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Using Spreadsheets in Geoscience Education: Survey and Annotated Bibliography of Articles in the Journal of Geoscience Education through 2003

Beth Fratesi
Department of Geology, University of South Florida, sfratesi@mail.usf.edu

H L. Vacher
Department of Geology, University of South Florida, vacher@usf.edu

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Abstract
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Keywords
geology, earth and space science, geoscience education, mathematics education, quantitative literacy, bibliography

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Sarah E. Fratesi
Department of Geology
University of South Florida
4202 E. Fowler Ave
Tampa FL 33620
sfratesi@mail.usf.edu

H.L. Vacher
Department of Geology
University of South Florida
4202 E. Fowler Ave
Tampa FL 33620
vacher@chuma1.cas.usf.edu

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Abstract

Thirty-eight papers published in the Journal of Geoscience Education (JGE) from 1989 through 2003 explicitly use or recommend the use of spreadsheets as part of classroom or field exercises, projects, or entire courses. Many of the papers include the spreadsheets, and some include the equations. The papers demonstrate how spreadsheets allow students to explore a subject through problem-oriented, interactive, and quantitative exercises. We provide an annotated bibliography and classify the 38 JGE papers by spreadsheet use, mathematics skill area, and geologic subdiscipline. Our discussion of five selected articles – abundance of elements in the Earth's crust; directional properties of inclined strata; U-shaped valleys scoured by mountain glaciers; the Laplace Equation for groundwater flow; the location of our solar system within the Milky Way galaxy – demonstrates the huge breadth of topics in the earth science curriculum. The 38 papers collectively, and the five examples individually, make the point that spreadsheets developed for geoscience education can provide context for principles taught in courses of other disciplines, including mathematics. Our classification by mathematics skill area follows the content standards of the National Council of Teachers of Mathematics (USA) and may prove useful for educators seeking problems for skills-based assessment.

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Keywords: geology, earth and space science, geoscience education, mathematics education, quantitative literacy, bibliography.

1 Introduction

The National Association of Geoscience Teachers (NAGT, [14]) is the principal professional organization of earth-science teachers in the US. Its publication, the *Journal of*

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Geoscience Education (*JGE*, [13]), is the main forum in the US for reporting research and exchanging ideas about educating students in the earth and space sciences. The focus of the journal is undergraduate education, although papers about pre-college education are increasing in frequency. The journal, which began in 1951, comes out now in five issues totaling 600–700 pages a year.

The field of geology is becoming ever more quantitative. Accordingly, the quantitative skills of students in both majors and non-majors courses have become an issue [10], [27], [29]. The NAGT sponsors and co-sponsors workshops to promote the sharing of ideas about growing the quantitative skills of students in geology classrooms. The *JGE* has added a column on Computational Geology. The Digital Library of Earth Science Education (DLESE) has made quantitative skills a subject area for a collection of student resources [4].

As quantitative skills have come onto the radar screen for the undergraduate geology curriculum, there has been an increase in the number of *JGE* papers that involve geological-mathematical exercises, problems or projects. The second author compiled a bibliography and index of such papers published in the *JGE* during the 1990s [26]. That bibliography contains 212 entries, the vast majority (177) of which concern one or more specific classroom activities. The bibliography contains an average of 20 papers per year for the first three years of the decade, and 25 papers per year for the last three years of the decade.

At the same time as the number of papers involving mathematics has increased in the *JGE*, the number of papers involving spreadsheets has also increased since the first one in 1986. The first three years of the 1990s, for example, saw three papers involving spreadsheets; these three papers constituted 5% of the *JGE* papers in those three years that had some mathematical content. In the last three years of the decade, there were 11 papers involving spreadsheets, or nearly 15% of the papers that had some mathematical content.

Through 2003, the *JGE* published a total of 38 papers that include spreadsheets in some way. Our purpose here is to survey these papers in the expectation that our colleagues in the broader education community will find spreadsheets developed for geoscience education to be a rich source of interesting, in-context, problem-solving opportunities beyond the confines of geoscience education. Our survey consists of a table classifying types of use and identity of subdiscipline; a selection of examples showing the range and diversity of the spreadsheets; and an annotated bibliography.

2 Overview of the bibliography

The 38 papers (Table 1) explicitly recommend the use of spreadsheets in one or more stages of a geology field or classroom exercise. A few articles describe entire courses and the use of spreadsheets in those courses. Some papers present exercises that are built completely upon the use of a spreadsheet. Discussion of the spreadsheets varies, but most of the papers include an example spreadsheet with some description.

The level of student involvement in the construction of the spreadsheet also varies.

At the low end, students are expected to enter values into a "black box" program that the instructor has constructed. At the high end, the students are expected to take full responsibility for the conception and execution of a spreadsheet to solve a posed problem.

Table 1 classifies the papers in a variety of ways: (1) the use of the spreadsheet in the exercise, (2) the kind of mathematics involved in the exercise, and (3) the geologic subdiscipline. The papers are grouped in the table by geologic subdiscipline.

Spreadsheet use is broken into four categories. "Data manipulation," for "Data entry and manipulation," includes importing, exporting, and formatting data and arises in papers presenting field exercises. "Plotting," including elementary data analysis, is used not only to examine data collected in some field exercises, but also to demonstrate trends and relationships to students in classroom activities. "Calculating" refers to the repetitive calculations that are so handily executed with cell formulas, whether as a series of calculations applied to a single value, or as a single calculation applied concurrently to a column of values. "Modeling," as we use the term here, is a form of calculation in which an array of values is used to represent a process, either spatially or temporally, or both.

Kinds of mathematics include Number, Algebra, Geometry, Measurement and Data Representation, and Probability and Statistics. These categories are those of the bibliography [27] of the 212 articles in the *JGE* containing activities in geological-mathematical problem solving. The categories are essentially the five content standards promulgated in the Principles and Standards for School Mathematics published by the National Council of Teachers of Mathematics (NCTM, [15]).

Number (38 out of the 38 papers) refers to concepts of numerical representation, methods of counting (e.g., combinations and permutations), and methods of calculation, including logic. It is difficult to imagine a circumstance in which using spreadsheets would not involve "number."

Algebra refers to analysis (35/38), including calculus but mainly precalculus, particularly the concept and use of functions, and of course, solving and manipulating equations. Exercises that use spreadsheets for modeling fall naturally into this category, because they use functions, whether explicitly defined as an equation or not. The high occurrence of algebra testifies to the statement by Friedlander [8], quoted in the review by Baker and Sugden [1], "Spreadsheets build an ideal bridge between arithmetic and algebra and allow the student free movement between the two worlds."

Geometry (24/38) includes trigonometry and two-dimensional or three-dimensional visualization. Much of geology falls under this category. It is no coincidence, of course, that "geometry" and "geology" have the same root.

Measurement and data representation (26/38) involves not only the practice of making measurements, but also simple manipulations of those measurements, such as calculations and descriptive statistics. The large number of papers in this category reflects a goal of geoscience educators in the US to engage students with actual data.

