by the vagueness and ambiguity of a large number of respondents. It is unclear whether the participants were unsure of the concepts themselves, refused to or could not be specific, or simply believed their responses to be sufficient. Multiple factors were determined that may have dampened user understanding for both versions of CABI. Many users were confused due to the progressive flooding of the valley. This coupled with users possible reluctance to toggle the visibility of layers may have affected participant learning. Of note is the high consensual understanding of red wells representing dry wells due to societal norms and the strong desire from CABI Version 2 participants for CABI Version 1 like controls. Although many Version 2 participants desired greater manipulation of the model no difference was seen between user results of both CABI versions.

4.4.2 Quantitative Analysis

This section analyzes the ordinal and interval data gathered in the survey. The survey asked participants to record start and completion times and answer seven Likert scale questions. Six of the Likert questions were measures of conceptual understanding and the seventh a query to find out how many wells each user had placed on their model. This analysis proposes the null hypothesis that users of both versions of CABI perform equally well.

Survey start and end times were gathered for each participant except two who forgot to write their completion time. The mean completion time of the 41 participants is 22 minutes, with a standard deviation of six minutes. The fastest and slowest respondents completed the survey in 13 and 46 minutes, respectively. Figure 4-22 graphs the relationship between the two CABI versions and survey completion time.

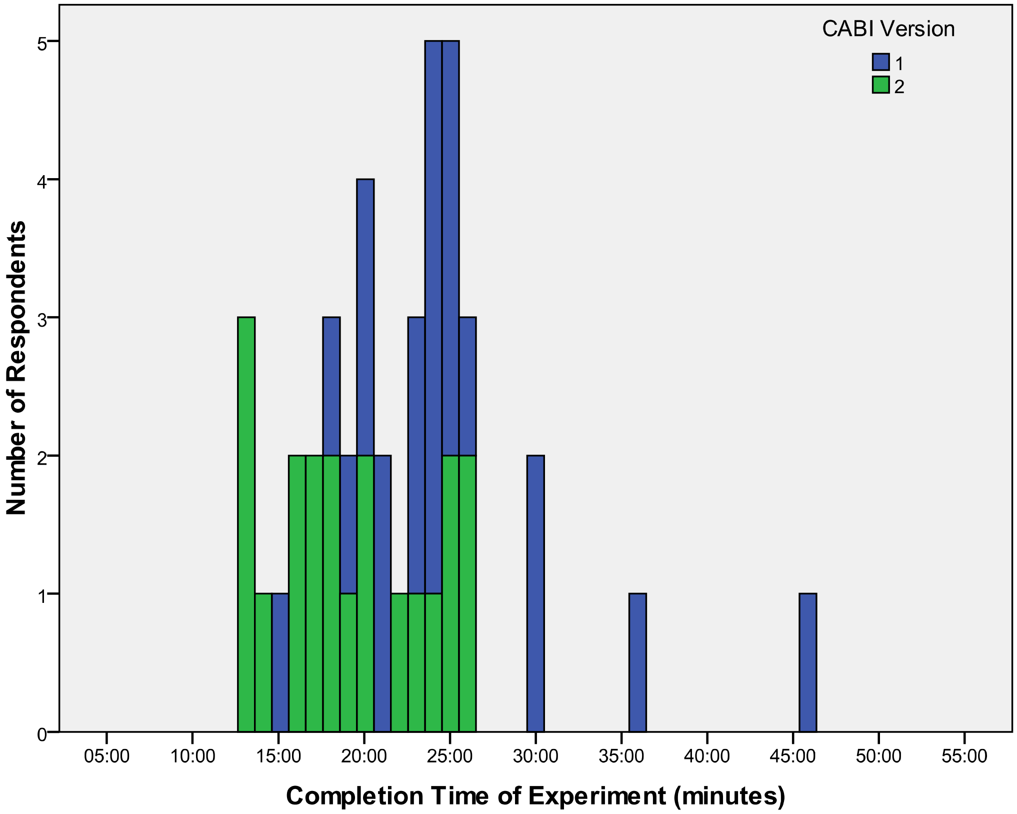


Figure 4-22: Histogram of survey completion times for CABI versions 1 & 2.

Figure 4-22 shows that users of version 1 CABI took longer to complete the survey. Applying t-test statistics to the completion time (rational data) of the experiment for both CABI versions yielded t(39) = 3.062, p = .004. This is much lower than the alpha level (p = 0.05) and statistically significant. The cause may be that Version 1 participants spent more time exploring their surroundings than Version 2 users. Additionally Version 1 CABI users may have spent time readjusting and re-evaluating their perspective, while constrained Version 2 users did not have the possibility to get ‘lost’ when viewing the model.

The means of the six Likert scale responses measuring conceptual learning were all approximately within one level of the correct response (Table 4-17) except for question 8g.

Table 4-17: Descriptive statistics for the six CABI Likert question responses which serve as measures of conceptual understanding.

CABI Survey Question	*N*	*Mean*	*Correct Response*	*Std. Deviation*	*Minimum*	*Maximum*
Q6a - Wells, which pump out groundwater, can alter flow of rivers nearby.	43	4.05	5	.899	1	5
Q6b - A well placed in a river will not alter the water level of the river	43	2.12	1	1.074	1	5
Q6c - Lower than usual groundwater levels do not affect streams	43	2.09	1	.840	1	5
Q7d - Wells, when placed on land, do not alter the height of groundwater	43	1.88	1	.905	1	4
Q7f - Natural groundwater levels recharge streams	43	3.72	5	.666	2	5
Q8g - A well, pumping groundwater, causes a cone of suction as seen in the image above	43	2.77	1	1.288	1	5

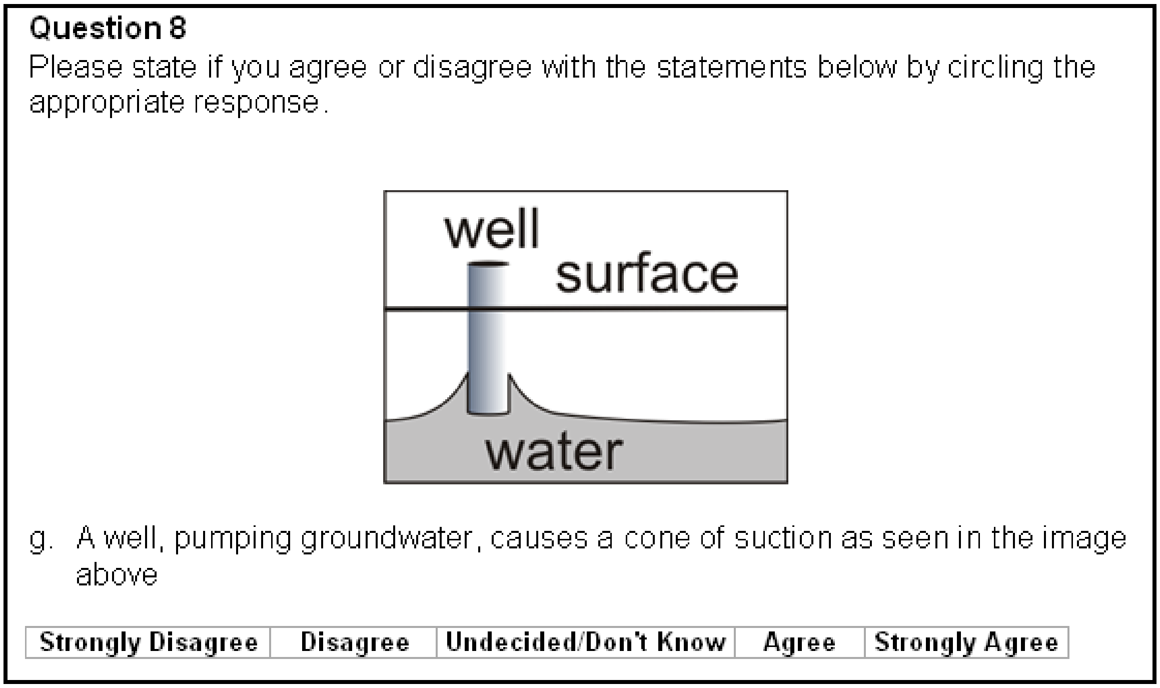
The Mann-Whitney test, used to determine whether the two versions of CABI share a similar distribution of responses, yielded no significant results. Ranked participant responses for each question show similar means for both versions of CABI (Table 4-18). This supports the null hypothesis that both CABI versions communicate concepts equally.

