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GIS and Introductory Environmental Engineering: A Way to Fold GIS into an Already-existing Course

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Dr. David Kelley, Associate Professor and Chair, Department of Geography David has a B.A. in Biology and a M.S. in Agronomy, and spent almost 10 years working with international development projects in various African countries before moving to Minnesota in 1995. He earned his Ph.D. in soil science and water resource science from the University of Minnesota and joined the Geography department at St. Thomas in 2000. David currently teaches courses in GIS, physical geography, remote sensing, and weather and climate. He is particularly interested in working with students and other researchers to explore landscape processes related to environmental quality, and in the application of geographic information science for land assessment and management.

Prof. Warren Roberts

GIS and Introductory Environmental Engineering: A Way to Fold GIS into An Already-Existing Course

The use of Geographical Information Systems (GIS) was implemented in the upper-division undergraduate technical elective Introduction to Environmental Engineering at Harvey Mudd College. Students integrated technical engineering skills, newly-learned geographical information system (GIS) skills, and the engineering design process, all in the context of the design of a debris flow barrier for a wilderness land parcel acquired by a local conservancy group.

Junior and senior general engineering students, the majority of whom had no experience with GIS, were taught ArcGIS (a GIS mapping program) in the context of an Introductory Environmental Engineering course. Students learned how to map locations, find and download geo-encoded data, and join data layers, in order to graphically present toxic release hazards near their home towns. ArcGIS skills and knowledge were assessed through completion of homework problems, and through the students' use of GIS data, software, and mapping during the design of a debris flow barrier for a local wilderness land parcel.

Assignment #1 consisted of students learning how to map and characterize toxic releases near their hometowns; these data were downloaded into a spreadsheet for later use in the ArcGIS software package. In Assignment #2, the students used ArcGIS to analyze these data for the potential of water, soil, and atmospheric transport. In addition to the homework assignments, the student team completed a team-based design project involving the characterization of the wilderness site; acquiring relevant GIS data; and studying the physics of debris flow. The team produced alternative designs for the barrier and chose the best design by applying design metrics. The alternative designs and rationale for the chosen design were presented to the board of directors of the local conservancy group.

Pre- and post-assessment data were gathered to analyze the success of the learning objectives. The design project in particular was useful in evaluating the students' skill, knowledge and ease in using the GIS tools for analysis of the wilderness land parcel.

Background

A Geographical Information System (GIS) is “an integrated system of hardware, software, and procedures designed to support the collection, management, manipulation, analysis, modeling, and display of spatially referenced data about Earth's surface in order to solve complex planning and management problems¹.” Characteristic of a GIS is the storing of thematic layers; each layer includes the location of the place (geo-encoding) and attributes of that place. A particular strength of GIS analysis is the ability to relate attributes from different layers (databases) through spatial relations, and to visualize the relationships using maps.

GIS education has been driven by geography and environmental education², although examples can be found in civil engineering^{3,4}, construction engineering and management⁵, and environmental engineering⁶. Many of these examples stress the importance of “GIS for work”, or “GIS as a toolbox”—the idea that GIS education and skills are needed to help prepare students

for their future career in industry—but a broader reason for GIS education is the notion of “spatial literacy.”

Spatial literacy includes the “teas[ing] out [of] complex interrelated elements of connected systems⁷”; and “the confident and competent use of maps, mapping and spatial perspectives to address ideas, situations and challenges. The ability to visualize and interpret location, distance, direction, relationships, movement and change through space is fundamental to content understanding and problem solving. Learning to think spatially is a form of learning how to learn⁸.” The National Academies Press published a report in 2005 likens spatial literacy to ‘writing across the curriculum’, a curricular subject not belonging to one discipline¹.

GIS education in engineering disciplines has involved scaffolding across multiple courses^{3,5}, as well as adding modules to already-existing courses^{4,6}. These studies argue that it is difficult to fit a GIS course into an already-crowded curriculum. This paper presents one way to fold GIS into a single, already-existing undergraduate Environmental Engineering introductory course.

GIS in Introduction to Environmental Engineering

Harvey Mudd College offers a degree in General Engineering, and students often gain more discipline-specific learning through careful choice of their technical electives and capstone clinic projects. Introduction to Environmental Engineering has been offered as an upper-division undergraduate technical elective since 1996. The course has typically been taught in a lecture-based, problem-solving format. The primary purpose of the course is to introduce students to the main concepts and applications in modern environmental engineering, including fate and transport of surface and groundwater pollution (both classical pollutants and toxic substances); risk assessment and analysis; and air pollution. The students are taught integral and differential methods to describe various transport mechanisms for water- and air-borne contaminants, and solve problems to analyze time-dependent and spatially-varying contaminant concentrations in the environment. Societal factors are discussed, particularly when introducing toxic chemicals and risk assessment/analysis. The social, economic, and political factors driving contamination and clean-up are addressed using real-world examples. During the Summer of 2012, we restructured the course to include GIS workshops; two homework assignments focused on GIS skills; and a half-semester community-based design project.