Probability and statistics (10/38) includes probability and inferential statistics. The small number of papers in this category is consistent with the small number of papers in the same category in [27]: remarkably (given the relevance of geologic hazards),

there are relatively few papers in the geoscience education literature that build students' quantitative knowledge of probability and expectation.

Geologic subdiscipline includes 12 categories conforming roughly to the US geology curriculum following introductory physical geology: historical geology, petrology (including mineralogy), sedimentology, structural geology, geomorphology, geochemistry, geophysics, hydrology (including hydrogeology), oceanography, environmental geology, planetary and space geology (including the Earth as a planet), and field geology. This classification is based loosely on the categories of [27], and those used in the annual indexes of the *JGE*. Not all of the subdisciplines in [27] are repeated here. We have added "field geology" for papers describing field trips, field projects, and keystone field courses, because many of these activities bring together more than one geologic subdiscipline.

3 Sampling of uses

Spreadsheet use is fairly evenly distributed amongst the four categories in Table 1: calculating (13), modeling (9), plotting (9), and manipulating data (8). In order to illustrate the diversity of uses of spreadsheets in these articles, we give two examples of spreadsheets used for calculating; two for modeling; and one for plotting. The papers in which spreadsheets were noted for data manipulation are strongly associated with a single aspect of geoscience education: field geology, particularly field courses. In nearly all cases, these papers simply noted spreadsheets as a technique that students used or could use – in the standard way – to process the data from their field study.

3.1 Example: Calculating the amounts of U–238 daughters in the Earth's crust

The spreadsheet of Figure 1 is one of a series of spreadsheets in Dutch [5] in which students can calculate some geochemical "vital statistics" of the Earth. The series of spreadsheets opens with a spreadsheet listing the chemical elements, their atomic weights, ionic radii, and abundance (ppm by weight) in the Earth's crust. The second spreadsheet lists or calculates basic information about the Earth's shells (continental and oceanic crust, mantle; outer and inner core): depth to boundaries, volume, mass, and average density. The third uses information from the first two to calculate the mass of each element in the Earth's crust and goes on, using Avogadro's number, to calculate the number of atoms of each element. The fourth combines the atom counts, ionic radii, and volume of the crust to calculate the volume ppm of each element, and in the process works out the interatomic space in the crust (41%, analogous to the porosity of loosely packed sand). The fifth in the series (Figure 1) calculates the crustal abundances of each isotope in the decay series of U-238.

The calculation of the isotopic abundances (Figure 1A) starts with the decay constants of the isotopes in the decay series (Col `C`) and the amount of the parent isotope, U-238 (Cell `D3`). The parent abundance comes from the earlier spreadsheet of all the elemental abundances. One key concept for students working this problem is the relation

JGE Survey

Table 1: Guide to bibliography of spreadsheets in geoscience education through 2003

Reference	Spreadsheet Use	Number	Algebra	Geometry	Measurement	Prob. & Stats.	Geologic Subdiscipline
Andersen, 2002	plotting	X	X		X		geochemistry
Biddle, 1995	modeling	X	X		X		geochemistry
Dutch, 1991	calculating	X	X				geochemistry
Foos, 1997	data manipulation	X	X		X	X	geochemistry
Roberts, 2000	modeling	X	X		X		geochemistry
Vacher #26, 2003	calculating	X	X		X		geochemistry
Manche and Lakatos, 1986	calculating	X	X		X	X	geochemistry
Bair, 2000	calculating	X	X	X	X	X	hydrology
Clapp et al., 1996	plotting	X	X	X	X		hydrology
Ousey, 1986	modeling	X	X	X			hydrology
Rose, 1997	modeling	X	X				hydrology
Saini-Eidukat, 1998	plotting	X	X		X	X	hydrology
Sanders, 1994	data manipulation	X	X	X	X		hydrology
Drake et al., 1997	data manipulation	X	X	X	X		field geology
Dunnivant et al., 1999	data manipulation	X	X	X	X	X	field geology
Ettensohn, 1997	data manipulation	X	X	X	X		field geology
Panno et al, 1998	data manipulation	X	X	X	X		field geology
Schlische and Ackerman, 1998	data manipulation	X	X	X	X		field geology
Vacher #15, 2001	calculating	X	X	X			field geology
Dilek et al., 1994	plotting	X	X	X	X	X	petrology
Holm, 1988	plotting	X		X	X		petrology
Malisetty, 1992	modeling	X	X				petrology
Martin, 1993	modeling	X	X		X		petrology
Mayfield and Schiffman, 1998	calculating	X			X		petrology
Vacher #25, 2003	calculating	X	X			X	petrology
Klasner, 1992	data manipulation	X	X	X	X	X	geophysics
Kruse, 1995	plotting, calculating	X	X	X	X		geophysics
Harbor and Keattch, 1995	modeling	X	X	X	X		geomorphology
Larrieu, 1995	modeling	X	X	X			sedimentology
Soreghan, 1999	plotting	X	X	X	X		sedimentology
Berger, 1997	modeling	X	X		X		oceanography
Shea, 1993	plotting	X	X	X	X	X	planetary geology
Vacher #22, 2002	calculating	X	X	X			planetary geology
Vacher #23, 2003	calculating	X	X	X			planetary geology
Nieto-Obregon, 2001	plotting	X		X	X		historical geology
Frey, 2003	calculating	X	X	X	X		environmental geology
Vacher #12, 2000	calculating	X	X	X			structural geology, hydrology
Vacher #14, 2001	calculating	X	X	X		X	structural geology, hydrology, geochemistry

between half-life and decay constant (Col C). Another key concept is how equilibrium abundances in the decay chain are set up by the balancing of inflows and outflows at each of the intermediate steps. This equilibrium produces the cell equations of Column D (the equations disregard the slight differences in atomic weights). A third is the concept of branching decay that occurs late in the decay series. The results (Col D of Figure 1B) provide a strong study in orders of magnitude.

All introductory geology books note the "most abundant elements" in the Earth's crust and in the Earth itself. Such rankings are *de rigeur* for upper undergraduate-level courses in geochemistry. As [5] points out, working through these spreadsheets adds not only a deeper sense of the crust's geochemical statistics, but also some surprises—for example, the disparity between the abundance rank by weight and abundance rank by number of atoms. In the process, the students get a lot of practice in unit conversions, scientific notation, spherical formulas (volume, surface area, shells), and hands-on work with density and Avogadro's number.

3.2 Example: Calculating the strike and dip of inclined strata by solving the three-point problem

Sedimentary strata are oftentimes spectacularly displayed as horizontal layers, as they are in the Grand Canyon, USA. In many places, however, they are not horizontal, but rather deformed into "geologic structures." Thus the orientation of strata varies from place to place, and, obviously, it is essential for geologists to be able to communicate the precise orientation of strata at any given location. To do this, geologists use two angular measures: strike and dip.