Table 4-18: Mann-Whitney test results for Likert responses on CABI survey show there exists a similar distribution of answers for both versions of CABI.

CABI Survey Question	*CABI Version*	*Mean Rank*	*p*
Q6a - Wells, which pump out groundwater, can alter flow of rivers nearby.	1 2	21.32 22.71	.680
Q6b - A well placed in a river will not alter the water level of the river	1 2	23.50 20.43	.394
Q6c - Lower than usual groundwater levels do not affect streams	1 2	20.68 23.38	.434
Q7d - Wells, when placed on land, do not alter the height of groundwater	1 2	19.82 24.29	.205
Q7f - Natural groundwater levels recharge streams	1 2	22.39 21.60	.816
Q8g - A well, pumping groundwater, causes a cone of suction as seen in the image above	1 2	21.59 22.43	.823

The seventh Likert question (7e) asked users the number of wells they had placed on the model. In hindsight this should have been an integer response rather than Likert question. Again both CABI versions had similar distributions with the average user placing 11 – 20 wells on the model. There was no significant relationship between number of wells placed and overall performance score.

Question 8g (Figure 4-23) had a mean response of 2.77 due to 53 percent of participants unsure or agreeing (to a degree) with the false statement. This question also had the largest variance shown by the higher standard deviation in Table 4-17. This question is unique as it was the only one with a diagram. Participants had more difficulty with this question than any other as can be seen by the even distribution across the Likert levels (Figure 4-24).



Question 8

Please state if you agree or disagree with the statements below by circling the appropriate response.

g. A well, pumping groundwater, causes a cone of suction as seen in the image above

Strongly Disagree	Disagree	Undecided/Don't Know	Agree	Strongly Agree

Figure 4-23: Question 8g of the CABI survey had the most incorrect responses. The mean answer was closest to the 'Undecided/Don't Know' response.

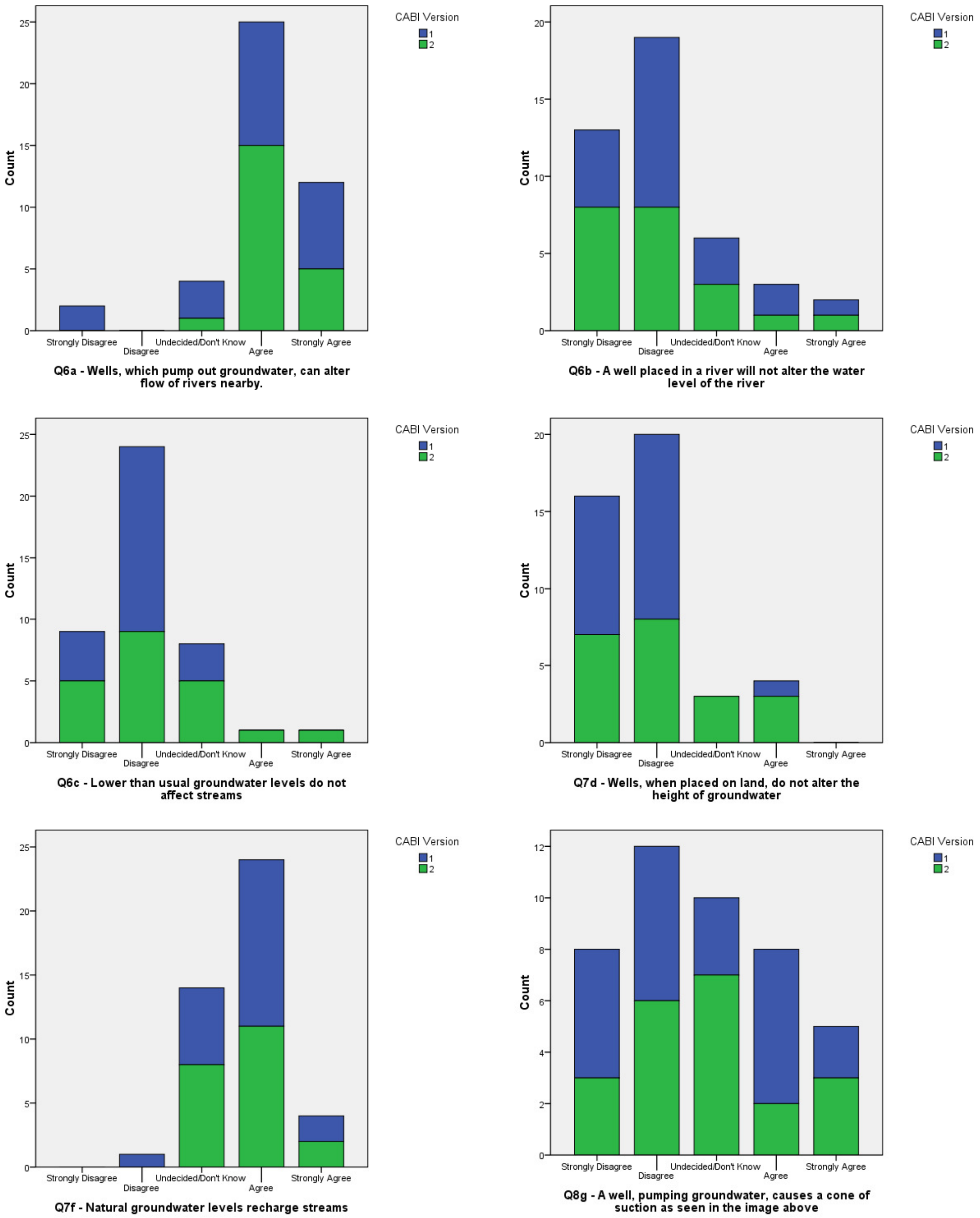


Figure 4-24: Likert question histograms showing distributions of both CABI versions. Question 8b (bottom left) has a flatter distribution than other questions.

Evaluation of individual Likert questions yielded no significant results.

Calculating average scores provided a means of analyzing scores as interval data while otherwise being ordinal. All Likert scores were converted according to the following formula to create average scores on a five point scale:

Overall Score = (Q6a + (6 - Q6b) + (6 - Q6c) + (6 - Q7d) + Q7f + (6 - Q8g)) / 6

Equation 4-1: CABI Likert scale scores converted to averages.

The resulting scores for each individual can either dampen or accentuate differences between the two versions depending on whether participants of one group responded more consistently than the other. ANOVA statistical analysis showed no significant results. Participant scores for both versions of CABI have similar distributions supporting the null hypothesis (Figure 4-25).

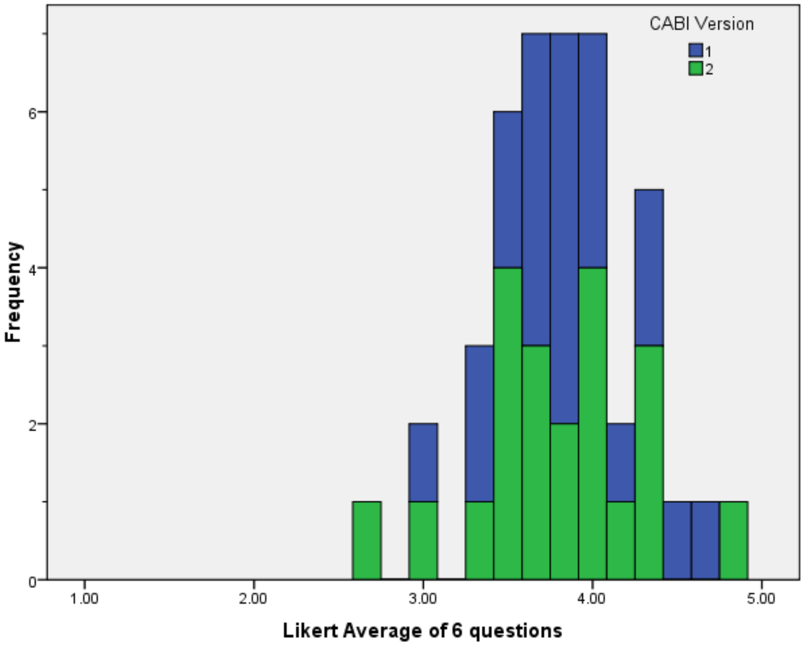


Figure 4-25: Histogram of average scores for Likert questions shows similar distributions for both versions of CABI.

No significant statistical relationship was found between Likert average scores and completion time even though Version 1 users took longer to complete the survey (Figure 4-26). The difference in survey completion time is again visible in the figure.

