Summary of the Field Tests of the Alpha Version of the Plume Busters Software

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Introduction

Plume Busters is designed to enhance the teaching of ground-water principles to students in earth and environmental science classes. Software development was funded by a grant from the National Science Foundation. Using the Plume Busters software students take on the role of an environmental consultant and apply the principles of ground-water flow and well hydraulics to solve a simulated contamination problem. The software consists of (1) a JAVA-based model to simulate ground-water flow and the movement of contaminants through the aquifer and (2) a set of linked HTML pages. The user interacts with the numerical model through a user interface called Map View. Map View contains a gridded map of the spill site vicinity and a series of function buttons that allow the user to add and collect water samples from monitoring wells, resample monitoring wells, add production/injection wells, submit a wellfield design, ask for money, and advance the simulation one week at a time. The set of linked HTML pages sets the stage for the simulation, provides information to the user participating in the simulation, and establishes the rules of the simulation. Development of the software alpha version was completed by the late fall of 2003.

Student volunteers attending the University of Kansas Upward Bound Math Science Experience informally tested an early version Phase 1 of the Plume Busters software.

Formal software testing was undertaken beginning in February and extending through April 2004 using students enrolled in community (junior) and four-year college science classes. Instructors were solicited directly or volunteered to allow the use of the students in their classes as testers of the software. Students enrolled in 5 undergraduate science courses at 3 universities and 2 junior colleges were selected. Unfortunately, formal testing could not be arranged at any high schools. The procedure for conducting the testing was as straightforward. Students volunteering to take part in the testing were given consent forms to read and sign and were given a pre-test to establish a baseline of their understanding of ground-water and earth science principles. Once the pre-test was completed the student testers were given a survey form to fill out while they worked with the software. Once the session with the software was completed, the student tester was given a post-test to assess any changes in the level of understanding of ground-water and earth science principles.

This report on the alpha testing is in two parts. The first part of the report focuses on the student surveys and the second part on the pre- and post-testing. Each part contains a s brief discussion of the survey or testing instruments followed by a summery and discussion of the results.

Acknowledgements

This project supported by a grant from the National Science Foundation (Award Number GEO-0224507). On behalf of my colleagues on this project, I wish to express our gratitude to Dr. Carl McElwee, Les Thomas, Judith Spor, Dr. Marcia Schulmeister, and Dr. David Krischner for the loan of their students as testers of the Plume Busters software. The author also wishes to thank the student testers for their willingness to participate in this research project.

THE DATA FROM THE SURVEYS COMPLETED BY STUDENTS TESTING THE PLUME BUSTERS, ALPHA VERSION SOFTWARE

Student testers were supplied with survey forms to be filled out while they were working with the alpha version of Plume Busters (Table 1). The forms were designed to elicit basic information on how successful the students were in getting through the software and features of the software that were deemed helpful or not helpful. Measures of success included the number of times the application was restarted in Phase 1 (Locating the Plume), the number of days needed to complete Phase 1 and Phases 1 and 2, and the amounts of money spent in Phase 1 and Phases 1 and 2. Under the category of features that were not helpful, the survey asked the students to supply suggestions for improvements to the software. A total of 68 software testers filled out the surveys during the alpha testing.

Table 1. Survey questions asked of the student testers of Plume Busters, alpha version.

1. In Phase 1, how many times did you have to restart your search for the plume before you located it with 3 wells?
2. On your first successful attempt to locate and remediate the plume, How many days did it take you to complete Phase 1? _____ How much money had you spent at the end of Phase 1? _____ How many days did it take you to complete Phases 1 and 2? _____ How much money had you spent at the end of Phase 2? _____
3. What features of Plume Busters were most useful to help you understand the subject matter and to improve your skills?
4. What features of Plume Busters were not helpful, were confusing, or need improvement? Please be specific and make recommendations.

Number of Restarts of the Ground-water Model Application in Phase 1

A Restart button is available on the Plume Busters Model Application interface if for any reason the user wishes to start over at the beginning of Phase 1. This option was added to allow users to try again to locate the plume where it was felt that further attempts would be futile. During alpha testing the number of times students elected to restart the simulation ranged from 0 up to 25 but the median number of restarts was 3 (Figure 1).

Time and Money spent in Phases 1 and 2

For Phase 1 (Location of the plume) the amount of time spent ranged from 21 days to 324 days and the median time period was 21 days which is the minimum amount of time required to install and sample 3 monitoring wells (Figure 2). The amount of money spent to locate the plume

ranged from $15,000 to $200,000 and median amount was 15,000, the minimum amount needed to install and sample 3 monitoring wells (Figure 3).

The Plume Busters Model Application tracks the total amount of time and money spent since the pipeline break was discovered. Thus, at the end of Phase 2 (the remediation phase) the time and money spent noted at the end of the simulation is the total for both Phase 1 and 2. The total simulation time in days is the time spent by the user working with the application (total time spent minus 42 days). During the alpha testing the simulation time spent up through the end of Phase 2 ranged from 49 days to 518 days and median time spent was 147 days and the total money spent ranged from $28,000 to $420,000 with a median expense of $57,000 (Figures 4 and 5).