To understand strike and dip, imagine an inclined plane. The strike is the direction of a horizontal line embedded in the plane; the angle of choice is usually the azimuth (the angle [0° to 360°] measured positively clockwise from north, such that due west, for example, has an azimuth of 270°). The dip is the angle (0°–90°) measured downward from the horizontal as seen in the vertical plane perpendicular to strike. The dip angle needs to be coupled with a direction: for example, strata with a strike of 45° azimuth can have either a northwest or a southeast dip; in such cases, if the dip is 30° to the northwest, say, one can record the orientation as strike AZ 45° and dip 30° NW. Because strike refers to a line and not an arrow, a record of AZ 225° and dip 30° NW is the same orientation. Vertical strata have a dip of 90°.

Just as two points define a straight line, three non-collinear points define a plane. Strike and dip of a stratal surface (e.g., the top of a particular sandstone formation), therefore, can be determined by measuring the elevation of the surface at three known locations. Thus results a classic three-point problem of structural geology: What is the strike and dip of inclined strata given the elevation of an identified surface at three locations (approximating the surface as a plane)? This problem is a staple of structural geology courses (upper undergraduate). Generally, the problem is solved graphically as a laboratory exercise. Commonly, the data that are used are from wells: each point represents where a particular well intersects the formation, and the elevations are determined from depths below ground of the top of a particular formation.

	A	B	C	D
1	U-238 SERIES			
2	NUCLIDE	HALF LIFE (yrs)	D.CONST	AMOUNT (ppm)
3	U-238	4468000000	1.55103E-10	3.60E+19
4	TH-234	0.065982204	10.50283195	**=D3*C3/C4**
5	PA-234	2.23401E-06	310204.4936	**=D4*C4/C5**
6	U-234	245000	2.82857E-06	**=D5*C5/C6**
7	TH-230	80500	8.6087E-06	**=D6*C6/C7**
8	RA-226	1622	0.00042725	**=D7*C7/C8**
9	RN-222	0.010468172	66.20066693	**=D8*C8/C9**
10	PO-218	5.79892E-06	119505.0098	**=D9*C9/C10**
11	PB-214	5.09544E-05	13600.38358	**=D10*C10/C11**
12	BI-214	3.74553E-05	18502.04467	**=D11*C11/C12**
13	PO-214	5.19685E-12	1.3335E+11	**=D12*C12/C13**
14	PB-210	22.3	0.031076233	**=D13*C13/C14**
15	BI-210	0.013716632	50.52260479	**=D14*C14/C15**
16	PO-210	0.378863792	1.829153418	**=D15*C15/C16**
17	PB-206	STABLE		
18	BRANCH DECAYS			
19	AT-218	6.34E-08	**=0.693/B19**	**=0.0002*D10*C10/C19**

	A	B	C	D
1	U-238 SERIES			
2	NUCLIDE	HALF LIFE (yrs)	D.CONST	AMOUNT (ppm)
3	U-238	4468000000	1.55103E-10	3.60E+09
4	TH-234	0.065982204	10.50283195	**5.32E-02**
5	PA-234	2.23401E-06	310204.4936	**1.80E-06**
6	U-234	245000	2.82857E-06	**1.97E+05**
7	TH-230	80500	8.6087E-06	**6.49E+04**
8	RA-226	1622	0.00042725	**1.31E+03**
9	RN-222	0.010468172	66.20066693	**8.43E-03**
10	PO-218	5.79892E-06	119505.0098	**4.67E-06**
11	PB-214	5.09544E-05	13600.38358	**4.11E-05**
12	BI-214	3.74553E-05	18502.04467	**3.02E-05**
13	PO-214	5.19685E-12	1.3335E+11	**4.19E-12**
14	PB-210	22.3	0.031076233	**1.80E+01**
15	BI-210	0.013716632	50.52260479	**1.11E-02**
16	PO-210	0.378863792	1.829153418	**3.05E-01**
17	PB-206	STABLE		
18	BRANCH DECAYS			
19	AT-218	6.34E-08	**1.09E+07**	**1.02E-11**

Figure 1: Spreadsheet used to calculate crustal abundances of U-238 decay series. A: Spreadsheet with formulas. B: Results of calculations using the equation spreadsheet above. (Adapted from [5], Figs. 7 and 8.)

The three-point problem of geology is analogous to the problem in calculus of finding the equation of a plane given the x, y, z coordinates of three points on it. The spreadsheet of Figure 2 [26] shows one of the ways of solving the problem. The objective is to find the equation of the plane

$$ax + by + cz + d = 0 \tag{1}$$

passing through the points (x_A, y_A, z_A), (x_B, y_B, z_B), and (x_C, y_C, z_C), which are laid out in Block `B5:D7`. The spreadsheet finds the coefficients (a, b, c, d) from determinants composed of the coordinates of the points and columns of 1's as shown in Rows 10-24. It continues with the intercept z_0 and slopes $m_x = \partial z/\partial x$, $m_y = \partial z/\partial y$ of the plane (Rows 27-29), and then the strike and dip (Rows 31-32). A logic formula (Cell `B33`) operating on the signs of the partial derivatives provides the discrimination of the direction of dip.

This article on the three-point problem [26] is one of a series, Computational Geology, that the second author writes, which appears as a column in the *JGE*. As stated in the initial column ([25, p292]), "the intent ... is to promote the use of mathematics in the undergraduate geology curriculum.... (Each) column will be a discussion of some mathematical issue in a geologic setting. It is hoped that these discussions will be a helpful resource from which (geoscience educators) can draw collateral reading material for students in classes in which mathematics is used." The spreadsheet of Figure 2 was the first spreadsheet to appear in the Computational Geology columns. Spreadsheets are common in the columns now because they have proved to be such an effective way of communicating the mathematics of geological-mathematical problem solving.

3.3 Example: Modeling the shape of glaciated valleys

U-shaped valleys are a characteristic feature of glaciated mountains. We doubt that there is an introductory geology textbook anywhere that does not include one or more striking photographs of U-shaped valleys set amongst the rugged, rocky peaks and ridges of Alpine mountains. The geologic story of U-shaped valleys is that former V-shaped, river-cut valleys were deepened into U's by the huge erosion beneath now-vanished glaciers. Students see before glaciation and after glaciation block diagrams and, in laboratory exercises, learn by drawing cross-profiles from maps to recognize the patterns of topographic contours that typify glaciated-mountain terrain. Harbor and Keattch [11] take the experience further by having the students use a spreadsheet calculation to model the deepening of a glacial valley beneath a present-day glacier.

The glacier for the study is the Athabasca Glacier in Alberta. The authors give the students enough information to calculate the present-day rate of downcutting ($2\,\mathrm{mm\,y^{-1}}$, from a sediment discharge of $24,000\,\mathrm{m^3\,y^{-1}}$, and an area of $12\,\mathrm{km^2}$). They also give the students a cross-section showing contours of the glacial velocities (Figure 3), noting that they intersect the base of the glacier and hence there are basal velocities which vary along the cross-section. Then, the problem is: Where is the base of the glacier after 100,000 years of continued erosion?