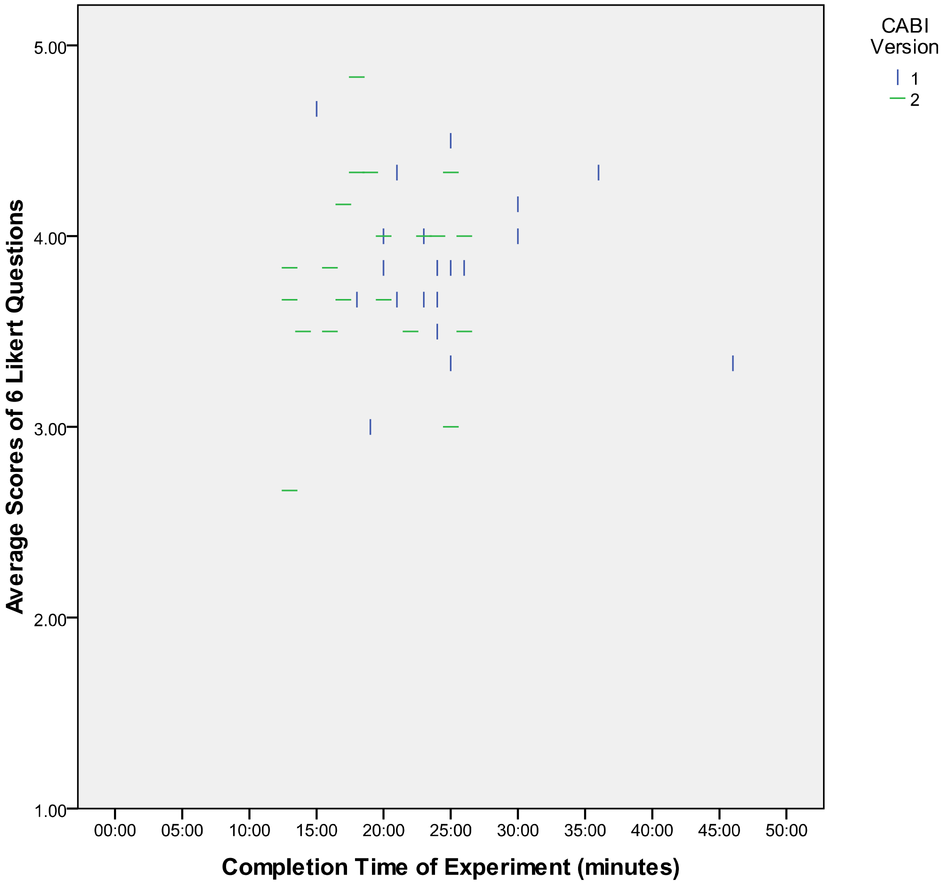


Figure 4-26: CABI average scores of Likert conceptual understanding questions related to survey completion time.

The analysis showed no significant results regarding individual or aggregated Likert questions of the two CABI versions, supporting the null hypothesis. Statistically significant is the difference in completion time of the survey between the two CABI versions. However, greater CABI exposure time for Version 1 participants did not yield better Likert score results.

4.4.3 Results

Testing of CABI was aimed to determine how much constraint and/or freedom users required (between two options) when exploring a virtual cut-block containing volumetric concepts such as groundwater. Specifically whether the user should be able to view the model from the whole 180 degree arc or be locked at 45 degrees, while still being able to spin the model. Theoretically the version which allows users to better understand the concepts and score higher on the survey is the better control interface.

Analysis of textual responses and Likert questions however showed very similar distributions for both versions of CABI. The only statistically significant result is the faster experiment completion time for Version 2 CABI participants. This, however, does not reject the null hypothesis which is strongly supported by the qualitative and quantitative results.

While faster experiment completion time for Version 1 CABI users makes it tempting to label CABI Version 2's constrained controls as more efficient, the number of participants may have been to small to allow detecting of other advantages that CABI Version 1 users might gain from their longer interaction. There may be multiple explanations for the difference in survey completion time. It is possible that CABI Version 1 users gained little measurable knowledge from exploring the area longer. Alternatively CABI Version 1 controls may be more distracting or disorientating rather than empowering learning. It is also possible that a type two error occurred and one of the two versions is more effective at transferring concepts yet the survey or number of participants was simply not effective at measuring different central tendencies for the two versions of CABI. These results support findings by Winn (2002, 501) that participants of more immersive virtual environments take longer to complete activities due to greater exploration without a gain in quantitative measures.

Question 8g is the only Likert question that had majority of incorrect answers (most users were not within one Likert level of the correct answer). Perhaps participants found the diagram unclear, dissimilar to the model, or simply did not sufficiently observe the diagram. The diagram was expected to be compared with the CABI model to allow users to easily identify the statement as false. The cause of such low scores for this question is unknown as no user made comments regarding this question.

The importance of constructing educational tools with societal coding norms in mind was emphasized by the two-thirds majority that understood the meaning of red wells whether the users had experienced them in CABI or not.

Users who did not understand the effect wells have on groundwater may have not toggled the visibility of the surface layer to get a better view of the water layer. Whether one version of CABI encourages toggling of layers is unknown. No usability or interaction data were gathered that could show whether users who toggled layers had higher scores. Some participants may have inefficiently used the ‘Toggle Surface’ button to best view the relevant subsurface information.

CABI has the potential to allow constructivist learning in order to provide users with a robust understanding of the concepts. The added interaction beyond text and a diagram is meant to allow users to test their internal hypothesis of how the process functions. Whether CABI increases conceptual understanding, however, is unknown since a repeated measures test was not completed.

4.5 Conclusion

DRASTIC, Arborville, and CABI were constructed to explore the communication of inherently 3D phenomena regarding groundwater, surface water, and their interactions. A combination of low participant motivation and small sample numbers makes it difficult to determine differences between the interface versions.

DRASTIC, which communicates the most complex concepts of the three, required an additional information page before users could proceed to use the interfaces in order to clearly understand what was occurring. The unremarkable introduction led to many participants ignoring it only to be confronted with an interface they may not have found interesting or understood the context of as a result. Since viewing times of the introductory and interface web pages only weakly correlate with higher scores it is difficult to determine whether the interfaces have variation between them. The DGSFC Scale tested the participants understanding of the DRASTIC system rather than how well each interface allowed users to view variations in groundwater susceptibility across space. The task questions were more suitable to determine the efficacy of the DRASTIC interface versions yet proved to be overly difficult for all participants yield little variance between interface versions. The three DRASTIC versions cannot be differentiated enough to make a recommendation as to which one is the most effective.

Arborville, as a result of variable resolution requirements, had extremely imbalanced samples. Only one version had sufficient numbers to determine significance but could not be compared to the other versions. While it may seem that the more complex Arborville version increased interface use time, it could not be determined whether it was more effective. The combination of the sample size imbalance, low participant motivation, and programming errors in data capturing make evaluating the eight Arborville versions largely impossible.

CABI, the most complex and experimental of the three interfaces, showed little variation between the two versions in terms of user performance. However, if performance is measured as a function of time, then the constrained version is significantly (statistically) more efficient. Either the added freedom of CABI 1 increases factual and conceptual learning but was not captured by the paper survey, or it is more likely to disorient or confuse the participants. Having further usability data may give insight into how constraints or freedom alter learning. The testing samples did not show significant differences to determine if one of the two CABI control schemes is clearly superior. Many CABI Version 1 participants expressed a desire for greater control freedom but without knowing if this is beneficial it only reduces interface efficiency.

The differences between the variations of the three interfaces, DRASTIC, Arborville, and CABI, most likely affect their user's experience. Due to the complications encountered during empirical testing this research was not able to reveal whether the interfaces and their variations affected factual and conceptual learning of users differently or determine underlying factors.

CHAPTER 5: DISCUSSION AND RECOMMENDATIONS

The design and programming of the three interfaces, DRASTIC, Arborville, and CABI, was a long, labour intensive process that included iterative testing to assure correct functioning of the interfaces. Testing of the effectiveness of the three interfaces as educational tools after their completion was limited by a number of factors. This research project's empirical experimental process suffered, due to the small number and low motivation of participants. Additional setbacks included the absence of valid control groups, incorrect expectations regarding participant display resolutions, and portions of records being lost. These factors made a variety of qualitative, quantitative, and alternative analysis difficult or even impossible. Across the three interfaces and their variations some meaningful significant results were still identified. However, an attempt to characterize participant use of interfaces yielded modest results.

The cause of these unsatisfying results, while due to many individual factors, is partially the result of designing, developing, creating the testing framework, and testing multiple interfaces concurrently. Overall, thirteen interface versions were constructed and tested by a combined total of 471 participants. However, Figure 5-1shows the considerable shortfall in participant numbers by experimental treatment.