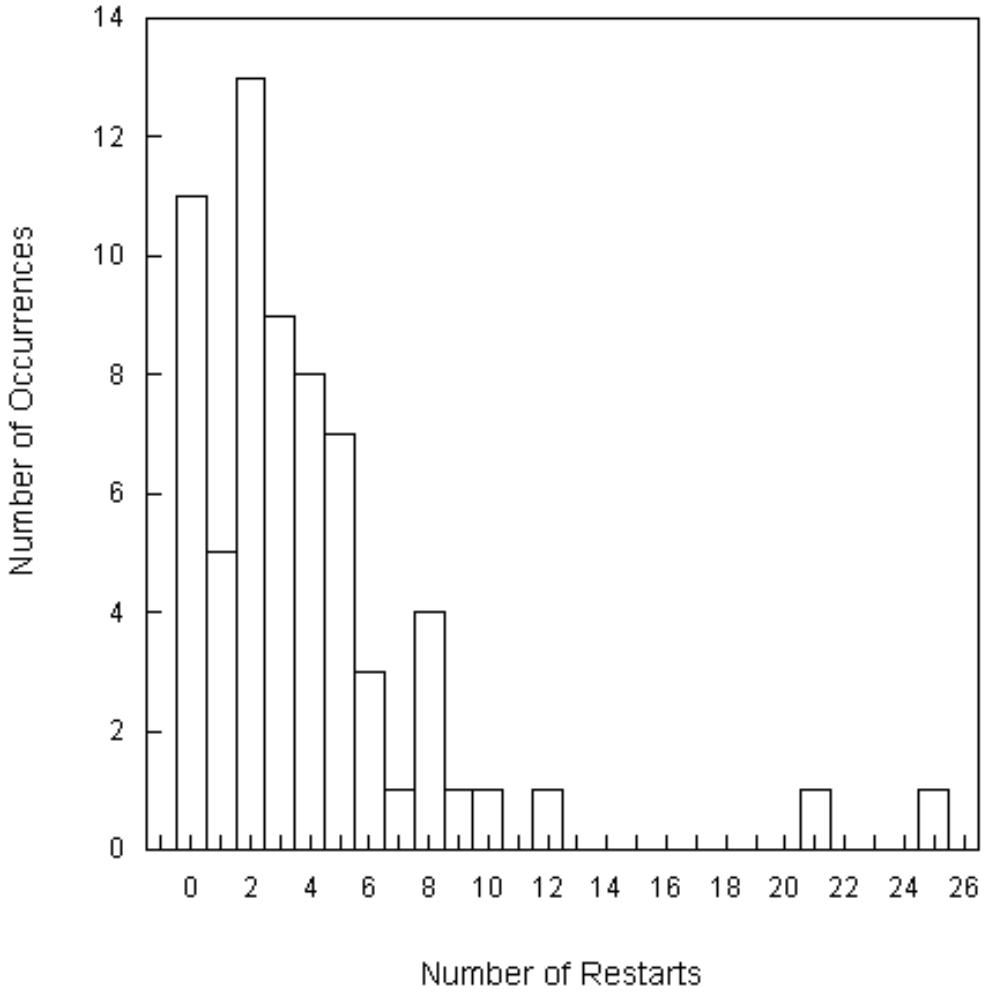


Figure 1. Number of times the student tester elected to restart the Plume Busters application during Phase 1.

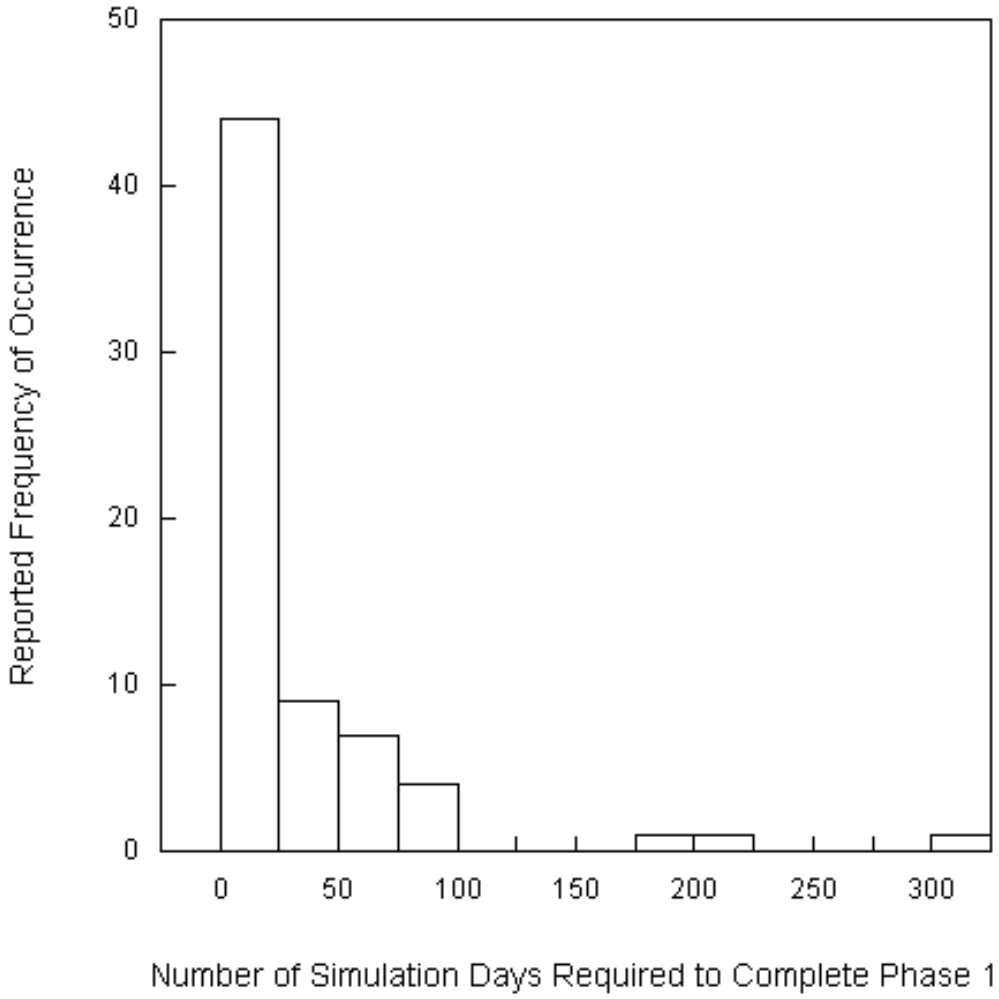


Figure 2. Histogram showing the distribution of the simulation time spent by the student testers locating the plume in Phase 1 of the alpha version of Plume Busters.