We taught the students GIS concepts using two workshop sessions and two homework assignments; the students then applied those concepts as part of a half-semester design project for a local conservancy group. The first homework assignment used a web-based GIS; the second assignment used the ESRI program ArcGIS using geo-encoded data the students had downloaded as part of assignment #1); and the design project involved obtaining data and making maps in order to characterize a local wilderness site, especially with respect to debris flow potential. Assignments #1 and #2 occurred in the first half of the semester; the design project took place in the second half of the semester. In terms of course grading, we assigned six evenly-weighted homework sets, of which two were the GIS assignments described here. The homework counted for 20% of the course grade. The design project, a third of which was GIS work, counted for 25% of the course grade.

Assignment #1: TOXMAP, Chemical Classification, and Downloading Data

The goals of the first assignment were to introduce students to a web-based GIS; to classify chemicals, especially by transport class; and for students to learn how to download geo-encoded data on toxic release facilities. TOXMAP⁹ was used to accomplish those goals. Assignment #1 (Exhibit 1) introduced the students to TOXMAP, a web-based GIS from the Division of Specialized Information Services of the US National Library of Medicine. TOXMAP can be used to create maps of toxics releases in the United States, using data from the US

Exhibit 1. Assignment #1: Using TOXMAP to generate geo-coded data of toxics releases

TOXMAP (toxmap.nlm.nih.gov) is a web-based GIS used to visualize EPA Toxics Release Inventory (TRI) data. Using TOXMAP, find at least 12 TRI Reporting Facilities located around your home town (zoom out on the map, if necessary.) Construct a table of the chemicals released by these facilities, and sort each chemical into these classes: ammonia, ozone-depleting compounds (ODC), volatile organic compounds (VOC), acid, water-soluble alcohol, heavy metals, poison, or other (use 'other' if the chemical does not fit into any of the previous categories.) For each chemical, determine if it is transported in air, soil, or water (check volatility, water solubility, particle adherence properties) and report this in the table. Note: the chemical may be transported in multiple ways, depending on its properties. Since this table could get a bit long, limit yourself (if necessary) to the primary source chemical from each facility, and move to the next largest release amount from a facility if the chemical is duplicated from a previous source. You may stop listing chemicals when you have at least a dozen in your table.

Hand in:

- 1) A printout of the TOXMAP map showing the name and location of your home town and at least six of the closest TRI Reporting Facilities.
- 2) A list of the name of at least 12 TRI Reporting Facilities, sorted by on-site release amount.
- 3) A table listing chemical name, sorted class, and transport path types (air, soil, water.)
- 4) A spreadsheet of the raw results from the Map Controls TRI [save results] listing 2010 Facilities. NOTE: save this file for use in later homework assignments.

Hints: the TOXMAP Chemical Page for each chemical has a link "Environmental Fate and Exposure" that should help you classify the potential transport paths. You may use the linked sources on the TOXMAP pages to classify the chemical classes, or other sources (please cite references if you use other sources.)

Environmental Protection Agency's Toxic Release Inventory¹⁰ (TRI). In addition to creating web-based maps, TOXMAP will also allow a user to download TRI data, which includes the facility ID and name, address, latitude and longitude, name of chemicals released, and amounts released.

For the assignment, we asked the students to create a map of toxic releases around their home town; in particular, they needed to create a map that had at least 6 TRI Reporting Facilities. We

also asked them to identify the closest 12 TRI Reporting Facilities, and to create a table listing the chemicals released from these 12 facilities, sorted by chemical class: ammonia, ozone-depleting compounds (ODC), volatile organic compounds (VOC), acid, water-soluble alcohol, heavy metals, poison, or other (using 'other' if the chemical does not fit into any of the previous categories.) In addition, the students needed to determine the transport media (soil, air, or water) of each chemical. The deliverables for this homework assignment were: 1) A printout of the TOXMAP map showing the name and location of your home town and at least six of the closest TRI Reporting Facilities, 2) A list of the name of at least 12 TRI Reporting Facilities, sorted by on-site release amount, 3) A table listing chemical name, sorted class, and transport path types (air, soil, water), and 4) A spreadsheet of the raw results for use in later homework assignments. (It is the raw results table that includes the geo-encoded data that the students will upload into ArcMap—the analysis and mapping program of ArcGIS—for the second homework assignment.)

TOXMAP introduced the students to a web-based GIS. To create a map, they simply needed to type in their hometown (town and state) or zipcode. No specific in-class tutorials of TOXMAP were given to students. TOXMAP uses ESRI's ArcIMS and Place Finder Web Service¹¹, although, like many good web-based GIS, this is transparent to the user. Depending on how many TRI sites are returned on TOXMAP's default map, the students may have needed to zoom out on the map, if their original map did not include enough facilities (the students need at least 6 facilities for part 1 and at least 12 facilities for part 2.) The maps are rudimentary in the sense that they do not include a North arrow, and identical symbols (blue squares) indicate the location of the facilities (Figure 1.) To get more information on chemicals released, and amounts, the user simply clicks a facility on the table, and another page pops up with details (Figure 2).