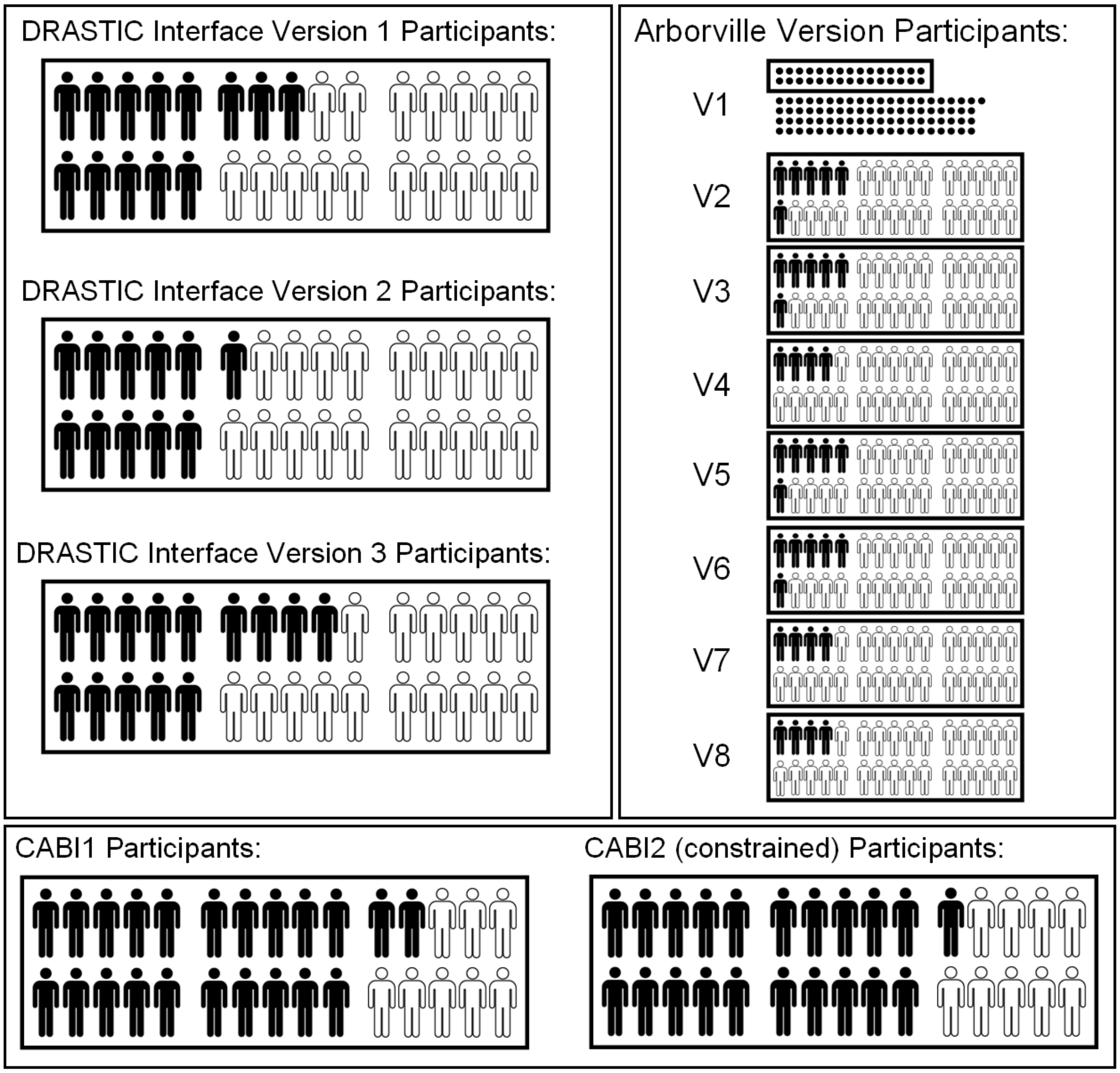


Figure 5-1: Number of participants for each interface variation. The bounding box represents 30 - the desired participant number.

A more focused experimental design on fewer interfaces more thoroughly tested using fewer interfaces might have yielded more significant results. However, even in light of these shortcomings and difficulties, this thesis: i) designed and implemented three completely new geovisualization interfaces from scratch (and a total of thirteen variations) – all of which were grounded in the context of hydrogeology and stakeholders in the Okanagan Basin; ii)developed a rich methodology describing online testing of stakeholder groups; iii) developed and implemented novel user interaction data capture and analysis techniques(mouse tracking, mouse track mapping and density analysis); and iv) gathered a diverse collection of design, methodological and user behaviour data – all of which will be highly valuable to inform future public education and outreach visualization tools.

This chapter discusses the methodology and results of this empirical study. Interface testers' motivation and suitability at representing the population is discussed. Interface design and programming recommendations outline responses to issues that reduced interface and testing efficiency. Technological issues are also discussed, such as display resolution, and the debate of Flash versus SVG. Suggestions are given for the designs of the follow-up versions of DRASTIC, Arborville, and CABI. Finally a summary of recommendations is made to future interface designers and the CWN for communicating volumetric concepts such as groundwater.

5.1 Test Sample Characteristics

Across all three experiments many participants completed their interface use in a cursory manner in an attempt to minimize their survey completion time. The characteristics of the sample participants are discussed in this section.

5.1.1 Testing on Target User Group

SFU undergraduate students registered in an introductory geography course were the main participants testing DRASTIC, Arborville, and CABI. Although they may appear similar to OB stakeholders their motivation regarding learning about groundwater may or may not be similar.

In their study on creating a geovisualization tool for decision-makers, Slocum et al. (2003) encountered the problem of applying recommendations from concept experts to the design of the interface. This project's research question aimed to determine whether variations in interaction design influenced the perception and understanding of volumetric hydrogeologic concepts.

For this thesis, research using SFU students was believed to be a valid alternative to OB stakeholders due to similar knowledge levels regarding the topic, interest (geography students), and availability. In retrospect the SFU participant sample may have had little interest in the subject matter contained in DRASTIC, Arborville, and CABI. Due to time constraints and unsuccessful attempts to communicate with water-focused user groups such as the OB Water Board and the CWN, using OB stakeholders was not possible within the scope of this study.

Lawless and Brown (1997) introduced three common navigational profiles describing how and to what length users interact with learning environments. They distinguished between the *Knowledge Seeker*, *Feature Explorer*, and *Apathetic User*, which respectively focus on learning, how the interface works, and finishing the exercise as quickly as possible. The DRASTIC, Arborville, and

CABI empirical results are largely not statistically significant due to apathetic user types who often did not complete the tasks or if so with minimal effort. While the blame could also be laid on the interfaces not captivating the users it is more likely that participants lacked interest in the topic. It is important to note that these interfaces were created for people who have some interest in hydrogeologic issues relevant to them. Testing the interfaces with stakeholders experiencing water constraints, conflict or regulation will most likely yield different results than using SFU students.

Without a valid control group this thesis cannot determine the efficacy of the educational tools created. While participant's low motivation may have reduced the ability to determine whether certain interface versions are more effective than others, it also indicates that the interfaces are not effective for the sampled students. Had the content been more engaging to SFU undergraduates, perhaps results between interfaces versions would have been significant. A larger sample of more suitable subjects and changes to the testing methodology are required to check the validity of results.

5.1.2 Participant Motivation

SFU students seemed to lack interest in exploring the interfaces for this project as they were more focused on completing the tasks in the most straightforward, effortless, and fastest manner. This may equally be a reflection on the interfaces, yet it seems that this behaviour was present across DRASTIC, Arborville, and CABI which vary in immersion. Animations may increase motivation through their captivating narrative and lack of interaction. Quantitative empirical testing, however, still requires interaction to gather data.

When asking open-ended questions to low motivated participants (as was done for CABI), it would have been helpful to specify or force (using web form constraints) that they describe or elaborate their responses. This may reduce the number of Yes/No responses which have little analytical value. When using online text fields it is possible to require a minimum number of characters. While using the SFU university population for testing is practical it may be more desirable to use other populations for testing in the future unless the subject matter is of more interest to this demographic. Narrative can be a powerful tool to increase interest and motivation, but it still must be relevant to the user.