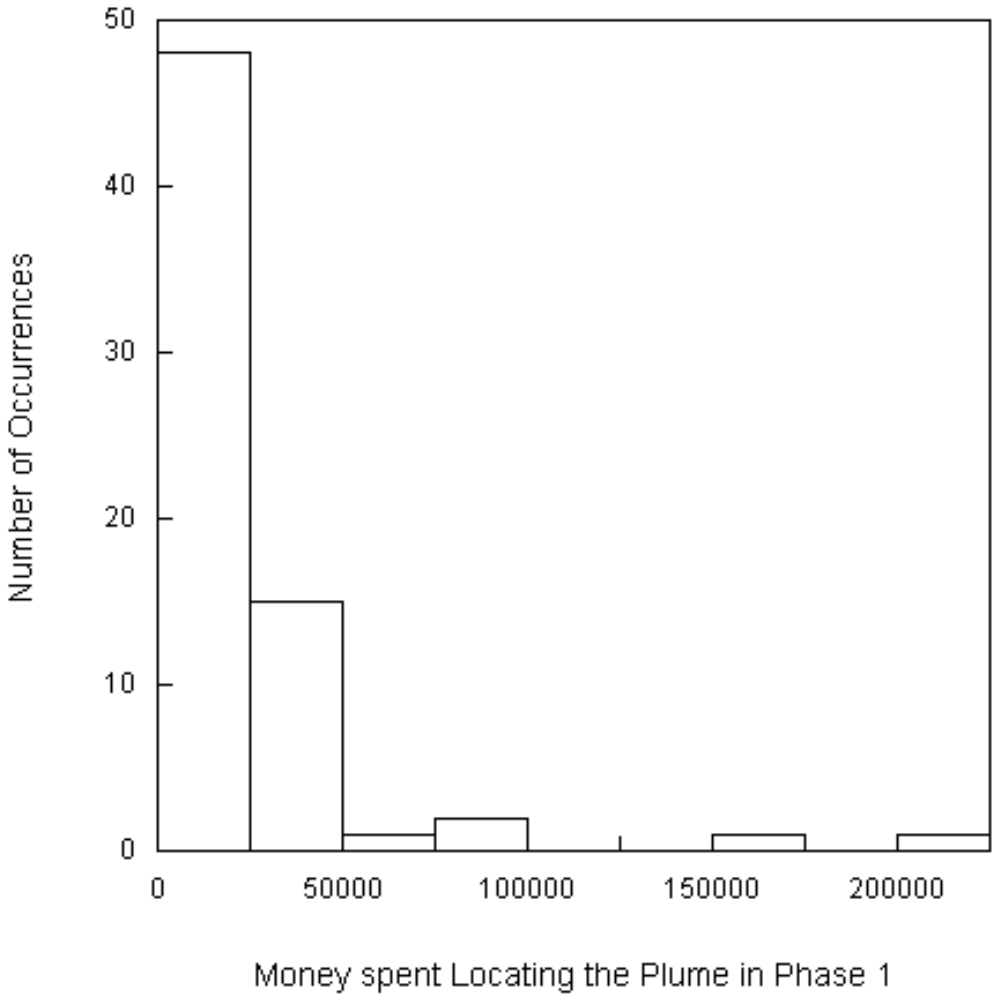


Figure 3. Money spent by the student testers to locate the plume in Phase 1 the alpha version of Plume Busters.

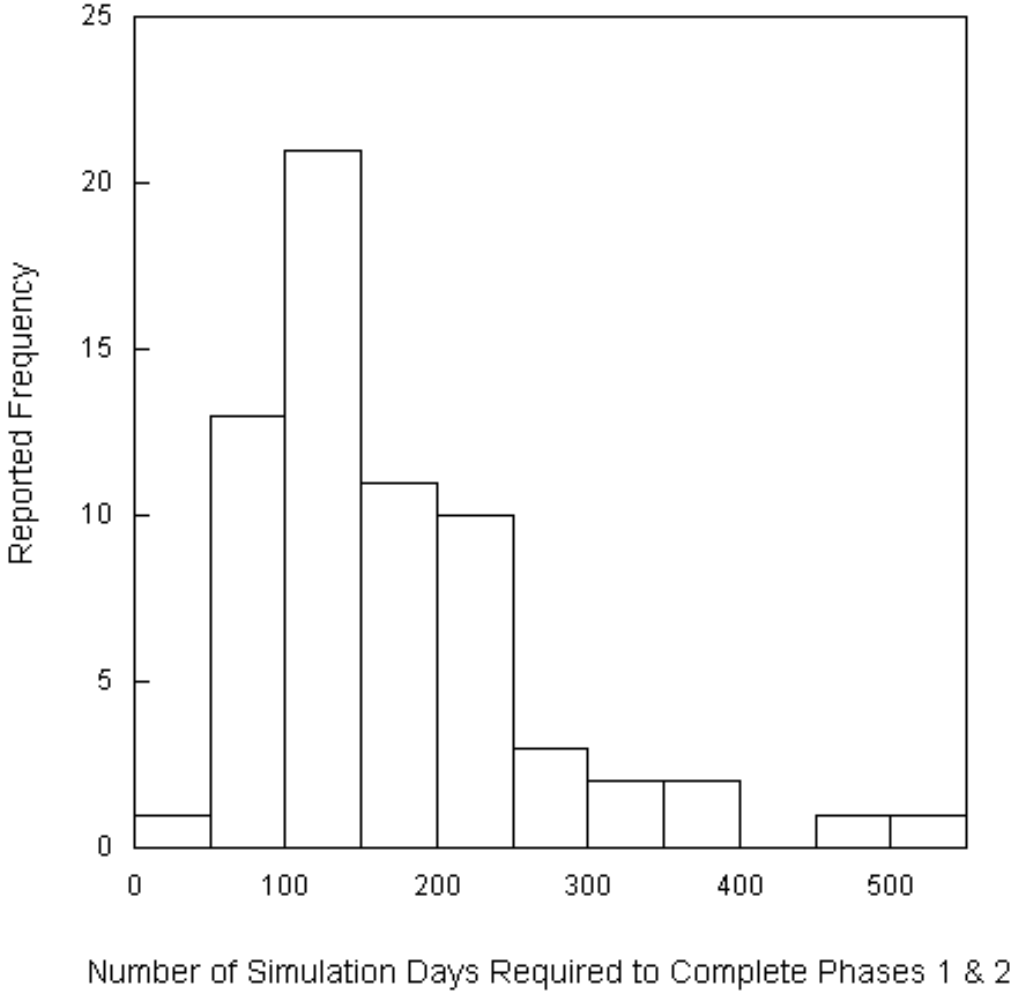


Figure 4. Histogram showing the number of simulation days the student testers needed to complete Phases 1 and 2 of the alpha version of Plume Busters.