Assignment #1 also asked the students to classify the chemicals in two ways: by chemical class, and by transport class. Students can use links from TOXMAP to find this information by clicking on a chemical name. This produces a pop-up box with search links for the chemical (Figure 3) which the students can use to classify the chemicals. In particular, the "Environmental Fate and Exposure" link gives information such as vapor pressure at 25 degrees C; soil organic partition coefficient (K_{oc}); Henry's Law constant; acid dissociation constant (pK_a); routes of human exposure; and environmental sources and fate. Students are allowed to use other sources to classify the chemicals, but if they used other sources, they were asked to explicitly cite their sources. The TOXMAP links often gave more information than the students could use, and therefore some students were overwhelmed at first glance. Many of these students naturally used Wikipedia, as it was familiar to them. However, for many chemicals, the students needed to utilize the TOXMAP links in order to classify transport class, as Wikipedia doesn't always describe chemical fate and transport in detail. For these students, urging them to look for particular pieces of information in the "Environmental Fate and Exposure" link was necessary, as they otherwise wandered into other, less-focused, and perhaps questionable, on-line sources.

The third goal of Assignment #1 was to have the students download geo-encoded data from TOXMAP. The homework assignment (Exhibit 1) points the students to the "Map Controls, TRI [Save results]" portion of the web page. Clicking the [Save results] link produced a comma-separated list of facilities and chemical releases, including facility name and address, latitude,

longitude, county name, chemical names and release amounts. Students were told to save this file for later use.

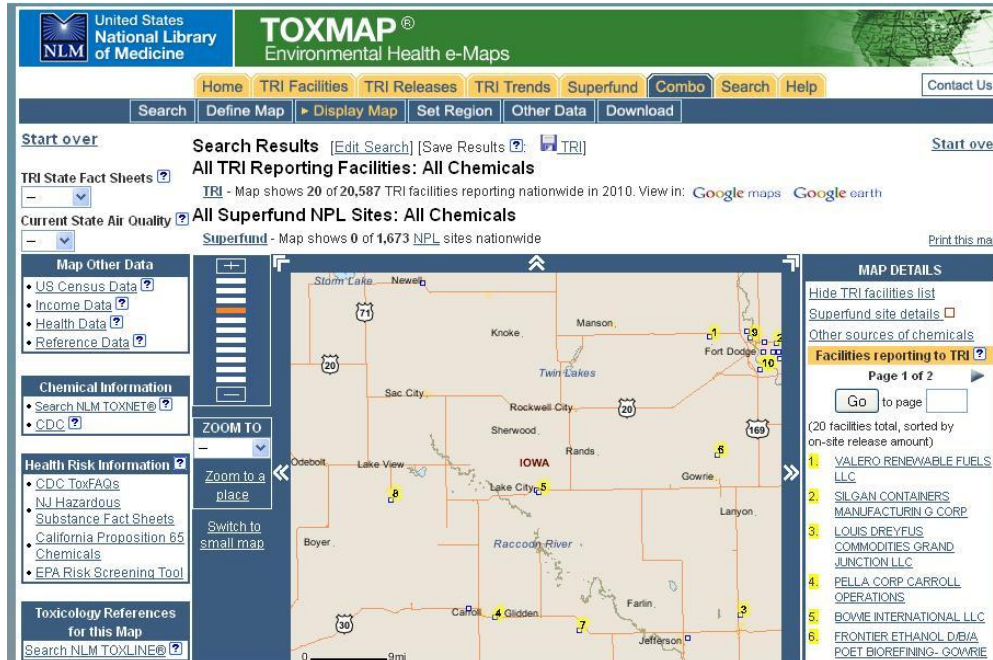
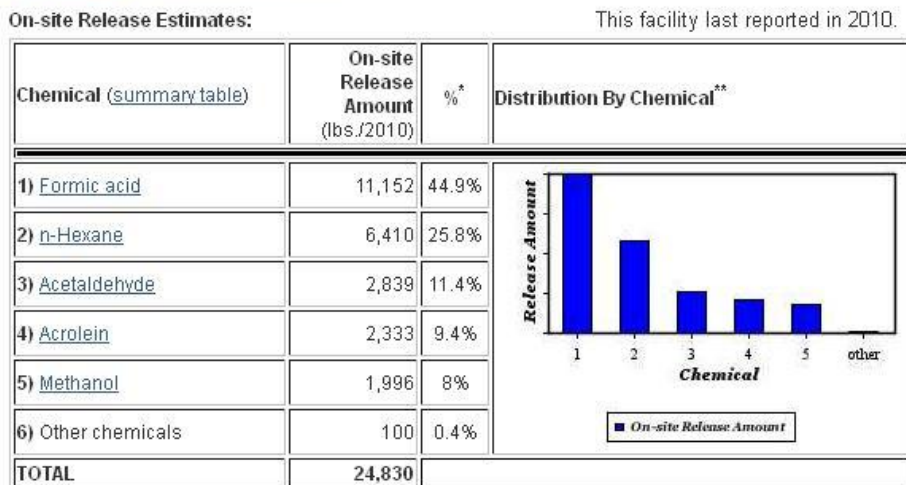


Figure 1. TOXMAP map of TRI Facilities near Lake City, Iowa. Numbered blue squares indicate the facilities on the map, and a list of numbered facilities appears to the right of the map.