The students examine three hypotheses for the glacial scouring:

1. The erosion rate is constant across the width of the valley.

	A	B	C	D	E	F
1						
2						
3						
4		x	y	z		
5	A	400	1200	3400		
6	B	1000	200	2700		
7	C	2200	900	2400		
8						
9						
10		=C5	=D5	1		
11	a =	=C6	=D6	1	=	Eq. 1
12		=C7	=D7	1		
13						
14		=B5	=D5	1		
15	b = -	=B6	=D6	1	=	Eq. 2
16		=B7	=D7	1		
17						
18		=B5	=C5	1		
19	c =	=B6	=C6	1	=	Eq. 3
20		=B7	=C7	1		
21						
22		=B5	=C5	=D5		
23	d = -	=B6	=C6	=D6	=	Eq. 4
24		=B7	=C7	=D7		
25						
26						
27	z0	=-F23/F19				
28	mx	=-F11/F19				
29	my	=-F15/F19				
30						
31	strike	Eq. 5				
32	dip	Eq. 6				
33		Eq. 7				
34						
35						

	A	B	C	D	E	F
1						
2						
3						
4		x	y	z		
5	A	400	1200	3400		
6	B	1000	200	2700		
7	C	2200	900	2400		
8						
9						
10		1200	3400	1		
11	a =	200	2700	1	=	7.9E+5
12		900	2400	1		
13						
14		400	3400	1		
15	b = -	1000	2700	1	=	-6.6E+5
16		2200	2400	1		
17						
18		400	1200	1		
19	c =	1000	200	1	=	1.62E+6
20		2200	900	1		
21						
22		400	1200	3400		
23	d = -	1000	200	2700	=	-5.032E+8
24		2200	900	2400		
25						
26						
27		z0	3106.173			
28		mx	-0.48765			
29		my	0.407407			
30						
31	strike	39.9				
32	dip	32.4				
33		se				
34						
35						

```
Equation 1 = MDETERM(B10:D12)
Equation 2 = -MDETERM(B14:D16)
Equation 3 = MDETERM(B18:D20)
Equation 4 = -MDETERM(B22:D24)
Equation 5 = DEGREES(ATAN(-F15/F11))
Equation 6 = DEGREES(ATAN(sqrt((F11^2+F15^2)/F19^2))))
Equation 7= IF(AND(D28>0,D29>0),"sw", IF(AND(D28>0,D29<0),"nw",
   IF(AND(D28<0,D29>0),"se", IF(AND(D28<0,D29<0),"ne", "on an axis"))))
```

Figure 2: Spreadsheet to solve the three-point problem. A: Equation spreadsheet. Cell equations for `F11`, `F15`, `F19`, F23 and `B33` are given in the box below the spreadsheets. B: Results of calculations performed using the equation spreadsheet. (Adapted from [26], Fig. 11.)

2. The erosion rate is directly proportional to ice thickness at each point along the cross-section.

3. The erosion rate varies with the square of ice velocity at each point along the cross-section.

The students divide the cross-section into twenty-two, 67 m wide vertical segments. For the first hypothesis, they simply deepen the valley by a uniform 200 m at each segment. For the second and third hypotheses they do a numerical calculation, for which the authors recommend a spreadsheet (Figure 4). The students enter Columns `B` and `E` after reading the basal velocities and measuring the thicknesses, respectively, from the velocity cross-section. They square the basal velocities (Col `C`) and sum the basal velocities and depths (Cells `C23` and `E23`). Next, they evaluate the constants A and B of the hypothesized erosion rates:

$$\text{hypothesis 2}: \qquad E = AU^2 \tag{2}$$

$$\text{hypothesis 3}: \qquad E = Bd \tag{3}$$

where E is erosion rate ($\mathrm{m\,y^{-1}}$), U is basal velocity ($\mathrm{m\,y^{-1}}$), d is ice thickness, A is in $\mathrm{y\,m^{-1}}$ and B is unitless. This evaluation is possible because the students know the average erosion rate. Thus

$$A = \frac{W_t E_{ave}}{\sum_i W_i U_i^2} \tag{4}$$

$$B = \frac{W_t E_{ave}}{\sum_i W_i d_i} \tag{5}$$

where W_i and W_t refer to the width of a segment and the total width, respectively. The results are $2.1 \times 10^{-6}\,\mathrm{y\,m^{-1}}$ and 9.5×10^{-6} respectively, which the students use in Columns `D` and `F` to calculate the new depths of the base of the glacier at each section location after 100,000 years of erosion. These new depths are shown in Figure 3. The students complete the assignment by making an educated guess for the location of the top of the ice.

Harbor and Keattch [11] use this problem in an upper undergraduate geomorphology course that includes geology, geography, conservation, and education majors. According to Harbor and Keattch ([11, p533]):

> The lab exercise ... provides an approachable introduction to ideas of form-development modeling for undergraduates. In combination with traditional tasks (landform recognition and morphometry) it gives students a more balanced idea of glacial geomorphology, and a stronger foundation for understanding advanced work in the discipline. The student gets experience dealing with alternative process models (erosion laws), dividing continuous

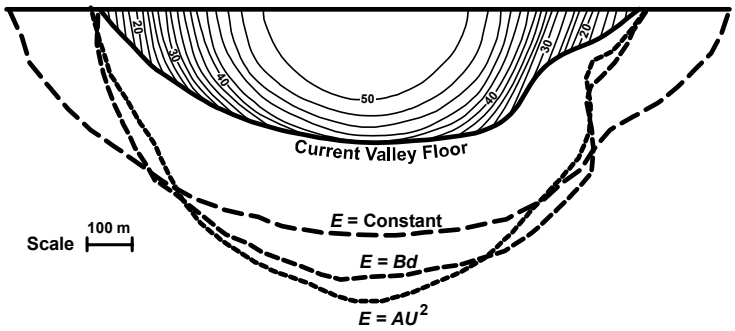

Figure 3: Velocity profile and new cross-sectional valley shapes calculated using each of the three erosion laws. The thick solid line is the original valley form. The thinner lines are velocity contours, labeled in meters per year. (Adapted from [11], Fig. 2.)

distributions into small segments for solution (the basis of many numerical-modeling approaches), and back-calculating constants in an equation (equation calibration). In discussing the limitations of the approach used in the exercise, students begin to think about the dangers of long-timescale extrapolation in systems with feedbacks between process and form, and the limitations of a form-development model that deals only with one geomorphic process (there are no side-slope processes included).

3.4 Example: Modeling groundwater flow by solving Laplace's equation on a grid

The water table is the top of the "zone of saturation". Drill a well, and you encounter groundwater at the water table. Geologists and environmental scientists want to make maps of the water table for another reason besides the fact that it shows the depth where one encounters water-saturated rocks or soil: the map of the water table shows the direction and quantity of groundwater flow. The slope of the water table is an indication of the force driving groundwater flow. The water table is the potentiometric surface for the groundwater of shallow (unconfined) aquifers.

Potentiometric surfaces of deeper (confined) aquifers are not congruent to the water table (or each other), indicating that there is a potential drive for water to cross the low-permeability layers that separate the aquifers. Despite these complications, one can say that the "level" that water stands in wells open to a single aquifer (i.e., its potentiometric surface) is a measure of the hydraulic potential at that point. We use "level" in quotes here, because it is not a horizontal surface, and that's the point. The potentiometric surface varies in elevation from place to place, and the groundwater flows accordingly.