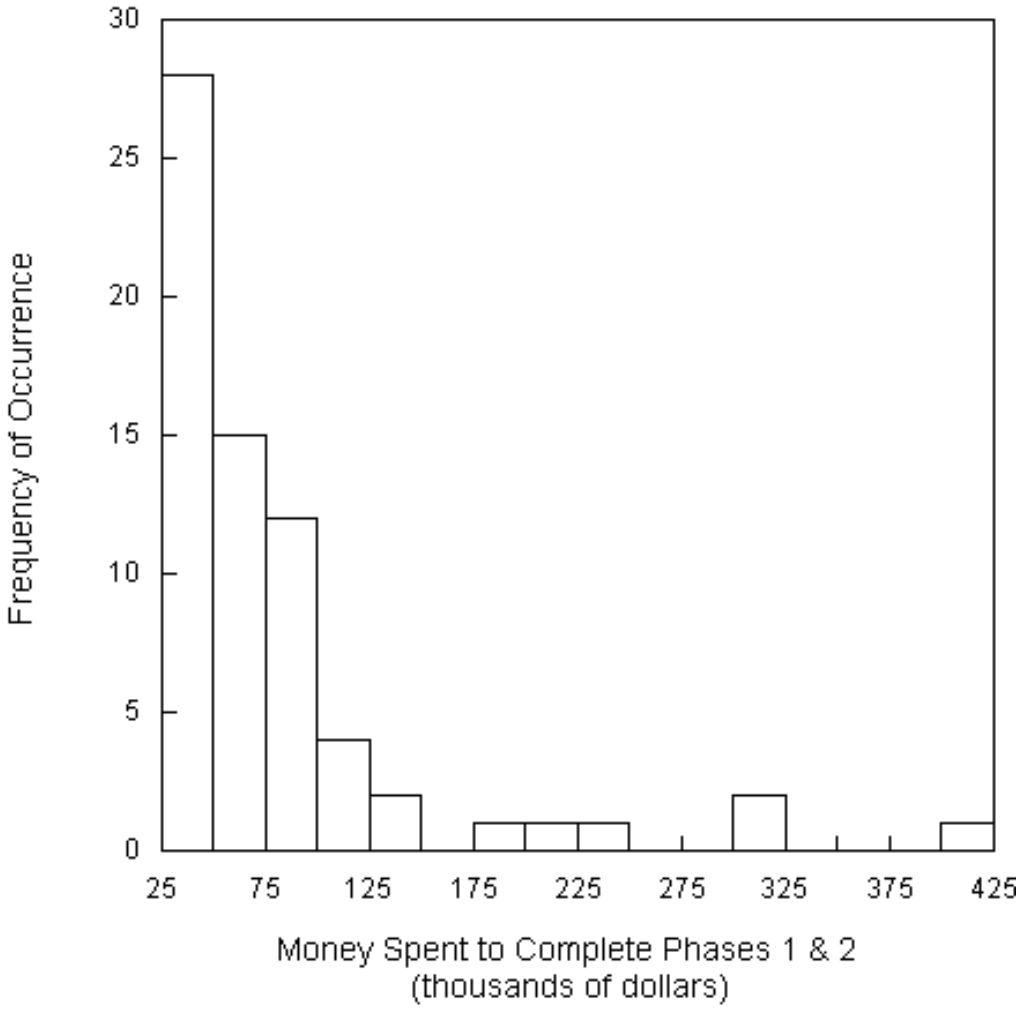


Figure 5. Histogram showing the total amount of money spent by the student testers to complete Phases 1 and 2 of the alpha version of Plume Busters.

What features of Plume Busters were most useful to help you understand the subject matter and to improve your skills?

Table 2 is a summary of the comments about specific features that were helpful and the number of students who made them in tabular form and other more general comments as a list.

Table 2. Specific features noted as helpful by the student testers.

Specific Feature of Plume Busters	Num. of Positive Responses
1. The HTML page of instructions for working with the application and the rules for each phase of Plume Busters	10
2. The water-table map	3
3. The Darcy's Law write-up; information on porosity	5
4. Explanation of remediation methods	4
5. Visuals	13
6. Glossary	12
7. The Introduction section of Phase 1	6
8. The map of the site in Map View	1
9. Calculator button in Map View	3
10. The calculator	9
11. Toolbar for navigation through the HTML-linked pages	1
12. Links to the Glossary	1
13. Resources and references helpful	5
14. Congratulations pop-up window at the completion of each phase	1
15. Ability to change pumping rates	1
16. The ruler for locating the monitoring wells	1

Below is a list of other less specific/general comments and response frequency:

1. Plume Busters was easily understood (4)
2. Good real-world application (4)
3. Learned about contamination and remediation (8)
4. Step-by step explanation (2)
5. Plume busters provided good information to help you find the plume (3)
6. The calculator made it relatively easy to find the plume
7. Self-explanatory if you read the instructions (2)
8. Re-reading the Rules was helpful
9. Developed an appreciation for how much time and money is required to correct an environmental problem.

The summary in Table 2 and the list of more general comments indicate that the visuals, the glossary, the page summarizing the rules, the information provided and the descriptions of application button functioning, and the calculator were most frequently mentioned by the student testers. A number of student testers commented that they learned a lot about ground-water contamination and remediation technology and a few commented on the real-world feel of the software. Several student testers indicated the value of reading all of the information before proceeding to the Plume Busters application.

What features of Plume Busters were not helpful, were confusing, or need improvement? Table 3 is a summary of the comments about specific features that were helpful and the number of students who made them in tabular form and other more general comments as a list.

Table 3. Specific features noted as not being helpful by the student testers.