1. VALERO RENEWABLE FUELS LLC TRI Facility ID: 50501VRSNF193HA [top](#)
 1930 HAYES AVE
 FORT DODGE, IA 50501
[Google Maps](#) [TRI State Fact Sheet](#)
 Latitude: 42° 30' 40" N
 Longitude: 94° 17' 60" W



* Percents may not add to 100 because of rounding.

** Small values may not be visible on chart. Refer to the On-site Release Estimates table. Mouseover bars for release percentages.

- [▶ All chemicals reported by this facility](#)
- [▶ On-site release summary for this facility](#)

Figure 2. Example of TOXMAP TRI Facilities output (sorted by on-site release amount)

Formic acid (RN: 64-18-6)

Chemical Information

NLM Searches of 2

- [Toxicology Databases](#)
- [Human Health Effects](#)
- [Manufacturing/Use Information](#)
- [Environmental Fate and Exposure](#)
- [Occupational Exposure](#)
- [MedlinePlus@](#)

CDC Searches of 2

- [Toxicology FAQ](#)
- [Health Assessments](#)
- [All CDC Documents](#)

Health Risk Information 2

- [CDC ToxFQs](#)
- [New Jersey Hazardous Substance Fact Sheets](#)
- [California Proposition 65 Chemicals](#)
- [EPA Risk Screening Tool](#)

[About Chemicals and Toxicity](#)
[close window](#)

US National Library of Medicine® National Institutes of Health
Department of Health & Human Services

Figure 3. TOXMAP Chemical Page for formic acid showing information links.

Assignment #2: ArcGIS and Mapping Hometown Toxic Release Hazards

For Assignment #2, we wanted to move the students from the web-based GIS of TOXMAP (with its transparent use of ESRI programs, and built-in data searching) to the more powerful ESRI program ArcGIS using user-loaded GIS data. The overarching goal of Assignment #2 was to use the more sophisticated GIS program to graphically analyze toxic release hazards near their hometown. The particular goals of assignment #2 were to learn to add spreadsheet-based geo-encoded data to ArcMap, the mapping program in ArcGIS; analyze these data using ArcMap; use Query Builder; create new data layers; make a spatial join between data layers; all to serve the purpose of creating readable, informative maps.

The main concepts of Assignment #2 are from “The Fate and Transport of Toxic Releases¹²” by David Kelley. This case study is from the NSF-funded National Center for Case Study Teaching in Science, whose mission is to “promote the development and dissemination of materials and practices for case teaching in the sciences.¹³”

Kelley’s objectives for his case study were:

- To use the scientific method, real-world data, and insights from class lectures and readings to gain a better understanding of the relationships between environmental quality and the potential impacts of economic development.
- To facilitate students’ examination of where they live and what they buy.
- To facilitate students’ examination of the consequences that arise from modern industries and conveniences.

- To explore the environmental consequences of accidental or purposeful release of potentially hazardous substances in a mixed urban/rural setting.
- To expose students to the use of GIS as a tool to examine complex environmental issues with a spatial context.

Kelley notes, regarding the study: “While it can be used as-is with little preparation for an introductory environmental studies course, other disciplines might want to preface the exercise with a discussion of partitioning coefficients, remediation technologies, or environmental law, depending on the discipline. For my use, I spend a class period ahead of time discussing the use of chemicals in our society, the economic and political placement of the sites/businesses that use these chemicals in our midst (often along railroad lines or barge terminals for bulk transport), some ethical considerations regarding where these sites are located (near poorer, or ethnic, or politically disenfranchised populations), and the potential ramifications to the health, safety, and welfare of humans and their environment should an accidental release occur¹⁴.”

Kelley’s case study provided the students with shapefiles and GIS data for the Twin Cities, Minnesota area, including TRI data (already classified by chemical type, but not classified by transport type.) His study is intended to span two 65-minute class periods, with the first class covering various definitions and introducing the TRI database, and the second period occurring in the GIS lab, where the students complete the exercise, including grouping the chemicals by transport class, and producing maps of air, groundwater, and soil hazards. In particular, the students learn to use the ArcMap function “Spatial Join” to show how soil properties, in conjunction with the TRI chemical data, can be used by a GIS program to spatially locate particular hazards in a way that would be difficult to do only using tabular data.