5.1.3 Perceptual Affordances

The GSC Waterscape poster graphic when transformed from paper medium to the Arborville digital testing framework, participants perceived new false affordances. As a paper poster the, “Doing it wrong” and “Doing it right” headings cannot be understood as interactive, since the medium is static. When the content was changed to a digital form in an interactive medium so did the perceived affordances. The transposing of 2D content across mediums brings different expectations that need to be considered.

Perceived affordances change between cultures and mediums (i.e., paper, TV, or PC). The symbolism of crosses in computer cultures as meaning “close”, “error”, and “no” caused an early Arborville tester to perceive the “undo interaction” buttons as errors in the interface. This example underlines the importance of taking into consideration spatial but also socio-cultural differences such as age, gender, lifestyle, and philosophy when designing educational tools.

5.2 Interface Design and Programming Recommendations

The design and programming of these interfaces required large amounts of work. Analysis of the empirical data collected for this thesis did not reveal significant findings between interface versions that influence learning. Based on the limited data available, this research cannot determine differences between the various interfaces designed. Most recommendations are methodological in nature regarding the design and testing of DRASTIC, Arborville and CABI.

5.2.1 Perspective Visualization

DRASTIC, Arborville, and CABI each provide an increasingly sophisticated perspective of their content. DRASTIC provides an orthogonal / map view of the Greater Town of Oliver. Arborville used perspective view with the aid of a mini-map with a different frame of reference. CABI also provided a perspective view but of interactive 3D terrain. Arborville mimicked the GSC Waterscape poster and inherited its perspective presentation of contents. Terrain, the Arborville proof of concept, presented content orthogonally, but it is not clear what method may be better. Arborville and CABI could have been designed to display content orthogonally, but the perspective view was chosen because it mimics the human perception of 3D space.

5.2.2 Analyses & Testing Framework

When tracking user behaviour, especially mouse tracking and interaction, data can quickly balloon in size. While it is easy to only record x and y coordinates of the mouse cursor, time for each mouse point can be very useful as well when analyzing user behaviour. For example it allows replaying the user's behaviour like a screen capture. Building a framework that can play mouse tracking data could allow easier analysis than ArcGIS currently offers. Additional data such as capturing survey scale response times for individual questions can also be useful to determine the quantity of thought between survey responses and completion or problem questions that may need to be modified.

The advantage of constructing a data review framework early allows it to be used during interface and survey testing. A review framework could easily display either textually or visually the performance indicators of individuals or groups of participants. While extensive testing was performed on Arborville, its many components led to errors slipping through and resulting in data loss. Analysis of the results during testing made blank fields that had been erased appear to be incomplete surveys. Had a review framework been in place before testing Arborville the various logic errors could have been spotted sooner. Performing error testing with a review framework can save time and prevent costly mistakes.

5.2.3 Animated Visualization

In order to isolate the differences between the OB Waterscape poster segment and Arborville version 8, the number of intermediary versions became quite large. If time had allowed, the creation of an additional Arborville version as an animated video would have been interesting as it is another common communication medium. Using animated videos adds the narrative element which can increase immersion. Animations are a passive medium, especially if narrated rather than having text. Comparing this additional version of Arborville could quickly become complex since it raises many new interface design topics such as studying textual versus auditory narration, narrator intonation, and gender. The number of additional Arborville versions could quickly balloon further. It would be an interesting project completing the spectrum of communication mediums. Animations can be more captivating and with their passive nature can also reduce the amount of motivation required to pay attention.

5.2.4 Multiple Map Display

In the analysis of the HTML version of the DRASTIC interface a clear decrease of interest, based on mouse hits, was detected. While the sequential nature of these maps is important due to its allegory to DRASTIC, it may be beneficial to place maps of greatest importance at the top of a web page. Alternatively interaction can be used as was done in the Basic SVG version of DRASTIC. This was not proved to be better but mouse tracking showed a more even attention paid to all maps. If there is no dependency on the buttons as with the SVG versions of DRASTIC the maps could themselves be buttons that enlarge to increase legibility (Figure 5-2).

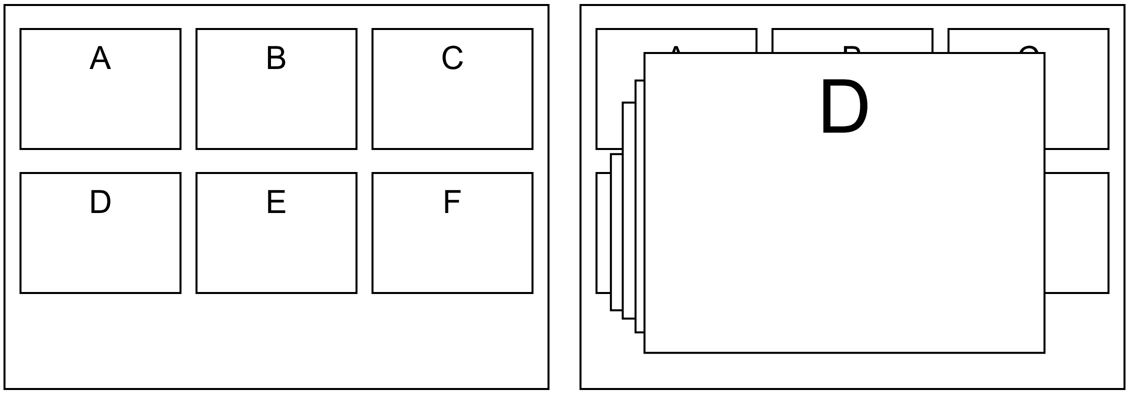


Figure 5-2: Possible multiple map display without hierarchy.

5.2.5 Empirical Measures

Testing of the DRASTIC and Arborville interfaces measured factual and conceptual knowledge through repeated Likert questions, tracked mouse movement, and captured survey completion time. DRASTIC, unlike Arborville, had task questions that were asked after interface use. CABI was quite different as it gathered mainly qualitative responses that were later coded, but also six Likert questions. Tracking mouse movement, button interaction, and well placement for CABI could have been beneficial. This can be implemented by writing to a log file or if connecting to a remote server to upload data.

While DRASTIC, Arborville, and CABI measures yielded few significant findings, alternative additional measures could be used in future testing to measure the change in facts and concepts learnt by participants.

5.2.6 Discrete Concepts

In the creation of Arborville Version 8, the goals were usability and communication of concepts through constructive interaction and animations. With a large number of facts and concepts to communicate the interface rapidly became dense and compromises, such as interaction options, were made to fit everything. Keeping the interface clear, elegant, and simple in hindsight would have required separating most concepts into individual chapters so they could be addressed separately on mainly empty landscapes. Not only would this have been a more focused experience for the participant but also much less complex to create and program while allowing greater user freedom. Arborville Versions 3 to 8 may be less effective than desired due to their small and many potentially distracting features, large amounts of text, and overly large and distracting mini-map. Restricted by screen size the need to package everything densely reduced possible interactivity further. The resulting interface was so dense that it required an above average resolution. By separating the concepts into sequential chapters designed for lower resolution displays, future interfaces may be more effective. This could increase the narrative and provide a more focused task to captivate users.

5.2.7 Constraints

While the interface and survey can contain errors introduced by their creators, minimizing mistakes done by participants can largely be achieved through constraints that limit the ability of users to proceed without completing required tasks. While the website containing the DRASTIC interface also has a link to download SVG and the button to proceed to the next step of the experiment, Arborville only has one of these three items visible depending on whether the user was missing SVG (link to SVG download), had SVG installed (link to launch Arborville in a new browser window), or has completed interface use (a button to proceed). This guarantees that any participant who completed the survey will have at least seen the interface. Other constraints such as having the proceed buttons on survey question pages disabled until all the required questions are answered can prevent incomplete form submissions. Constraining the user makes survey creation simpler to complete for the user while reducing the likelihood of a programming error.

Constraints can be applied by choice or by compromise as was done in Arborville. In an effort to compress many concepts into one interface ‘page’ the variety of interaction decreased and users were constrained to one location for each interaction type. This made the experience perhaps less interesting for users when tasked to ‘exploring Arborville’. Giving users tasks with explicit scores that need to be completed within a time limit may stimulate users more than having them explore an environment. This may be difficult to apply in certain interfaces but is more likely to encourage an engrossing experience to participants.

The recommendations above reflect some of the greatest problems encountered in this research project. Future versions of DRASTIC, Arborville, and CABI could respond to the issues above by altering their design.