Specific Feature of Plume Busters	Num. of Negative Responses
1. Rules	1
2. Terminology	2
3. Confusion about how to move from Phase 1 to Phase 2	2
4. Confusion about how to use the Calculator	4
5. HTML-linked pages need to be simplified to focus more on the problem at hand	1
6. Estimating the porosity from the well logs	4
7. Unsure about how to locate the monitoring wells from the directions provided	3
8. Too much information and too many instructions to read and digest before working with Map View; too wordy	10
9. Did not understand that the placeholder values in the Calculator could be changed	1
10.Unsure of which remediation method to choose form the HTML-linked pages	2
11. Not enough information on Darcy's Law, average ground-water velocity, and travel time	3
12. The buttons in Map view need to be marked in a better, more intuitive way	2
13. Submitting the remediation design was confusing	2
14. Data Repository not understood	1
15. Could not decide on which pumping rate to use in remediation	1
16. Better explanation of the travel distance calculation	4
17. The + and – signs for pumping rates	1
18. No information was provided on how best to site the remediation wells	1
19. Had trouble modifying production pumping rate	1
20. Could not find the hydraulic conductivity and hydraulic gradient information	1
21. Unsure about how to locate the plume from the instructions	2
22. Too many windows to keep tack of	3
23. Instructions on how to remediate the aquifer not very helpful	2
24. The goal of locating the contamination in 3 wells, 2 in the same budget round not obvious	1
25. Many of the resources were not helpful	1
26. Application confusing with the buttons and the grid	1

Below is a list of other less specific/general comments and response frequency:

1. More background instruction needed (2)
2. Hints should be provided about where to put the monitoring and production/injection wells (4)
3. Needed outside help to figure out what type of wells were needed in Phases 1 and 2
4. Need to have only one button for placement of the monitoring wells (2)
5. Initially did not understand what to do and ended up just placing wells randomly (5)
6. Needed to read all of the HTML-linked pages for each phase before getting to the application suggests posting the rules separately before working with the application
7. Need to vary the hydraulic gradient and flow direction each time the user starts the application over from the beginning. This will discourage memorizing where the plume was found from previous runs. (2)
8. Had trouble saving the porosity estimates back to page with the map
9. Calculator did all of the work; too much repetitive guessing
10. Calculator did all of the work. Why have all the information on Darcy's Law and the average ground-water velocity calculation if the calculator is doing all of the work?
11. Graphic artist needed to improve the quality and realistic look of the graphics and improve their attractiveness.
12. Need an example problem to show how to locate the plume and do the remediation
13. Application was confusing
14. The instructions and resources need to be integrated with the application to minimize the toggling back and forth between windows (2).
15. Difficulty following written directions
16. Directions should be displayed as the student goes through each phase.
17. Tabs for the Resources and references should be located to the side of the computer screen for help at any time.
18. Directions unclear (3).
19. Reading all of the reference material should be mandatory before moving to the application in Phase 2.

The summary of comments in Table 3 and the list of more general comments suggest a different picture from the list of features the student testers found helpful. The amount of information to be read and digested seemed to cause the most trouble for the student testers. Some commented that there was too much extraneous information. For some there was confusion about what to do from the instructions or how to proceed from Phase 1 to Phase 2. Many wanted to go directly to the Plume Busters application and skip the Plume Busters HTML-linked pages. However one student tester stated that going through the HTML-linked pages relevant to each phase should be required before proceeding to the application. Although not explicitly stated, many of the comments seemed to express frustration with not being able to just work with the Plume Busters application.

One classroom instructor indicated that his student testers assumed that the topics in the navigation toolbar were to be read in sequence and not as needed. He suggested changing the structure of the navigation so that all of the information relevant to Phase 1 in the References Section is included with Phase 1 and so on. Some student testers made similar suggestions

indicating a need to read all of the information relevant to each phase before proceeding to the application. Some also suggested a need for viewing the Locating the Plume and Remediating the Aquifer pages while working with the Plume Busters application. One student tester stated that there is a need to integrate the HTML-linked pages and the Plume Busters application into a single program rather than the two parts that operate independent of each other.

In terms of concept understanding, some expressed the need for more information on how to estimate porosity and make the travel distance calculation. Some were confused about how to use the calculator or about the placeholder values in the calculator that appear when the calculator is first displayed. Suggestions were also made about having an example situation involving locating the plume and remediating an aquifer to give users a better feel for what is expected or will occur.

Some student testers commented that the application of basic concepts to problem solution had been sacrificed by making the calculator too user-friendly. Along this line, the restart button on the Plume Busters application afforded the student testers to make multiple attempts at locating the plume and in the process to know where to look for it in succeeding attempts. Eventually students would not need to use the calculator to locate the plume; they would simply remember where they had encountered it from previous trials. Thus the validity of the data collected on money and time spent on each phase of Plume Busters is somewhat suspect. To remedy this, one instructor suggested creating multiple scenarios or changing properties values or boundary conditions from one session with the simulation to the next.

Summary and Discussion of the Student Tester Survey Results

The surveys generally indicate that the software functions properly on PCs running Microsoft Windows-based operating systems and seems to be compatible with Microsoft Internet Explorer, Netscape, and Mozilla browsers. However, the look and feel of the HTML-linked pages and the form taken by the mouse-activated cursor in the Plume Busters application depend on the version of the browser and the vintage of the operating system. For example if the operating system is Windows XP, the mouse-activated cursor will resemble an insertion-point marker, such as found in word-processing packages rather than a cross hair. In most cases the screen resolution needs to be set at the highest level possible (1280 x 1024) because of the JPEG images used in the HTML-linked pages. The text portions of the HTML-linked pages may be all but unreadable if computer-screen resolution is set low or even in mid-range. Downloads from CD-ROMs onto PCs do not always proceed smoothly and depend on the vintage of the Windows operating system. This is because with different versions of the Windows operating system, different installers are needed before downloading can be successfully negotiated. Interestingly, one University of Kansas Environmental Geology student tester downloaded the software from the Kansas Geological Survey website onto a Macintosh G-4 with an OS-X operating system and found it to be fully functional. For those who downloaded Plume Busters from the Kansas Geological Survey's web site, some student testers indicated difficulty with downloading the required Java Run-time Environment software to their local computer.

Looking at all of the comments supplied by the student testers it appears that the range of difficulty posed by Plume Busters to the student testers varied widely. Some indicated that it was easy to work through the simulation and the process of going through the simulation was

relatively self-explanatory. Some stated that the software was confusing and that it was very difficult to progress through the Plume Busters application. The primary difficulty for those who had trouble seems to hinge on the level of comprehension and understanding achieved by the student tester from reading the HTML-linked pages. In most cases, the key ground-water science concepts incorporated in Plume Busters had been covered in class recently. The level of frustration experienced seemed to be higher and the degree of success lower than for those who did not read the HTML-linked pages. Many of the responses seemed to suggest also a need for having at least the basic information (rules, explanation of the buttons on the Plume Busters application, and perhaps even a piece on the calculator) readily available while the focus of attention is on the Plume Busters application.