We modified Kelley’s case study as follows: we had the students download their own toxic release data from TOXMAP—these were the data that they then needed to upload to ArcMap; we did not provide any railroad or other maps, but let the students find them as basemaps in ArcMap; and we did not provide soil data (we had the students use the web to obtain soil data—thus giving the students more practice with finding, downloading, and importing GIS data.) However, the basic idea of the case study was unchanged; the students were to create maps of hazards, and specifically, learn to use “Spatial Join” and the Structured Query Language (SQL) syntax of Query Builder in ArcMap.

To prepare the students for Assignment #2, the students attended two 65-minute GIS workshops at the college’s GIS Lab. These workshops introduced students to ArcGIS, and students got hands-on instruction in making maps, finding and loading GIS data, using Spatial Join, and Query Builder. Students were provided with ArcGIS software and student licenses (so they could load the software onto their personal computers) and had access to the GIS Lab. We also loaded ArcGIS onto one computer in the Engineering Computer Lab.

Assignment #2 is presented in Exhibit 2. To complete Assignment #2, the students needed to “add” the TRI data in ArcMap; recall, the TRI data were tagged with latitude and longitude. The students learned how to associate longitude and latitude to XY coordinates, and how to select the geographical coordinate system. Once the TRI data were loaded in ArcGIS, most students easily added basemap layers, and thus recognized their hometown.

Exhibit 2. Assignment #2. Using ArcGIS and spreadsheet data to make toxic release maps.

This assignment involves the use of GIS data and the ArcGIS software analysis tool to examine the impacts of possible releases of toxic substances near your home town. We will learn to add spreadsheet-based data to ArcGIS, analyze these data in ArcGIS, use Query Builder, create new data layers, make a spatial join between data layers, and of course, create readable, informative maps.

Using your TOXMAP data from Assignment #1, load these data into ArcGIS. Your spreadsheet should have a column that lists the chemical class (ammonia, ozone-depleting chemicals (ODC), volatile organic compounds (VOC), acid, water-soluble alcohol, heavy metal, poison, or other. You may want to label that column of your spreadsheet something like ChemGroup. Note: ArcGIS really does not like spaces or commas in any field of a spreadsheet, so try to avoid those both in the column name and in how you label the chemical class itself (you may need to edit your spreadsheet at this point.)

1.) Create a map that shows the toxic releases near your hometown, color-coded as to chemical class. Include a legend in your map, and you will likely want to load a basemap on which to show your data. Depending on the extent of your map, county boundaries, roads, and railroads may help understanding of the releases.

2.) Create a map that shows the air hazards near your hometown. There are many ways to do this, including having a column in your spreadsheet that identifies hazard as possible air pollutants, or using Query Builder to manually identify which pollutants are air hazards. (It's a good idea to create a new shapefile of only the air hazards, once you have those identified.) Indicate the size of the releases graphically.

3.) Create a map that shows the groundwater hazards near your hometown. To do this, find and download soil data for your hometown. In particular, we need to consider whether a toxic release will be able to move through the soil and potentially contaminate the groundwater. For example, soil that is impermeable will not transport the chemical (instead, the chemical will tend to pool on the surface and contaminate the soil itself.) Add the soil data to your map, and figure out how to join the soil data to your TOXMAP data in such a way that you can find which locations have soil properties such that transport in groundwater is possible.

4.) Create a map that shows the soil hazards near your hometown. Again, you'll need to consider the soil properties and may want to create a new shapefile of these joined data.

What to hand in:

Write up a short explanation (no more than a page) explaining what you have done and why. Start with a statement of the problem, and explain how you have solved the problem, assuming your audience is someone who knows nothing about GIS or the behavior of toxins in the environment. In your write-up, explain how you grouped each compound (air, water, soil transport) and why (you can re-use your explanation from homework #2 here.) Turn in the four maps, making sure the maps are informative, have legends, etc.

The assignment required that the students to create three different shapefiles in order to create the air, groundwater, and soil hazards maps. To create the groundwater and soil hazards map, the students were asked to use the web to find and download GIS soil data for their hometown, and ‘add’ these data to their project. A particularly useful tool in GIS is the ability to join attributes from one dataset to attributes from another dataset, based on the spatial relation. In Kelley’s case study, and here in Assignment #2, the students needed to associate the transport class of the chemicals (soil or groundwater hazard) with drainage attributes of the soil itself. This allowed the students to make maps identifying releases of groundwater hazards on permeable soil, and soil hazards on impermeable soil.

The students had been taught during their GIS workshops how to use SQL syntax in Query Builder. Therefore, in order to make the groundwater hazards map, the students were expected to use Query Builder to identify those chemicals that were groundwater hazards and which were released on soils that had drainage characteristics such that the chemicals could be expected to move through to soil to underlying groundwater. Similarly, the soil hazards map could be constructed by using a SQL query to identify appropriate chemicals that were released on soils that had poor drainage. In each case, Spatial Join was used to create a new layer where the chemical attributes and the soil attributes were associated due to their spatial relation.