5.3 Technical Issues

5.3.1 Flash versus SVG

As stated in the methodology an alternative to using SVG for interface design was Flash. While SVG and Flash are very similar 2D graphic platforms with supporting scripting languages, SVG does not have the same abilities as Flash. Flash can integrate video and music much more easily, but more importantly, works equally well on all internet browsers. SVG has varying abilities depending on the browser or plug-in used to view SVG graphics. Flash currently allows easier outreach to the masses. A proprietary product, it has the weakness of designing black box interfaces. Unlike SVG, where all files and programming are open to review and replication, Flash does not allow others to build upon previous designs. Commercially this is considered an advantage to prevent competitors from stealing product design. It is possible, however, if desired, to make Flash source code available for others to build upon. The main constraint of Flash however is its proprietary Flash Player, which while currently free may not always be. While it may be tempting to develop using Flash, in the long run it is best to not be dependent on proprietary software. Supporting open standards such as SVG helps it grow so it can eventually be equally powerful as Flash with out the proprietary draw backs.

5.3.2 Technological Limitations

When using Arborville, latency between certain interactions and feedback, and the inability to directly track CABI interface use are due to limitations of technology and time to implement. Technological limitations can be overcome with greater programming efficiency and time. Focusing on an individual interface can allow it to be further refined. The development of the DRASTIC, Arborville, and CABI, while functional, were still primitive releases in a software development cycle.

5.3.3 Standard Resolution

The drive for cheaper displays have increased the number of non-standard resolution displays in use. Interface content should be created with the expectation that it will viewed by a large portion of users with resolution of 1024 by 768. This means resizing the actual SVG or flash application to approximately 950 pixels wide by 600 pixels high to allocate space for the browser and website margins, buttons, and status and navigation bars. This would ensure a more balanced distribution of samples in each version when testing multiple interface variations.

5.4 DRASTIC, Arborville, and CABI Recommendations

This section attempts to apply the recommendations above to the three interfaces designed in this research project. In addition to the recommendations above, findings from formal and informal testing, provide next steps for the designs of DRASTIC, Arborville, and CABI.

5.4.1 DRASTIC

While it was not possible to determine which version of DRASTIC was most effective empirically, the practicality of the Basic SVG version seems to logically outweigh the conventional HTML version. The conventional version can always be used by those who do not have or do not wish to install SVG. Deciding between what features of the basic version and the advanced version to select for a final version is more complex. Users with dissimilar knowledge can react differently to a multimedia application due to the amount or manner in which content is presented. What may over stimulate one user can bore another (Lindgaard et al. 2005, 216). The advanced SVG version may simply confuse certain users. This is why the DRASTIC cumulative mode could simply become an optional mode for those who wish greater control and insight. Flexibility in the amount of information a user can access shapes their experience to suit their needs. This comes with the caveat that users may not always know their limits, a feature explorer may still explore beyond their conceptual understanding.

While the DRASTIC cumulative mode used a monochromatic scale a polychromatic one allows greater differentiation. The difficulty in applying this to the cumulative mode is that added semi-opaque layers result in different colours (Figure 5-3). Part of the elegance of the monochromatic scale manner is the creation of new visualizations without added data when multiple factors are turned on. Using a polychromatic scale would require a large number of different data sets. In addition a monochromatic colour palette makes viewing easier for people who are colour blind.

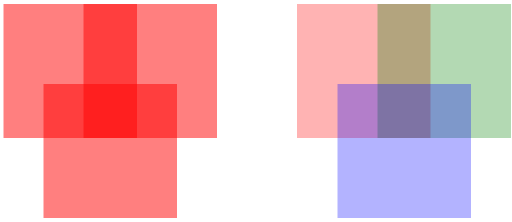
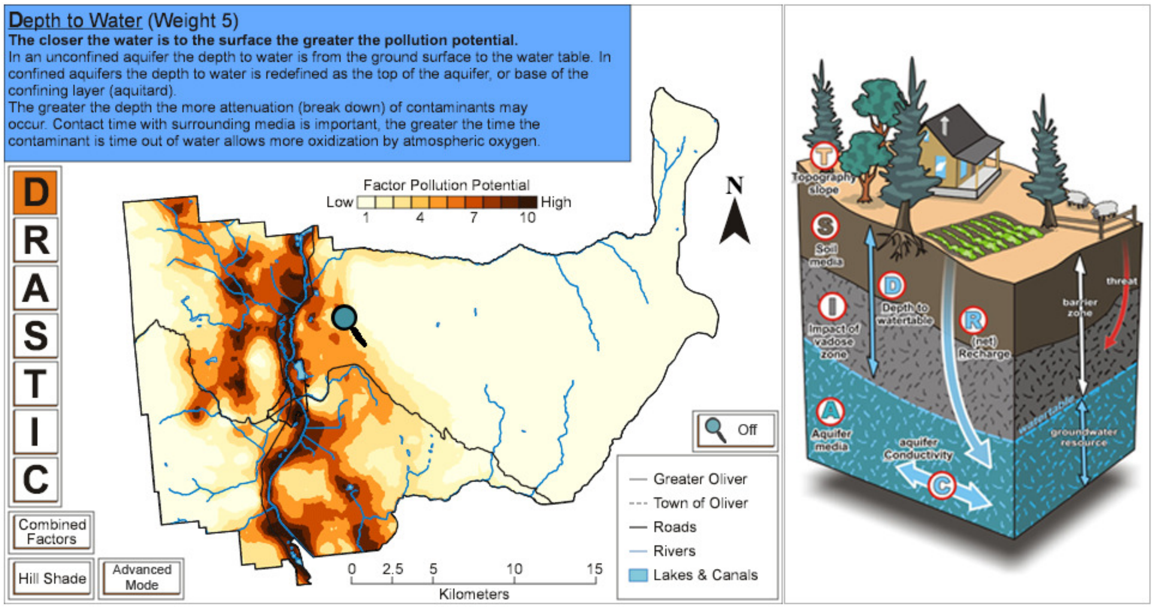


Figure 5-3: Monochromatic layers overlaid (left) and polychromatic layers overlaid (right). It is not possible to use a polychromatic scale with varying opacity to cumulate layers.

The DRASTIC introduction may have appeared too scientific and scared participants from reading it. An alternative method of reinforcing the DRASTIC factors was suggested by Dr. Murray Journeay, a CWN collaborator with the GSC. By using a magnifying glass metaphor, users could view a perspective representation of a terrain block with the various DRASTIC factors scaled to represent their value at the location clicked on (see Figure 5-4 right). This comes with the limitation that while variations in data are discrete, not continuous as they are in nature. Like the suggested advanced cumulative mode the magnifying glass could be offered as an option. Figure 5-4 shows a mock-up of the suggested improvements.



Depth to Water (Weight 5)

The closer the water is to the surface the greater the pollution potential.
In an unconfined aquifer the depth to water is from the ground surface to the water table. In confined aquifers the depth to water is redefined as the top of the aquifer, or base of the confining layer (aquitard).
The greater the depth the more attenuation (break down) of contaminants may occur. Contact time with surrounding media is important, the greater the time the contaminant is time out of water allows more oxidization by atmospheric oxygen.

Figure 5-4: A rough mock up of the recommended improvements for future DRASTIC versions. The magnifying glass in the centre of the map could be clicked on locations on the map to the left to modify the model in the right window. Note the 'Advanced mode' and '[Magnifying glass] Off' buttons. Graphic created by Richard Franklin & Robert Turner of the GSC and modified by the author.

5.4.2 Arborville

Originally, Arborville was designed to allow the user to place each land use icon at a variety of locations. The plan quickly became unfeasible due to the complexity in scripting all possibilities as well as interactions between features placed at various locations. The ability to only place each land use type at one location weakened the need for drag and drop interaction since there were no longer choices of where to drag the land use types to. Breaking up the concepts into different scenarios or pages would allow for much easier scripting. Each setting/page would allow a different concept to be placed on the terrain in a variety of locations. For example, the user could place a well next to a stream, another well, or spring and study the effects between various locations (Figure

5-5). The user could then see how locating wells in different spatial locations alters or limits the negative effects of groundwater pumping.

An example of one of these scenarios shown in Figure 5-5 could task the user with pumping an explicit amount of water within a time limit and with a limited budget to use for drilling wells. Scenarios would have some task constraints, such as not reducing the stream level beyond a threshold or causing a well already in place to dry out. Real-time graphs could used to explicitly show how the new wells are affecting surrounding water levels in addition to groundwater levels in the terrain. This goal-orientated approach is conducive to a strong narrative that together may help motivate users.