It is clear that significant structural changes need to be made to the alpha version of Plume Busters to streamline it. These changes should help to further clarify the process of finding the plume using the calculator to site and sample monitoring wells and to remediate the contaminated aquifer once the contamination has been located. The following is a list of some of the more significant changes needed:

- To improve user reaction to the software, it would be helpful to provide links to some of the material currently residing in the References section from the main information flow of the HTML-linked pages. Alternatively, this material could be integrated into the current flow of the HTML-linked pages, but at a cost of possibly losing the attention of users. Perhaps taking the Locating the Plume and Remediating the Plume sections out of the current flow of information (Introduction → Rules → Locating the Plume or Remediating the Plume) and allowing access to these pages through separate tabs along the side of the computer screen might provide users with more immediate access to help. Some of the problems experienced by the student testers could be remedied by integrating both parts of Plume Busters with mechanisms for feedback between the two parts in response to actions taken by the user. This change in design would make the software more interactive and could provide more guided learning than currently exists in the software.
- To reinforce the application of the science principles, mechanisms need to be included in the programming to change the simulation between attempts and thus discourage attempts to by-pass use of the calculator. Alternatively, the restart feature could be removed from the programming. This would put more of a premium on being able to determine travel distance. To increase the chance of success, some of the uncertainty would need to be eliminated, such as the range of values of aquifer porosity and hydraulic gradient.
- Some aspects of the software are probably not appropriate for four-year college undergraduates and junior college-level students. Specifically, the section of the Data Repository dealing with porosity estimation needs to be simplified or methods of porosity estimation from well logs needs to be explained. A few of the student testers indicated this to be a problem, but the pre- and post-tests indicate that most could not describe how to make these estimates from the well logs or extrapolate estimates from points with known values to points where porosity had not been measured.
- Some modification to the software will need to be made to facilitate its incorporation into secondary science curricula. Class time in high school is typically 45 to 50 min in length. This will require significant streamlining of the software for the software to fit into class

schedules. Further, the material will need to be made appropriate for the basic skill level and processing ability of students at this academic level.

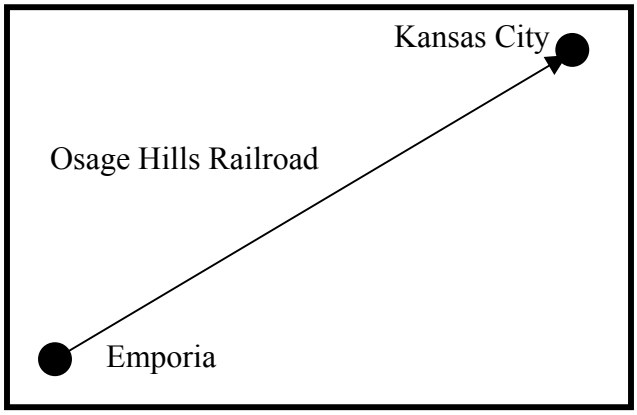
PRE- AND POST-TESTING RESULTS

Pre- and Post-Tests

Pre- and post-tests were administered to the student testers of Plume Busters to (1) evaluate student understanding of the distance, rate, and time relationship, (2) provide a baseline on student understanding of hydrogeology, (3) evaluate ability to estimate porosity range of heterogeneous aquifer materials given limited subsurface and geospatial information, and (4) assess changes in subject matter understanding resulting interactions with the software. The pre- and post-tests consisted of the same 5 questions (Figure 1a-e). For each question, the student was asked to describe a strategy for solving each problem with the provided information.

1a

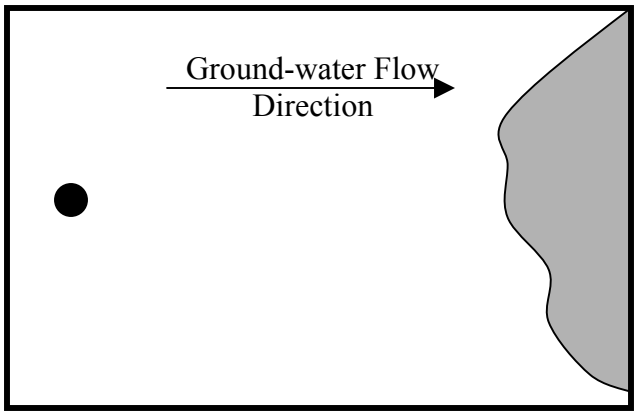
PLUME BUSTERS
PROBLEM 1



An Osage Hills Railroad train leaves Emporia for Kansas City, a travel distance of approximately 125 miles. The train is moving at a constant speed of 25 miles per hour. After the train leaves Emporia the FBI learns that a terrorist has placed a bomb on the train that is due to detonate 3 hours after the train's departure. As an FBI agent you must locate the train, find the bomb, and disarm it. You know from past experience that it will take you 30 minutes to disarm this type of bomb. Describe how you would determine the maximum distance the train can be from Emporia to give you enough time to save it from destruction.

1b

PLUME BUSTERS
PROBLEM 2

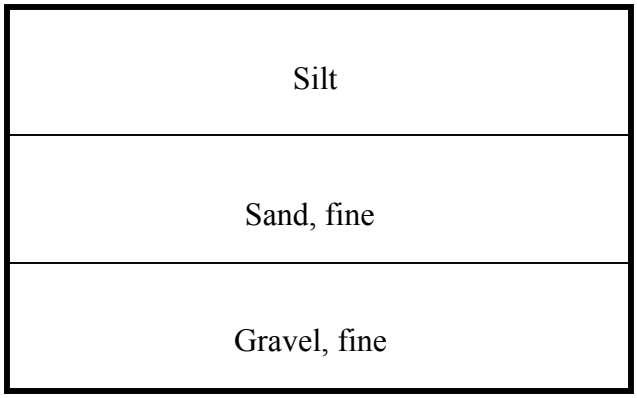


A contaminant enters the ground-water system approximately 1,000 feet away from a lake at the black dot shown on the map above. The ground-water flow direction is toward the lake and hydraulic gradient is 0.005 feet per foot. The aquifer hydraulic conductivity is 250 feet per day and its porosity 30%. Describe how you would determine the distance traveled by the contaminant 100 days after its release into the ground-water system.