In summary, the new skills the students learned from Assignment #2 were how to add geocoded data (in spreadsheet form) to ArcMap, and to use tools such as Query Builder and Spatial Join to analyze data and create new layers and maps. The GIS workshops, as well as Assignments #1 and #2 were all completed in the first half of the semester. During the second half of the semester, the students worked on a small design project for a local conservancy group. As part of the project, the students used GIS to analyze debris flow in the area, and created maps that were used during the design process, and as deliverables for the conservancy group.

Assignment #3: Debris Flow Design Project

The project involved the design of alternative debris flow barriers for a local conservancy group. The Arroyos & Foothills Conservancy (AFC) is an Altadena, California community-based organization working to steward the land, and provide access and educational experiences for the area residents. In June of 2012, AFC and the Crescenta Valley community preserved 7.75 acres of wilderness land, called the Rosemont Preserve. The preservation of this land effectively doubled the amount of “open space” available to the La Crescenta community.

The Rosemont Preserve is at the mouth of Goss Canyon. Goss Canyon is a 300-acre wilderness area mostly maintained as wilderness by private landowners. Directly south and west of Rosemont Preserve are residential areas of La Crescenta. In 2009, the Station Fire burned 650 km² of the Angeles National Forest, including Goss Canyon. Due to the increased threat of mudslides from the fire-denuded hillsides, LA County Public Works (hereafter referred to as “the County”) installed concrete K-rails, a type of Jersey barrier often used as a traffic barrier to protect residential areas from the possibility of additional debris flow. Three years after the Station Fire, many of the K-rails have been removed, but a 48-meter-long line of them remains below the Rosemont Preserve. Local residents find the K-rails to be an eyesore and detrimental

to property values, and the AFC is particularly interested in working with the County to find a more aesthetically-pleasing alternative to the K-rails below Rosemont Preserve.

The design project was intended to focus on the design process, and served that purpose well; we also knew that it could potentially include a significant GIS component. However, unlike the homework assignments, we were very hands-off, and did not give the students a list of GIS deliverables, as we were curious to see what the students would deem important for the design project, and for their client. The students came up with three main tasks for the project: 1) creation of detailed GIS maps of the area, 2) recommendations for floodplain restoration around the K-rails, and 3) design and evaluation of alternatives to the K-rails. At the beginning of the project, the Conservancy provided the students with a number of documents, including a 1995 map of Goss Canyon (Figure 4) and drawings of a debris flow barrier.

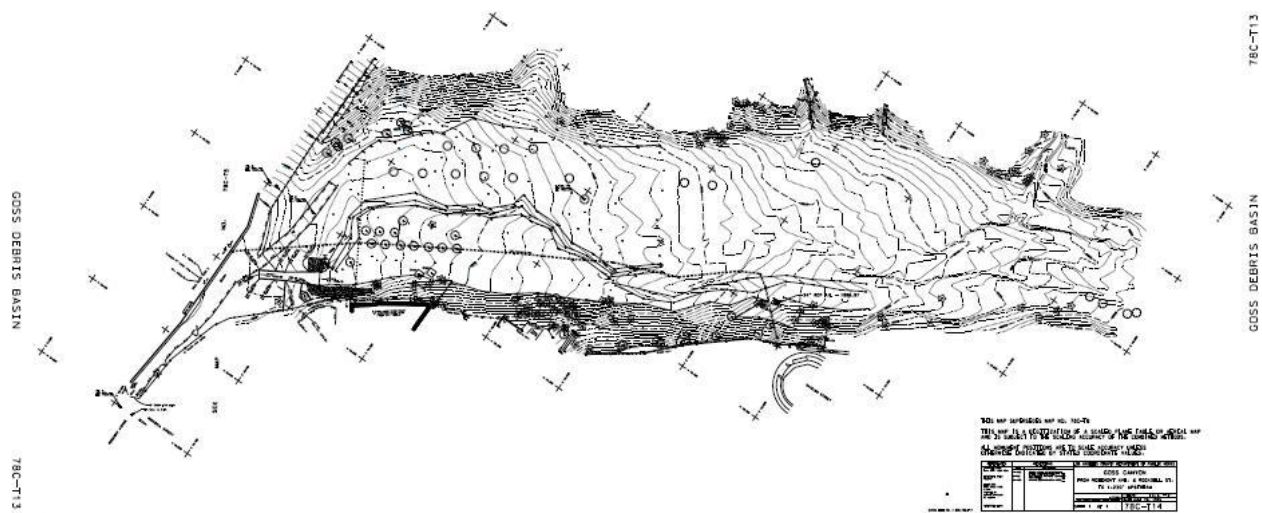


Figure 4. LA County Public Works map of the Goss Debris Basin.