	A	B	C	D	E	F
1	Section	U	U^2	10^5AU^2	d	10^5Bd
2	1	12	144	30	27	26
3	2	16	256	54	80	77
4	3	20	400	84	121	115
5	4	24	576	121	168	160
6	5	27	729	153	208	198
7	6	31	961	202	235	224
8	7	35	1225	257	255	243
9	8	37	1369	287	281	269
10	9	39	1521	319	302	288
11	10	40	1600	336	308	294
12	11	41	1681	353	322	307
13	12	42	1764	370	322	307
14	13	41	1681	353	322	307
15	14	39	1521	319	315	301
16	15	37	1369	287	302	288
17	16	33	1089	229	281	269
18	17	30	900	189	241	230
19	18	29	841	177	188	179
20	19	25	625	131	134	128
21	20	18	324	68	101	96
22	21	14	196	41	74	70
23	22	10	100	21	27	26
24	23	Sum	**21000**	Sum	**4614**	

Figure 4: Data and results for estimating erosion at each segment of the cross section using the velocity and ice-depth-based erosion laws. Segments are a uniform length (67 m) and are ordered starting with the lowest number segment on the left-hand side of the section shown in Figure 3. The variables A and B are calculated from the sums of U^2 and d, respectively. (Adapted from [11], Table 1.)

The key relationship is Darcy's Law (eq 6).

$$\mathbf{q} = -\frac{k\rho g}{\mu}\nabla h \tag{6}$$

In eq (6), $\mathbf{q}$ is the specific discharge (volume rate of flow per unit cross section; proportional to velocity); k is permeability (inverse of resistance) of the porous medium; ρ and μ are density and viscosity, respectively, of the groundwater; g is acceleration due to gravity; and ∇h is the hydraulic gradient, where h is the hydraulic head, the elevation that water rises to in a well at the point in question (gh is the force potential). For many map-view flow situations, Darcy's Law in combination with the continuity equation (conservation of mass) produces the well-known *Laplace Equation* (7).

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = 0 \tag{7}$$

Thus, the equation applies to steady-state flow in a confined aquifer, or in an unconfined aquifer in which the variation in h is small relative to the thickness of the aquifer, and where, in each case, the aquifer does not receive or lose flows from above or below (recharge in the case of an unconfined aquifer; so-called leakage in the case of a confined aquifer). For cases involving recharge or leakage, the right-hand size is not zero, but rather a function of recharge (or leakage), aquifer thickness, and $k\rho g/\mu$ – in other words, the equation is the *Poisson Equation*. For cases where the unconfined aquifer is not very thick relative to the variation in h, the problem is more complicated, and, among other things, the Laplace and Poisson equations need to be written in terms of h^2 rather than h. Further, it is also assumed that the porous medium is both homogeneous (same k from place to place) and isotropic (no directional properties for k), or otherwise the left-hand side would be more complicated.

In one of the very first papers mentioning spreadsheets in the *Journal of Geoscience Education*, Ousey [17] discusses how they can be used to calculate the elevation of the potentiometric surface on a grid. He discusses steady-state flow in homogeneous, isotropic, confined and unconfined aquifers, using both the Laplace and Poisson equation, but concentrates mainly on the Laplace equation and confined flow. He discusses both specified-head and no-flow boundaries.

The first of five, progressively more complicated (and hence more interesting) examples is a simple 7×7 grid with outer cells having a specified head (10.00 m) (Figure 5). The innermost cell is designated as a well that is being pumped so that its water level remains constant at 5.00 m. The assignment is to calculate the head in all of the blank cells and then to contour the heads and draw flow lines (which are perpendicular to h–contours in isotropic media).

Students solve this problem by inputting the finite-difference version of the Laplace equation into each cell and iterating until the values converge. The finite-difference Laplace equation for a square cell is

$$h_0 = \frac{h_1 + h_2 + h_3 + h_4}{4} \tag{8}$$

In eq (8), h_0 is h at the cell in question, and h_1, h_2, h_3, and h_4 are the heads at the cells to the left, to the right, directly below, and directly above, respectively. In other words, the cell equation for the Laplace equation on a square grid says that the value at each cell must be the average of the four adjacent cells. Figure 6A shows the layout of the spreadsheet, using $R + L + U + D$ as a shorthand for "right + left + up + down" to represent the relative-address references in the cells. Figure 6B shows the solution, which is obtained with but a few iterations. To complete the problem, the students must reshape the rectangular grid into a square grid to draw a flow net using the fact that flow lines are perpendicular to h–contours in isotropic media. The result is a symmetric cone of depression showing water flowing from the canals at the boundary to the fixed-head well at the center of the square.

Ousey [17] reports using spreadsheet modeling such as this in his introductory physical geology and environmental geology courses. He says ([17, p305]):

> The knowledge required is simple enough to enable beginning students to electronically manipulate pumping wells to "see" phenomena like the development of a cone of depression, mutual interference of adjacent wells, or the effect of regional groundwater flow on the shape of a cone of depression.... Many students are enthusiastic enough about the exercises to continue past the scheduled laboratory class time in the campus microcomputer room.

At the other end of the geology curriculum, the second author of this paper uses spreadsheet exercises for steady-state Laplace and Poisson solutions in his course, "Physical Principles of Groundwater Flow." That course is the first of a three-course, graduate-level sequence in physical hydrogeology in the Geology Department of USF. He likes to tell the students that several of their exercises, in which the Laplace equation is solved for flow in cross-sectional views, are identical to those in Allan Freeze's PhD dissertation [6], [7]. That work was a monumental breakthrough at the time, requiring mainframe computer capabilities and very efficient program coding (back in the days of decks of computer cards and overnight waits for results). Now, with spreadsheets, students can solve such problems in an instant at their desktops or on their laptops. In the process, they get incomparable insight to flow patterns and how those flow patterns are affected by various parameters and boundary conditions. The students also get excruciating practice in contouring, because computer-contouring packages are not allowed in the course. The purpose of the course, including the hand-contouring, is for students to grapple with the fundamentals before setting foot into the land of off-the-shelf groundwaterflow packages.

Regarding off-the-shelf groundwater-modeling packages, the paper by Ousey [17] can be usefully considered as one of a pair of companion pieces on the subject. Ousey [17] is the education-oriented piece. The other is an appropriately technical paper [16] in a journal for groundwater professionals. The theme of that paper – and this theme was seconded by Ousey [17] – is that spreadsheet programs are sufficiently powerful and intuitive that one can build and run a (2D) model, so long as it is not too complex, in just a couple of minutes. Paraphrasing Olsthoorn ([16, p381]):

"I will show you how any hydrologist can build groundwater models using the same piece of general software that one may use to do the bookkeeping for the golf club."

	A	B	C	D	E	F	G
1	10.00	10.00	10.00	10.00	10.00	10.00	10.00
2	10.00						10.00
3	10.00						10.00
4	10.00			5.00			10.00
5	10.00						10.00
6	10.00						10.00
7	10.00	10.00	10.00	10.00	10.00	10.00	10.00

Figure 5: Water-table map showing external and internal boundary conditions for a simple groundwater-flow problem. Groundwater will flow from higher to lower head, so groundwater will flow toward the center cell, toward the hypothetical well. Each cell represents a square area of land.