1c

PLUME BUSTERS
PROBLEM 3

A.



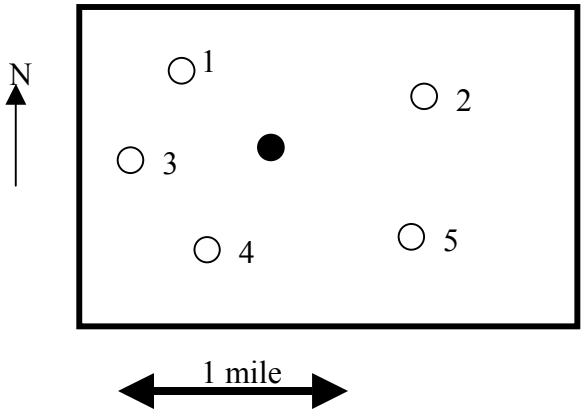
B.

Earth Material	High Porosity (%)	Low Porosity (%)
Silt	61	34
Sand, fine	53	26
Gravel, fine	38	25

The diagram in Figure A above is a vertical section through an aquifer in an alluvial valley. The aquifer consists of three types of earth materials in layers and each layer is 10 feet thick. Figure B is a table showing the porosity range that is usually assigned to the types of earth materials in Figure A. Outline the strategy you would use to estimate the representative porosity range of values at the site in Figure A.

1d

PLUME BUSTERS
PROBLEM 4

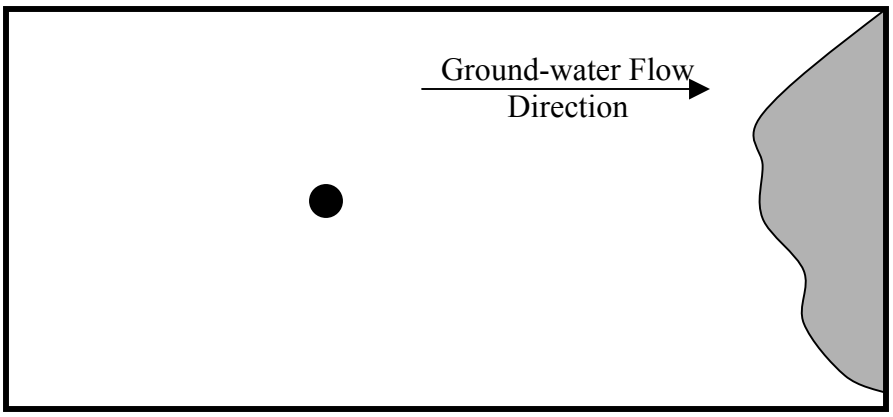


Site	Porosity Range (%)
1	25-35
2	25-35
3	25-35
4	35-45
5	30-40

Using the map and porosity range data, how would you estimate the porosity range (high porosity and low porosity) at the site indicated by the black dot?

1e

PLUME BUSTERS
PROBLEM 5



A contaminant enters the ground-water system approximately 1,000 feet away from a lake at the black dot shown on the map above. You are a consultant who has been hired to remove the contamination from the aquifer. Describe how you would go about doing this.

Figure 6a-e. The problems used in the pre- and post-test of the students involved in the alpha testing of the Plume Busters software.

Concepts and Skills Tested by the Test Questions

Question 1: Designed to evaluate readiness for the software by testing student understanding of the distance, rate, and time relationship.

Question 2: Designed to evaluate readiness for the software by evaluating student ability to describe the science concepts involved in determining the distance the plume had moved away from the injection point in the aquifer.

Question 3: Designed to evaluate student ability to estimate aggregate porosity range of a layered heterogeneous aquifer given the thickness of the layers and the range of porosity values for each layer.

Question 4: Designed to evaluate student ability to estimate the range of likely porosity values in an aquifer at a point given the estimated range of values at surrounding points.

Question 5: Designed to evaluate student ability to describe the process of locating a plume using monitoring wells and remediating an aquifer.

Composition of the Student Tester Population

A total of 57 four-year college and community college students took part in the alpha testing of the Plume Busters software (Table 4). Students attending four-year colleges made up approximately 68% of the total. The student testers were enrolled in a variety of courses, including Hydrogeology, Physics, Environmental Geology, Physical Science, and Water: Our Precious Resource when the alpha testing was being conducted. In terms of academic emphasis nearly all were undergraduates studying in earth science, geology, and hydrogeology majors and majors in other science, engineering, and non-science fields. Less than 10% of the student testers were hydrogeology majors and less than 25% were other earth science majors. The overwhelming majority of the students majored in fields outside of the natural sciences, geography, education, and engineering.

Table 4. Fields of interest of the student testers of the alpha version of Plume Busters

Institution	Hydrogeology	Other Earth Science	Environ. Science	Geography	Physical Science	Engineering	Education	Other
University of Kansas	1	4	0	1	3	6	5	10
Emporia State University	2	4	0	4	0	0	0	1
St. Louis University	0	0	0	0	0	0	0	9
Allen Co. Community College	0	0	0	0	0	5	0	1
Cowley Co. Community College	0	0	1	0	1	0	4	13
TOTAL	3	8	1	5	4	11	9	34

Results

Table 5 summarizes the change in student tester response to each of the questions posed on the pre-test after working with Plume Busters shown in Figure 6.

Summary and Discussion

The student testers made up a small but diverse population with respect to the type of institution attended, major fields of interest, and grade level. Considering these limitations, it is difficult to conclusively define patterns in the responses to individual questions posed on the pre- and post-tests and thus glean insight into the software's educational value. Within each of the five classes taught at the four-year and community colleges, those majoring in natural sciences (hydrogeology, earth science, and other physical science) and in engineering did not provide

Table 5. Summary of the results of the pre- and post-testing of the students involved in the alpha testing of Plume Busters, by institution. Problems numbers refer to the problems described in Figure 6a-e. + = evidence of improved understanding; 0 = no evidence of improved understanding; and – = no evidence of improved understanding but with incomplete answers on the post-test.