As part of the design project, a sub-group of 3 students created maps of location, elevation, aspect, and slope for Goss Canyon. The location map was deemed important by the students, as they were puzzled by the map provided by the County, and quickly moved to make their own map. The students produced a single map that delineated the location of the Rosemont Preserve; the K-Rails; the debris basin; and the drainage area. Quantifying the boundary of the drainage area was necessary, as it gives an indication of where the debris flow may occur, and allowed students to calculate the magnitude of the area which may produce debris flow.

In order to determine the drainage area, the students created slope and aspect maps (Figure 5.) Slope maps characterize the degree of terrain slope, and aspect maps display the cardinal direction of the slope. The students analyzed the aspect and slope maps to delineate the drainage polygon; then used this area to verify the LA County Public Works' estimate of debris flow in Goss Canyon. Until the students quantified this area, they were unable to understand how the County came up with the debris flow numbers. The students were able to find the debris production rate from the County's Sedimentation Manual, but needed the drainage area in order to match the County's design debris event estimate of 40,000 yd³. The students' estimated the

drainage basin area to be 0.24 mi², giving a design debris event estimate of 40,800 yd³, about 2% higher than the County's estimate of 40,000 yd³.

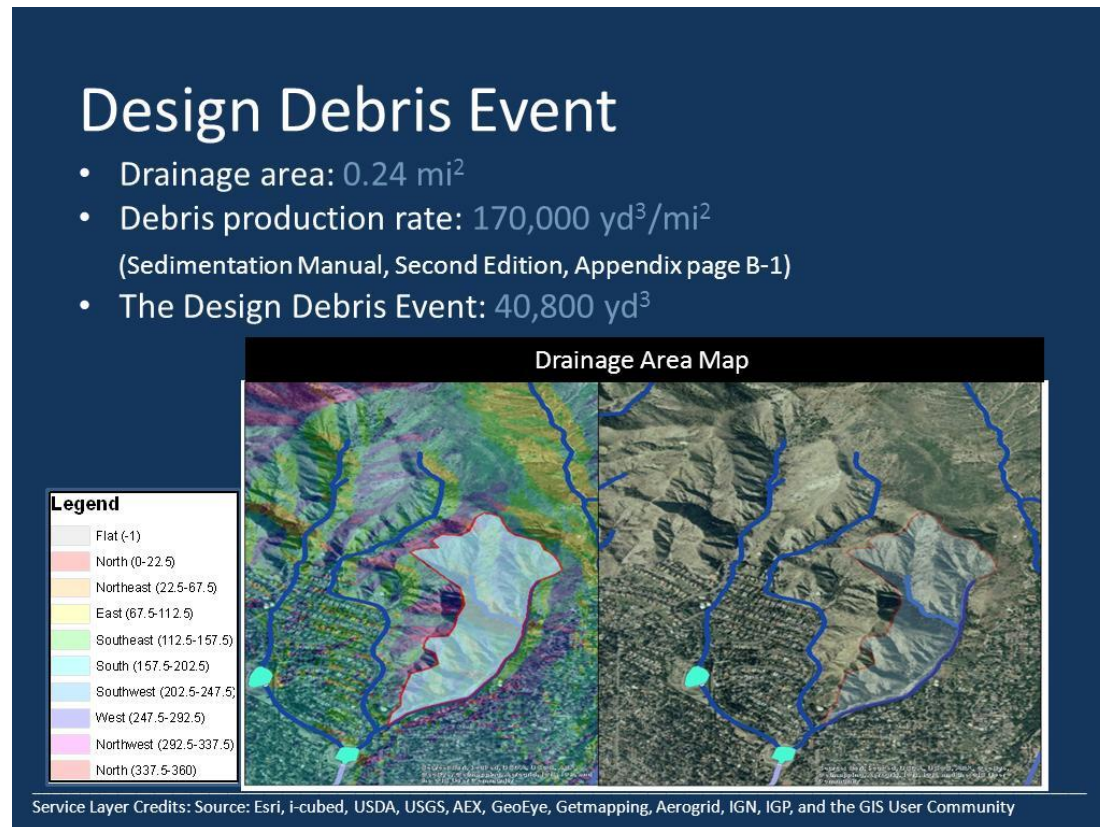


Figure 5. Slope and aspect map created to analyze the drainage area.

In order to create these maps, the students found GIS data for elevation. They also taught themselves to create slope and aspect maps, to draw polygons in ArcMap, and to calculate areas of polygons. Although these are GIS basic skills, we were pleased that the students realized what they needed to learn in order to carry out their debris flow analysis, and then proceeded to teach themselves these skills.