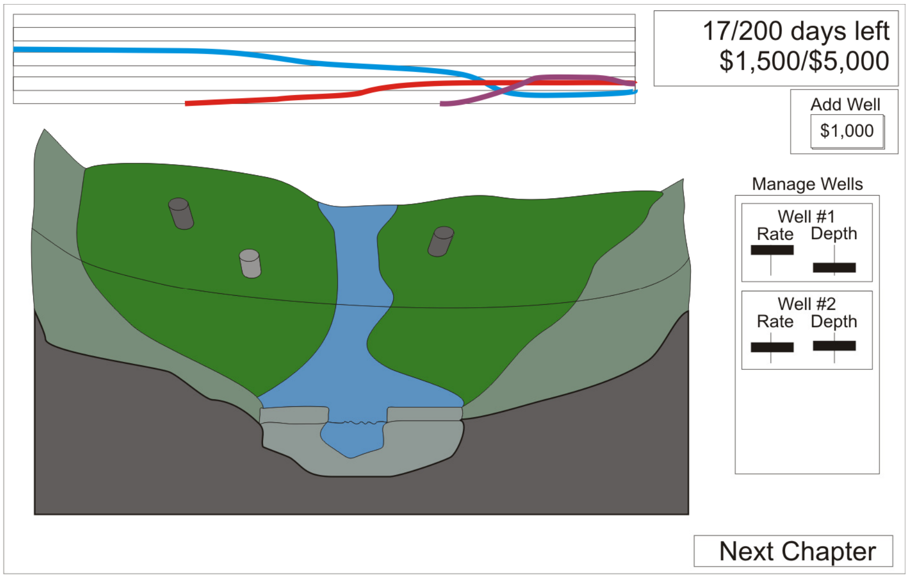


Figure 5-5: A simpler version of Arborville consisting of separate scenarios challenging the user with different land use oriented tasks.

Multiple scenarios could each focus on one aspect of hydrogeologic surface and subsurface interactions. Arborville Version 8 is exploratory and perhaps not task-orientated enough to keep participant attention. The densely packed concepts may overwhelm the user. Ideally the user would have a perfect setting for each concept being communicated rather than compromising by densely packing all concepts on one page. In addition to being densely grouped, the cityscape in Arborville Version 8 is too small to clearly observe changes. Large empty spaces such as the sides of the cubes that serve to show groundwater levels take much space. Future versions need to strike a better balance between content quantity and quality by making the limited content as large as possible so that it and any animations are clearly visible.

Arborville Version 1 testing participants seem to like the explicit and simpler interfaces which have simpler programming. Perhaps building multiple simple interfaces that focus on individual key topics is more efficient. Developers of future Arborville-like interfaces should spend less time on graphic details and more on concept simplicity allowing greater freedom of interaction.

5.4.3 CABI

CABI was significantly simpler in regards to narrative compared to DRASTIC and Arborville. As a prototype it is still an exploratory tool lacking guidance. The missing narrative may have repercussions for the user in terms of understanding its goal and purpose. Not having an introduction page can determine whether the interface is a success or failure for the user. However, embedding the interface into a welcoming and challenging scenario could also increase immersion and user motivation. The introduction page is not just a page of redundant information from the interface. It sets up the user’s experience, preparing them to call upon their past experiences to possibly facilitate their interface use.

Taking the Arborville concept to a greater level of complexity requires a shift from a browser platform to the desktop. Desktop based software allows a more flexible system such as CA where the interactions possible are more versatile due to CA's 'self-adapting' nature achieved through its equilibrium seeking program design. CA allows more flexibility than the scripted scenarios used in Arborville. The density of concepts in Arborville limits the interactions possible due to the complexity of programming. Using CA, many different forms of land use could be simulated without added programming complexity once the cell behaviour is designed.

CABI provided a proof of concept, focusing on one hydrogeologic concept – wells. To be more effective future testing needs to capture usability data directly from the software. In hindsight CABI should have written to an output file to capture the toggling of layers, model rotation, mouse movement, well count and locations. In addition to having better tracking of user behaviour other areas of CABI should be improved. Rather than have users click on the mini-map to place wells, a button 'place well' that allows the user to select a location to place the well would be more effective and intuitive. All wells in CABI had the same depth. The possibility to vary well depths and pumping rates would allow the user to directly understand how the rate of draw affects groundwater levels. Providing real time graphs of river mouth discharge as in Figure 5-5 above would help show longer term trends and effects.

These are just improvements to the groundwater pumping concept and packaging. Due to its program design, CABI would be able to combine several land use types such as impermeable surfaces and pollutant tracing. The fundamental design of CABI rests on square cells, yet terrain in the real world is commonly flatter. Cubes are effective at representing areas that have slopes of 45 degrees. Using square cells on the horizontal (x,y) plane with shallower depth (z) would render more realistic terrains and allow easier visualization. Some participants noted the style of CABI looked rough, which is especially true when compared to the graphics of current video games. Increasing the graphical quality to make the terrain seem smoother and have better lighting would also be useful graphic improvements to future CABI versions.

5.5 Recommendations for Future Interface Design Initiatives

This thesis presents many general recommendations for future interface design and empirical testing. A summary of these recommendations in regards to the CWN and other organizations desiring to develop interfaces visualizing groundwater concepts and processes are:

- Focus on one central issue and clear challenge.
- Provide multiple sequential simple exercises.
- Display series of maps interactively (DRASTIC Interface V2) rather than as a long list (DRASTIC Interface V1).
- Use open source technologies to allow others to build on previous work.

- Combine multiple modes of communications, text, graphics, interaction, and animations, for users with different learning styles.
- Expect screen resolutions of no greater than 1024 by 768 meaning 950 pixels wide by 600 high are available for an application.
- Test, using the target user population, early and often.
- During testing, take many detailed qualitative and quantitative measures.
- Build constraints into interface and testing framework to prevent incorrect use early.

Applying these guidelines to future CWN interface development projects may help create more effective educational tools and testing.

5.6 Conclusion

DRASTIC, Arborville, and CABI were designed to be fundamentally different in their approach to groundwater visualization, interaction, and perception. While the testing frameworks were ambitious in terms of their ability to capture results to determine differences between interface versions, logic errors, low participant motivation, and time constraints resulted in few significant empirical outcomes. Even so, this research endeavour yielded a rich set of interface, methodological and user observations. These observations help us parameterize key interface design considerations and user interaction factors that will inform future public hydrogeological education tools.

This study did not yield any ground-breaking, statistically significant user-interaction findings that change our understanding of geovisualization. However, it did demonstrate the ability to design and implement hydrogeological interfaces that embody principles of *knowledge discovery* and *revealing unknowns* found in the geovisualization literature. This work does contribute to the field of interface design in regards to methodological guidelines, interface design examples, and CABI's unique program design. CABI is particularly innovative in its use of 3D CA to model water, not for scientific modeling, but to control the behaviour of the liquid. It uses a method typically used for scientific modelling to allow a robust yet dynamic deformable environment through the placement of wells. CABI has the ability to bridge the divide between expert models and non-expert interfaces.

The design and programming of the eight Arborville versions was particularly time consuming. Future research projects of this magnitude should consider focusing on fewer interfaces while giving greater emphasis to the iterative process of design and testing. While DRASTIC, Arborville, and CABI failed to provide conclusive empirical results, it is not known whether they are effective means of communication, nor which of the variations may be better. Answering these questions requires further testing which is beyond the scope of this thesis.

CHAPTER 6: CONCLUSION

The importance of communicating research from within universities and research institutions to stakeholders is increasingly important. Stakeholders shape their surrounding environment. As populations increase, so do their impacts on our surroundings and planet as a whole. In the OB, water is a limited resource. How stakeholders manage their resource depends on their understanding of it. By communicating which areas are more sensitive to groundwater contamination or how pumping groundwater drains the same source as pumping from a river may increase discussion, planning, and even compliance among stakeholders. A key part of building factual and conceptual consensus is to develop tools that help diverse user groups build conceptual understanding of hydrogeology, which is inherently volumetric, dynamic, and complex.

This research project designed and built various tools to explore communication of facts and concepts to stakeholders using multimedia platforms that can reach a large audience. The goal was to determine whether traditional or advanced techniques, as well as other variation in interaction design, are more effective at communicating facts and concepts. This thesis was ambitious in its scope. It required designing and programming three significantly different interface types, creating variations, and testing them. This research could have been achieved through fewer variations and laboratory, rather than field, testing.

In an attempt to gather more meaningful and natural results a large number of Arborville versions were designed, and testing frameworks were created for both DRASTIC and Arborville. Determining differences in learning between interface variations is difficult and in an effort to do so this thesis project grew in complexity. While the empirical results were mostly not statistically significant, the methodological process of design and testing provides useful guidelines for similar future projects.