Testing Location/Class	ID	Pre- and Post-Test Problem Number				
		1	2	3	4	5
University of Kansas Environmental Geology	0031	0	0	0	0	+
	0245	0	0	0	0	+
	0982	0	–	0	0	+
	1399	+	+	0	0	+
	1855	0	0	0	0	+
	2898	0	0	0	–	+
	3372	+	+	+	0	+
	3421	0	0	0	0	+
	3704	0	–	+	+	0
	3735	0	+	0	0	+
	3976	–	+	–	+	+
	5047	0	0	0	0	0
	5657	–	–	0	0	+
	6592	+	+	+	+	+
	6969	0	0	0	0	0
	6990	0	+	+	+	+
	7202	–	0	+	0	+
	7532	0	+	0	0	+
	8357	0	0	+	+	0
	8821	–	+	0	0	+
	9152	0	+	+	0	0
	9301	0	+	+	+	+
	9893	+	+	+	0	+
	1345	0	0	+	+	+
	2961	+	+	+	+	+
Emporia State University Hydrogeology	5	0	0	0	0	+
	3	0	+	–	0	+
	4	–	+	0	0	+
	1	0	+	0	0	+
	2	0	0	0	+	+
Allen Co. Community College Physics II	1106	0	+	0	0	+
	2116	–	+	0	+	+
	0260	0	+	0	0	+
	5884	0	0	0	0	+
	2998	0	+	0	0	+
	4181	0	+	0	+	+

Testing Location/Class	ID	Pre- and Post-Test Problem Number				
		1	2	3	4	5
St. Louis University Water: Our Precious Resource	4058	–	–	0	+	0
	5559	0	0	0	+	+
	7650	0	0	0	0	0
	1888	+	0	0	0	+
	3447	0	0	0	0	+
	2218	0	+	+	+	0
	5143	0	+	0	0	+
	6444	0	0	–	0	0
Cowley Co. Community College Physical Science	1802	0	0	–	+	0
	2295	0	0	+	0	+
	3063	+	0	+	+	0
	3429	0	0	0	0	0
	3533	0	0	0	0	–
	4110	+	0	+	+	0
	4717	0	0	0	0	0
	5121	+	+	0	0	+
	5704	0	0	0	0	0
	7044	0	0	0	0	+
	7661	0	0	0	0	+
	8031	+	0	0	0	+
	6302	0	0	–	0	+
	Total +	10	23	15	17	41
	Total 0	40	30	37	39	15
	Total –	7	4	5	1	1

better answers to the problems posed on the pre-and post-tests than did those majoring in other fields. More than half the students were able to correctly solve Problem 1 on the pre-test. For those that did not correctly solve Problem 1, their answers indicate that they understand the relationship between distance, rate, and time, but they could not apply that understanding to the situation at hand. On the pre-test most of the students majoring in engineering and hydrogeology were able to describe the solution to Problem 2 or indicated that the solution had something to do with Darcy's Law or an equation that had recently been discussed in class. Most of the student testers did not answer or could not describe a plausible problem solution to Problems 3, 4, and 5 on the pre-test. Interestingly, of those that did provide a solution to Problem 5, their answers were plausible and involved aspects of current practice in remediation.

Overall, the responses improved somewhat between the pre-and post-tests with the greatest improvement for question 5, which is designed to assess what the student has learned about locating contamination and remediating the aquifer. For this question 70% showed improvement

in being able to describe the process. More than 80% of the students were able to identify the concepts and describe the strategy used to solve Problem 1 on both the pre- and the post-tests. While some showed improvement in their answers to this question between the pre- and post-test, about as many did not. For question 2, less than half of the students showed improvement in their answers either by showing the correct solution or by indicating that an application of Darcy's Law was needed for problem solution. Some students demonstrated confusion between the concepts of specific discharge and average ground-water velocity on both the pre- and the post-test. More than half of the students did not provide an answer or did not improve on their descriptions of the strategies they would use to solve Problems 3 and 4 on the post-test.

In general, it is clear from the answers to the pre- and post-test questions that student testers derived some educational value from working with the alpha version Plume Busters software. A majority of the student testers responded to Problem 5 with a recounting of the actions they took to locate and remediate the simulated plume in Plume Busters. Some of the students also showed improvement in the strategies for solving Problem 2 confirm this conclusion. Looked at more closely, the testing results suggest some design features should remain in place but others should be modified or removed from the software.

Student testers might have performed better on Problem 2, if the calculator had been less user-friendly and if the student testers had read through the material in the References Section on Darcy's Law and means to calculate average ground-water velocity and travel distance. In the design process it was assumed that the student using the software is adequately prepared to manipulate and use these concepts before working with Plume Busters. Information is included on these concepts and placed in the References Section with the idea that students could review this information, if needed for review. The Calculator was also designed to be user-friendly so that travel distance could be calculated directly without having to work through the calculation of specific discharge and average ground-water velocity. In the surveys of the software, several students lamented that the lack of emphasis on Darcy's Law in the software. However, the inability of most students to respond appropriately to this question on the pre-test suggests that the Calculator should not be modified.

Discussion of the responses or the lack of responses to Problems 3 and 4 rests on two key points. First, practicing hydrogeologists routinely deal with incomplete and uncertain or fuzzy data and thus, must often use empirical or theory-based methods to derive estimates of earth material properties and other parameters. Average aquifer porosity is often estimated from the expected range of parameter values for the earth materials that form aquifers and descriptions of the earth materials provided by driller's logs of boreholes. Secondly, methods of estimation rely on using weighted averages of each layer or on the harmonic mean depending on the direction of ground-water flow with respect to the layering of the aquifer. These methods would apply to Problem 3. In Problem 4, estimation of the aquifer porosity range of values at a point based on the ranges of porosity values at nearby points relies on a geospatial, statistical analysis.

To successfully estimate porosity in heterogeneous aquifers the student must have a background both in practical hydrogeology and geospatial analysis, which is unlikely at the undergraduate level even for those majoring in hydrogeology or earth science. This deficiency in training can be taken into account in the beta version of the Plume Busters software by providing (1) an

example problem to show the user how to estimate porosity from driller's log data, (2) a map of points porosity values where the user would be confronted with estimating only a single value of porosity for the aquifer near the pipeline break, or (3) by providing an estimate of aquifer porosity at the site in the data table contained in the Data Repository. While the third option is more expedient for the student through the simulation, it also reduces some of the day-to-day reality faced by practicing consultants when they take on this kind of environmental problem.