3.5 Astronomically speaking, where are we?

Jim Shea, for 25 years the Editor of the *JGE*, pushed hard for rigor in the geology curriculum. A favorite theme was that quantitative skills were not sufficiently emphasized. In this regard, his article [20] calling attention to the diminishing number of equations and other signs of mathematics in introductory geology textbooks is a classic.

His paper on the size of the Milky Way [21] presents one of many exercises he developed that were, he says (p. 490), "designed to encourage students in my introductory earth-science class to become more active and involved in their own learning rather than simply being told what is true and good." Continuing, he says that the exercise illustrates his intention to develop exercises that are "related to some fundamental advance in earth science that is important to the development of our modern view of the earth and its place in the grand scheme of things."

The exercise, which is included in [21] as a two-page handout for students, gives the x, y, z Earth-origin coordinates of 77 globular clusters in the Milky Way. Globular clusters are spherical collections of as many as a million stars, and were used by Harlow

	A	B	C	D	E	F	G
1	10.00	10.00	10.00	10.00	10.00	10.00	10.00
2	10.00	=(R+L+U+D)/4	=(R+L+U+D)/4	=(R+L+U+D)/4	=(R+L+U+D)/4	=(R+L+U+D)/4	10.00
3	10.00	=(R+L+U+D)/4	=(R+L+U+D)/4	=(R+L+U+D)/4	=(R+L+U+D)/4	=(R+L+U+D)/4	10.00
4	10.00	=(R+L+U+D)/4	=(R+L+U+D)/4	5.00	=(R+L+U+D)/4	=(R+L+U+D)/4	10.00
5	10.00	=(R+L+U+D)/4	=(R+L+U+D)/4	=(R+L+U+D)/4	=(R+L+U+D)/4	=(R+L+U+D)/4	10.00
6	10.00	=(R+L+U+D)/4	=(R+L+U+D)/4	=(R+L+U+D)/4	=(R+L+U+D)/4	=(R+L+U+D)/4	10.00
7	10.00	10.00	10.00	10.00	10.00	10.00	10.00

	A	B	C	D	E	F	G
1	10.00	10.00	10.00	10.00	10.00	10.00	10.00
2	10.00	**9.67**	**9.35**	**9.13**	**9.35**	**9.67**	10.00
3	10.00	**9.35**	**8.59**	**7.83**	**8.59**	**9.35**	10.00
4	10.00	**9.13**	**7.83**	5.00	**7.83**	**9.13**	10.00
5	10.00	**9.35**	**8.59**	**7.83**	**8.59**	**9.35**	10.00
6	10.00	**9.67**	**9.35**	**9.13**	**9.35**	**9.67**	10.00
7	10.00	10.00	10.00	10.00	10.00	10.00	10.00

Figure 6: Spreadsheet solution to the Laplace Equation. A: Equation spreadsheet. (R+L+U+D) is a shorthand referring to relative cell references. In cell B2, for instance, the complete equation is =(C2+A2+B1+B3)/4. B: Values resulting from calculating the equation spreadsheet. (Adapted from [17], Figs. 1 and 2.)

Shapley in the early 1900s as a means of determining the size of the Milky Way galaxy and our position in it. The main part of [21] is background information about the exercise, including a recount of the history and a table giving the celestial coordinates (right ascension and declination), luminosity, brightness, and distance of the 77 clusters. He also includes the equations by which we (or our students) can calculate the distance from the luminosity and brightness, and the x, y, z coordinates from the distance, right ascension and declination of the 77 clusters.

The exercise asks the students to plot the 77 globular clusters on xy, xz, and yz, scatter plots (Figure 7). It also asks the students to calculate the x, y, z coordinates of the center of the clusters (i.e., the center of our galaxy), the distance across the long dimension of the galaxy, and our distance from the center of the galaxy.

4 Discussion and conclusion

The Curriculum Renewal Across the First Two Years (CRAFTY) subcommittee of the Committee on the Undergraduate Program in Mathematics (CUPM) of the Mathematics Association of America (MAA) organized a series of workshops to gather input from faculty in non-mathematics disciplines on the needs in these disciplines for early-university mathematics education. The series included separate, discipline-based workshops with faculty from a wide range of fields including biology, business and management, chemistry, physics, four different kinds of engineering, health-related life sciences, and several others, although strangely not including earth science.

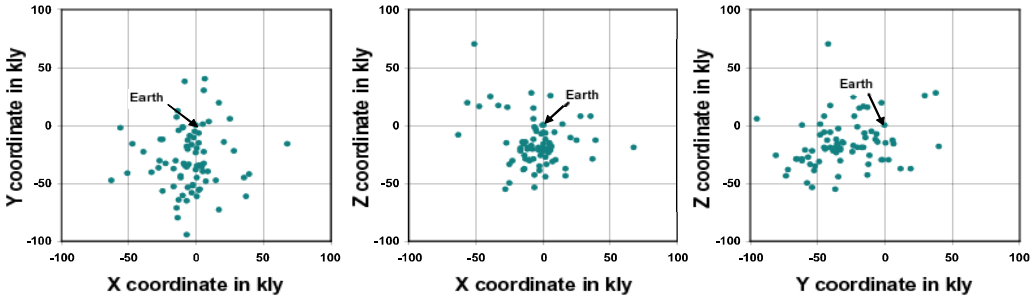

Figure 7: Plots of the Milky Way globular clusters in the xy, xz, and yz planes. Earth is at point $(0, 0, 0)$, but not at the center of the Milky Way. Coordinates are given in kilolightyears (kly). (Adapted from [21], Figs. 1, 2, and 3.)

The workshops produced a wealth of information in individual reports which the organizers have put together in an extraordinarily interesting volume [9]. Appropriately, the editors titled their introduction "A Collective Vision: Voices of the Partner Disciplines." Among the many nuggets in this introduction, one in particular will resonate with readers of this journal: "Emphasize the use of appropriate technology." Under that heading, there is the following ([9, p7]):

> A ... surprising statement from workshop participants was that spreadsheets are the technology of choice for a large number of partner disciplines. Although individual workshop reports stopped short of recommending spreadsheets as the primary technology in mathematics instruction, their widespread use is relevant to the technology choices made in mathematics courses that primarily serve other disciplines.

In the next paragraph, the editors went on to report the related finding: graphing calculators were not important to the educators in the partner disciplines. According to them ([9, p7]), "if calculators are chosen as the technology for a mathematics course, it must be understood that this is done for pedagogical reasons, not to support uses in other disciplines."

From our review of the *Journal of Geoscience Education*, we can definitely assert that the same is true in earth science education. As we have said, we found 38 articles specifically at least noting the use of spreadsheets. We don't recall any mention of graphing calculators. There was a handful of references to STELLA, and even fewer to MATLAB, Mathematica and the like.