Assessment

We gave the students self-assessment surveys at the beginning of the course (the entrance survey) and on the last day of class (the exit survey.) These surveys addressed four GIS skills and knowledge: 1) general map making with GIS, 2) awareness of the existence of geo-encoded data, 3) ability to find and download geo-encoded data, and 4) ability to join data layers on a map in ArcMap. Table 1 summarizes the survey results, where a score of 1 indicated a rating of “strongly disagree”, 3 indicated “neutral”, and 5 indicated “strongly agree”. The students’ average self-rating for their entrance map-making skills was 2. Their average rating for this skill in the exit survey was 4.11, indicating that the students agreed that the course had improved their GIS map-making skills. The second question assessed the students’ awareness of geo-encoded data, and the assessment showed that the students’ average self-rating increased slightly over the course of the class, starting at a 3.67 in the entrance assessment, and increasing to 4.56 in the exit

assessment. When analyzing the raw data, we saw that only 2 students assessed their skill as a 1 in the entrance survey; the remaining students rated themselves as a 4 or 5 in this category. In the exit survey, all students rated themselves as a 4 or 5 for this skill. Therefore, we can state that two students increased their self-rating from a 1 to at least a 4 (and possibly to 5) and that the other 7 students continued to rate themselves as 4 or 5.

Students also rated themselves as improving in their skills and knowledge of finding GIS data: the entrance survey showed an average of 2.33, which increased to 4.33 by the time of the exit survey. It seems that having the students download a minimum of three GIS data sets from the internet increases their confidence in this skill. The last skill/knowledge assessed was the ability to join data sets in ArcMap. The students' self-rating increased from an average of 1.67 in the entrance survey, to 4.11 in the exit survey. This skill showed the largest increase over the semester, but given that this is the most technical skill, and at the heart of GIS analysis, it is not surprising it increased. The raw data from the entrance survey showed that only one student rated their skill in this category as a 5; the exit survey showed 8 students rated themselves as a 4 or 5.

Table 1. Student self-assessment survey results for GIS skills/knowledge

Skills and knowledge assessed	Entrance response (average, N=9)	Exit response (average, N=9)
I can make a map of a location using ArcGIS.	2	4.11
I am aware that geo-encoded environmental data exists.	3.67	4.56
I know how to find and download GIS data.	2.33	4.33
I can join data layers on a map using ArcGIS.	1.67	4.11

We also assessed the members of the Conservancy who attended the students' final design presentation. Although we did not specifically mention GIS in the survey questions, the attendees were asked to rate the quality of the graphics in the presentation, and five attendees uniformly rated the graphics as a 5 (out of 5); about 30% of the presentation graphics were student-produced GIS maps.

Implementation Challenges

Challenges faced in implementing the GIS work in this course included carving away usually-taught technical content so that the GIS workshops and Design Project discussions had space during class time. We cut content on specific air pollution models (Gaussian models) and instead focused on the applicability of general models of dispersion, diffusion, and convection to multiple media types. For engineering programs where an introductory course may be a prerequisite for upper-level technical electives, reduction of this content may be a concern. At a college like Harvey Mudd, where we do not have discipline-specific engineering majors (and no downstream technical elective for which this introductory course is a pre-requisite), it was not an issue. Regarding the GIS software, one student (out of nine) was unable to install the program on her laptop; we made sure that the program was installed on a computer in the engineering

department computer lab, and also gave the students access to the Claremont Colleges GIS Lab, which contains multiple computers running ArcGIS. However, it would be good to expect that some students may have trouble installing the software on their personal machines, and have a solution in place for that issue. Another potential issue we encountered was a mismatch between what students expected from the GIS workshops, and what the instructor presented. My upper-level engineering students found the first session of the GIS workshop to be slow-paced, and expected more hands-on work. For students well-versed in computer programs, a quicker paced workshop with many hands-on examples may be a better option.

Conclusions

Junior and senior general engineering students, the majority of whom had no experience with GIS, were taught ArcGIS (a GIS mapping program) in the context of an Introductory Environmental Engineering course. Students were exposed to basic GIS skills and concepts through two 65-minute GIS workshops; a homework set using TOXMAP (a web-based GIS); a second homework set using ArcMap; and a small design project involving the characterization of a local wilderness site. Students learned how to map locations, find and download geo-encoded data, and join data layers, in order to graphically present toxic release hazards near their hometowns. The students also used newly-learned GIS skills to analyze debris flow potential of a nearby wilderness site. This was done as part of a small project to design an alternative debris flow barrier for a local conservancy group.

The students' GIS skills and knowledge were assessed using entrance and exit surveys. Comparison of the survey data indicated that the students felt their skills and knowledge of GIS had increased over the period of the course. In particular, their assessment of their ability to spatially join data layers using ArcMap increased from 1.67 (out of 5) to 4.11, with 8 of the 9 students self-reporting a score of 4 or 5 on this skill by the end of the course. Students also showed the ability to find GIS data and teach themselves new techniques to analyze the data in the context of a small design project. In particular, the students learned how to use slope and aspect maps to delineate an area of debris flow potential.

The basic GIS skills could be covered using homework assignments #1 and #2. However, we do not recommend assigning the GIS homework without having some kind of GIS workshop or hands-on training beforehand. The addition of the more free-form, open-ended design project caused the students to teach themselves more GIS skills, as well as gain more practice in finding online GIS data; adding these data to maps in the GIS program ArcMap; and analyzing engineering problems using the GIS.

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