Applying technology to education tools can result in compelling visualizations and novel interfaces that fascinate, impress, and communicate convincing falsehoods and truths. Novel interfaces will only be effective in communicating complex processes such as groundwater use and recharge if we fully understand how these interfaces work and are perceived by users. Analysis and user testing are necessary to understand how effective geovisualization interfaces are for specific stakeholder groups. User testing for DRASTIC, Arborville, and CABI did not provide conclusive results regarding whether the variations perform equally well. It did however provide subtle suggestions that some aspects of visual interfaces may influence user perception of real geographic processes.

The integrated approach to geovisualization interface design and analysis performed in this research provides a basis from which to guide future development of similar interfaces. This work has contributed to the OB CWN project by providing final versions of the DRASTIC Interface, Arborville, and

CABI. These interfaces will be integrated into the project website where long-term data gathering will be attempted.

This thesis research succeeded in implementing a set of geovisualization interfaces aimed at communicating groundwater concepts and challenges to OB stakeholders in new engaging ways, while being scientifically correct, and contextually relevant to the OB and CWN. Future groundwater education tools applied to multi-stakeholder settings such as the OB will need to consider similar visual interface design issues in order to effectively communicate science, and not just novelty. It will also be essential that future initiatives aimed at increasing public awareness, using engaging visual interfaces, allocate sufficient time and resources to adequately evaluate the effectiveness of the interfaces designed, while accommodating unexpected participant outcomes. The resulting interfaces can greatly benefit stakeholders with a thorough understanding of the target concepts.

CHAPTER 7: REFERENCE LIST

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APPENDICES

Appendix A – CABI Survey

Part One
Log in to the computer with the username 'geog111' and password 'geography'.

Start the program 'CABI'
In the bottom left corner click 'Start' → All Programs → Utilities → CABI

While this is loading (it takes over two minutes) please enter your Name, SFU email address, and the current time in the spaces provided below. Please **use a pen** for all the following activities.

Name: ____________________ **email**: _______@sfu.ca **time**: __:_____

While CABI continues to load it is important for you to focus on this activity for the following ten minutes. During that time please refrain from communicating with your neighbours. Once you have completed both sides of this sheet please hand it in to your TA at the front of the room and wait for your friends outside to chat or if you would like to quietly continue using CABI you may. Please read the entire question before beginning to interact with CABI.

Please follow the instructions below as well as possible and **do not interact with CABI model until after reading step 2**.

Do not proceed to the next page until the CABI model has loaded

Question 1
- Once CABI has loaded
- **Do not use the mouse yet**
- Please describe what you are seeing:

- What do you think can be interacted with?

- Describe the shape of the area you are looking at?

Do not proceed to the next page until you have completed this question

Question 2
- Use the mouse
- Place the mouse cursor on the model
- Click and hold down the mouse button on the model while moving the mouse
- Doing this should rotate the model
- Using the mouse to move the model, do you notice anything new?
- Please describe it below:

Do not proceed to the next page until you have completed this question

Question 3

- In the top right corner is a menu that allows you to make the three following layers appear and disappear: *Land surface, Groundwater,* and *Bedrock*
- Hide the *surface* and *bedrock* layers so that you can look at the water layer unobstructed
- Click the layer buttons until all the layers are visible again
- Below these buttons is a map of the area
- You can click on this map to add water pumping wells to the model
- Try adding a well now to the green areas on the right side of the map
- You will see a yellow well appear on the model
- Observe the model and describe any changes you see and to what layers:

Do not proceed to the next page until you have completed this question

Question 4

- Place a well on the water by clicking on the blue areas of the map in the menu
- What do you observe?

- Does the well placed in the water cause different changes than the well on land?

Do not proceed to the next page until you have completed this question

Question 5

- In the model, how do wells alter their surroundings?

Do not proceed to the next page until you have completed this question

Question 6

Please state if you agree or disagree with the statements below by circling the appropriate response.

a. Wells, which pump out groundwater, can alter flow of rivers nearby

Strongly Disagree Disagree Undecided/Don't Know Agree Strongly Agree

b. A well placed in a river will not alter the water level of the river

Strongly Disagree Disagree Undecided/Don't Know Agree Strongly Agree

c. Lower than usual groundwater levels do not affect streams

Strongly Disagree Disagree Undecided/Don't Know Agree Strongly Agree

Do not proceed to the next page until you have completed this question

Question 7

Please state if you agree or disagree with the statements below by circling the appropriate response.

d. Wells, when placed on land, do not alter the height of groundwater

Strongly Disagree Disagree Undecided/Don't Know Agree Strongly Agree

e. Approximately how many wells did you place on the model?

1-4 5-10 11-20 20-30 more than 30

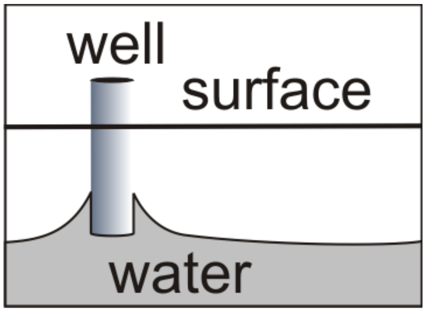
f. Natural groundwater levels recharge streams

Strongly Disagree Disagree Undecided/Don't Know Agree Strongly Agree

Do not proceed to the next page until you have completed this question

Question 8

Please state if you agree or disagree with the statements below by circling the appropriate response.



g. A well, pumping groundwater, causes a cone of suction as seen in the image above

Strongly Disagree Disagree Undecided/Don't Know Agree Strongly Agree

Do not proceed to the next page until you have completed this question

Question 9

- If you placed wells in certain locations they may appear or become red – why?

- Were the controls of the mouse to rotate the model satisfactory?

- What additional controls would you like to have?

- Do you have any suggestions to improve CABI?

Please write the **time**: __:_____ it is now

You may now close the program CABI

Thank-you!

If you have any additional comments please write them on the following page

Comments and Suggestions:

Appendix B – Arborville Status Bar Scores

Table 7-1: Status Bar changes to scales due to the interactions.

Interaction type	*Groundwater Supply*	*Environment Health*	*Citizen Happiness*
1a. Place Barn	0	- 25	- 30
Remove Barn	0	+25	+20
1b. Place Fence	0	+18	+20
Remove Fence	0	+7	0
2a. Place Logging Truck	0	- 40	- 30
Remove Logging Truck	0	+40	+30
2b. Place Logger	0	+20	+23
Remove Logger	0	+20	+7
3a. Place Sprawl	- 60	- 30	- 20
Remove Sprawl	+60	+30	+20
3b. Place Bigbox Store	- 60	- 15	- 20
Remove BigBox Store	+60	+45	+40
3c. Place Compact Community	+120	+45	+40
Remove Compact Community	0	0	0
4a. Place Industrial GW Pump	- 60	- 20	- 15
Remove Industrial GW Pump	+60	+20	+15
4b. Place Irrigated Crop	0	- 15	- 15
Remove Irrigated Crop	0	+15	+15
5a. Place well1	- 30	- 7	0
Remove well1	+30	+7	0
5b. Place well2	- 30	- 10	- 8
Remove well2	+30	+17	+8

Appendix C – CD-ROM Data

The CD-ROM attached forms part of this work. Therein contained are the final released versions of DRASTIC, Arborville, CABI, and the SVG plug-in required for Internet Explorer users.

Data Files:

DRASTIC Interface Release Version
File: DRASTIC_Interface.zip
Size: 578 KB
Comment: Requires SVG. SVG works natively in Firefox 3 or greater. Internet Explorer requires installation of the SVG plug-in enclosed on CD-ROM. Execute the enclosed HTML file.

Arborville Release Version
File: Arborville.zip
Size: 491 KB
Comment: Requires SVG and Internet Explorer 6 or 7. Internet Explorer requires installation of the SVG plug-in enclosed on CD-ROM. Execute the enclosed HTML file. Please note that while Arborville will display in Firefox colour and animations will not be represented correctly.

CABI Release Version
File: CABI.msi
Size:
Comment: Install the Microsoft Installer (msi file) and when complete run the short cut created on your desktop. Please be patient as CABI can take a few minutes to initialise. See the installation directory README file to customize model.

Adobe SVG Installer for Internet Explorer
File: Adobe_SVGViewer_Version303.exe
Size: 2,332 KB
Comment: Install. Restart Internet Explorer and test the SVG interfaces above.