It will be no surprise to readers of eJSiE that geoscience educators (and educators in other partner disciplines) have gravitated to spreadsheets. The virtues of using spreadsheets as teaching tools are forcefully presented by [1] in the kickoff issue. These virtues are resoundingly illustrated by the collection of articles from the *JGE*. In particular, after reviewing these articles, we note:

- Spreadsheets allow educators to move away from instructivist teaching: they "promote more open-ended investigations, problem-oriented activities, and active learning by students" ([1, p21, quoting [2]]).
- Spreadsheets "provide insights into the ... context without necessitating attention to extraneous distractions" ([1, p20, quoting [18]]).
- Spreadsheets, or more accurately, *the building of spreadsheets*, promotes abstract reasoning by the learner ([1, p21]).
- Spreadsheets "are interactive; they give immediate feedback to changing data or formulae; they enable data, formulae and graphical output to be available on the screen at once; they give students a large measure of control and ownership over their learning" ([1, p22, quoting [3]]).
- Spreadsheets save time. "The time gained can then be spent on investigating ... the so-called *what-if* scenarios. There is huge scope for investigation of dependence on parameters in almost any spreadsheet model...." ([1, p24]).

All these points argue, of course, that geoscience education has been, and will continue to be, well served by incorporating spreadsheets across the geoscience curriculum. But there is a flipside as well. Spreadsheets in geoscience education can facilitate mathematics education.

Many mathematics educators are advocating for mathematics in context. "Connections" is a benchmark process standard of the NCTM *Principles and Standards for School Mathematics*. The surging interest in Quantitative Literacy [20], [22], [23] is leading to efforts to promote mathematics across the curriculum [19], to break down disciplinary boundaries, and to form partnerships, even "conspiracies", between mathematics and nonmathematics educators [12]. It was with good reason that the CUPM of the MAA characterized their investigatory workshops as "Voices of the Partner Disciplines."

We are biased, of course, but we are happy to argue that earth and space science offers hugely interesting context. As illustrated by these 38 papers, the range is tremendous. If mathematics educators are looking for examples, case histories, and ideas to adapt to their own uses, then check out the articles in the following annotated bibliography and watch for more as the *JGE* continues to publish spreadsheets in geoscience education.

5 Annotated Bibliography of Spreadsheets in the *Journal of Geoscience Education* (*JGE*) through 2003

1. Andersen, C. B. (2002). Understanding carbonate equilibria by measuring alkalinity in experimental and natural systems. *JGE* **50**: 389–403.

   A classroom exercise involving the examination of Bjerrum curves helps to introduce the concept of carbonate equilibria. Spreadsheets enable students to construct a Bjerrum plot and theoretical titration curve and graph the gran function. In the

suggested exercise, students must derive equations for the plots, construct titration curves and compare them with the Bjerrum plot.

2. Bair, E. S. (2000). Developing analytical and communication skills in a mock-trial course based on the famous Woburn, Massachusetts case. *JGE* **48**: 450–454.

   Student involvement in a mock trial in an undergraduate geology course includes analyzing photographs, well logs, streamflow records, permeability tests, and water-level and water-quality data and presenting a case for or against the contamination of groundwater by corporations in Woburn, Massachusetts. The paper suggests using spreadsheets to compute flood intervals. It shows the spreadsheet but does not discuss it in detail.

3. Berger, W. H. (1997). Experimenting with Ice-Age cycles in a spreadsheet. *JGE* **45**: 428–439.

   The construction of a "Milankovitch Machine," which models the development of ice ages, allows students to explore the fundamentals of Milankovitch theory and consider major questions concerning climate change. Spreadsheet equations elaborate a set of four rules that produce a relatively accurate version of the ice record. Students can plot a sea-level index curve from the results of this spreadsheet and then, by changing the parameters in the spreadsheet, model the change in nature of the ice-age cycles at about 900,000 years ago. The paper includes an extensive background discussion for this in-depth exercise.

4. Biddle, D. L. (1995). Ion activity and speciation in environmental geochemistry. *JGE* **43**: 507–510.

   An exercise involving the titration of alkalinity includes a spreadsheet that calculates the ionic concentrations and activities in a solution containing calcium and sulfate. The description of the exercise focuses on the mathematical basis of the calculations and does not describe the titration methods. The paper includes an example spreadsheet and gives the cell equations.

5. Clapp, E. M., Bierman, P. R., Church, A. B., Larsen, P. L., Schuck, R. A., and Hanzas, Jr., P. H. (1996). Teaching geohydrology through analysis of ground-water resources and glacial geology in northwestern Vermont. *JGE* **44**: 45–52.

   An undergraduate hydrogeology class participated in a study of contamination in confined glacial aquifers. Students entered location data to spreadsheet software and exported them to contouring and cross-section packages.

6. Dilek, Y., Thomas, R. C., and Whitney, D. L. (1994). Team-teaching petrology in a tec tonic context. *JGE* **42**: 25–31.

   An upper-level petrology course may combine traditional hand-sample and thin-section techniques with computer modeling and graphical analysis to allow students to examine crustal processes in a tectonic setting. The article mentions the use of spread sheets to create various plots. It does not show or discuss the spreadsheets.

7. Drake, J. C., Worley, I. A., and Mehrtens, C. J. (1997). An introductory-level field-based course in geology and botany. *JGE* **45**: 234–237.

   Students in an usual interdisciplinary course in geology and ecology use spread sheets to keep and analyze tree data, construct channel cross sections and calculate dis charge. The article does not show the spreadsheet nor discuss it in depth.

8. Dunivant, F. M., Newman, M. E., Brzenk, R., Moore, A., and Alfano, M. J. (1999). A comprehensive stream study designed for an undergraduate non-majors course in earth science. *JGE* **47**: 158–165.

   This interdisciplinary stream study incorporates a field task, a period of analysis, and an integrated summary. The paper suggests using a spreadsheet to manage the data and calculate the stream discharge and shows an example. It does not discuss the spreadsheet.

9. Dutch, S. I. (1991). Geochemical calculations using spreadsheets. *JGE* **39**: 127–132.

   Spreadsheets are effective in creating modules for calculating elemental abundances, equilibrium abundances in nuclear decay chains, and isochrons. The paper gives a de tailed description of the construction of spreadsheets to perform these calculations in Lotus 1-2-3. It includes tables of formulas and values for students to use spreadsheets to calculate the mass and volume of the layers of the earth; atomic volumes in the earth's crust; U-238 decay series abundances; and isochron ages.

10. Ettensohn, F. R. (1997). An experiment in collaborative mapping at geology field camp. *JGE* **45**: 229–234.

    An alternative field camp exercise involving a mock contracting company enhances the field camp experience by setting up a business-like framework in which mapping assignments are carried out. The paper mentions using spreadsheets but does not discuss them.

11. Foos, A. M. (1997). Integration of a class research project into a traditional geochemistry lab course. *JGE* **45**: 322–325.

    A semesterlong class research project on aqueous geochemistry can be used to illustrate specific topics and provide students with research experience. The project includes a field segment, analysis of collected samples, examination of data quality, and presentation of results. The paper suggests using spreadsheets for data manipulation; it does not discuss them in detail.

12. Frey, S. T., Moomaw, W. R., Halstead, J. A., Robinson, C. W., Marsella, K. A., Thomas, J. J. (2003). Home energy conservation exercise. *JGE* **51**: 521–526.

    This article describes an exercise in which students calculate and modify the heat loss for a simulated house using the insulating capacities of various additions to

the house, such as weather stripping and storm doors. The authors suggest the use of a spreadsheet to work the problem and give the necessary equations.

13. Harbor, J. M. and Keattch, S. E. (1995). An undergraduate laboratory exercise introducing form-development modeling in glacial geomorphology. *JGE* **43**: 529–533.

    A cross-sectional model of ice flow and valley profile development in the Athabasca Glacier serves both as an introduction to spreadsheet modeling and an interactive teaching tool for examining the effects of flow and valley shape on erosion rates in glacial valleys. Students construct a model along the glacial valley cross-profile, calculate erosion rates using information from a velocity contour cross-section, and generate a new valley cross-profile from the total erosion after 100,000 years. The use of spreadsheets allows students easily to test the effects of three alternative equations governing erosion.

14. Holm, P. E. (1988). Triangular plots and spreadsheet software. *JGE* **36**: 157–159.

    One can create triangular plots with spreadsheet graphing functions if the concentrations of the three components are converted to (x, y) coordinates. This article shows how to make the transformation, and how to construct the triangle and field boundaries and label the chart.

15. Klasner, J. S., Crockett, J. J., and Horton, K. B. (1992). Hands-on teaching through a student field project in applied geophysics. *JGE* **40**: 53–61.

    Students in an undergraduate geophysics class must complete a field project incorporating magnetic, gravity, and radiometric studies. The article recommends entering geophysical readings into spreadsheets for data reduction but does not show or discuss them.

16. Kruse, S. E. (1995). Using cooperative-learning methods to teach quantitative material in an undergraduate geophysics course. *JGE* **43**: 357–360.

    Group projects and discussions draw students into quantitative discourse and analysis in an undergraduate geophysics course. The paper notes the use of spreadsheets but does not elaborate.

17. Larrieu, T. L. (1995). Basin analysis with a spreadsheet. *JGE* **43**: 107–113.

    "Backstripping analysis", the quantitative analysis of basin subsidence rates through time, makes an instructive exercise when performed with a spreadsheet equation solver. Newton's method approximates the solution to the "decompaction equation". The article shows how to organize the spreadsheet, interpret the results, and attribute compaction to one of several different subsidence mechanisms.

18. Malisetty, M. R. (1992). Use of a spreadsheet in teaching the CIPW norm. *JGE* **40**: 237–240.

Students can use the spreadsheet program described in this article to calculate the "probable mineralogy" of an igneous rock from its chemical composition: they enter the weight percentages of 11 oxides and obtain the normative percentages of 16 minerals. Performing these calculations in a spreadsheet requires that a simplified version of the traditional equations be used. The article does not include the equations or instructions for building the spreadsheet; instead, the author invites readers to request a copy of the spreadsheet.

19. Manche, E. P., and Lakatos, S. (1986). Obsidian dating in the undergraduate curriculum. *JGE* **34**: 32–36.

    The thickness of alteration rims in thin sections of obsidian samples depends upon hydration rate and age of the rock. This article describes an undergraduate laboratory exercise, includes an account of the hydration process, and shows an example spreadsheet used for calculations.

20. Martin, B. S. (1993). Interactive modelling of open magma systems with spreadsheets. *JGE* **41**: 164–169.

    Three alternative petrogenetic models describe the interaction of fractionation, assimilation, recharge, and eruption during plutonism. Students can use a spreadsheet to calculate and graph an example geochemical suite based on each model. The paper describes the equations governing the model and shows an example table of values.

21. Mayfield, J. D., and Schiffman, P. (1998). Measuring the density of porous volcanic rocks in the field using a saran coating. *JGE* **46**: 460–464.

    Calculating the density of a tuff in this introductory-level field exercise involves weighing the rock samples and coating them with plastic before immersing them in water to find the volume. The paper includes but does not discuss the spreadsheet used for calculations.

22. Nieto-Obregon, J. (2001). Geologic timescales, maps, and the chronoscalimeter. *JGE* **49**: 25–29.

    A chronoscalimeter is a circular graph which compares any span of time to a 24-hour interval. One can construct a chronoscalimeter with a spreadsheet program by entering labels and time spans into the spreadsheet and using a "ring" graph. Instructions include a sample spreadsheet and the resulting graph.

23. Ousey, Jr., J. R. (1986). Modeling steady-state groundwater flow using microcomputer spreadsheets. *JGE* **34**: 305–311.

    Spreadsheet cells form a finite-difference grid to calculate water levels in a well drawdown exercise. Examples demonstrate the broad application of this technique. The examples include horizontal confined aquifers; horizontal unconfined aquifers; an unconfined, inclined aquifer with a plume of contamination; and a cross-sectional regional groundwater model. The paper addresses the choice of

boundary conditions and gives the basic expressions used in the spreadsheets (verbally; not in equations).

24. Panno, S. V., Hackley, K. C., and Nuzzo, V. A. (1998). Teaching multidisciplinary environmental science in a wetland setting. *JGE* **46**: 157–163.

    This paper mentions the use of spreadsheets to process and manage data in an inter-disciplinary environmental field course. It does not discuss the spreadsheets in depth.

25. Roberts, S. J. (2000). Using a spreadsheet to introduce aqueous-speciation calculations to geochemistry students. *JGE* **48**: 203–208.

    Developing a spreadsheet to calculate the distribution of aqueous species helps students understand equilibrium constants and the concept of speciation. The calculation uses an iterative technique wherein the concentrations of all species containing a particular element are calculated and recalculated until the concentrations of the element converge and mass-balance equations are satisfied. This paper describes the algorithm used to construct the spreadsheet and gives the theoretical background, a version of the spreadsheet showing calculated values, and a version with equations.

26. Rose, S. E. (1997). A spreadsheet approach to the hydrologic cycle. *JGE* **45**: 369–372.

    Building a spreadsheet solution to a hydrological cycle flow chart requires that students convert hydrologic cycle processes from a schematic diagram to a tabular format. Given a flowchart with flux percentages and a starting precipitation, students create a spreadsheet to calculate the runoff due to baseflow, interflow, and overland flow. Adjusting the evapotranspiration imitates the effects of global climate change. The paper includes a copy of the assignment and gives background information.

27. Saini-Eidukat, B. (1998). A WWW and spreadsheet-based exercise on flood-frequency analysis. *JGE* **46**: 154–156.

    This exercise utilizes data downloaded from the USGS National Water Information System (now the National Streamflow Information Program) and plotted using a spreadsheet. Students produce and analyze flood-frequency plots for various rivers in the United States, calculate the recurrence interval using the Weibull equation (given and explained in the paper), and answer a series of questions about the data.

28. Sanders, L. L. (1994). A problem-based graduate-level course in practical hydrology. *JGE* **42**: 337–344.

    In a graduate-level hydrology class employing cooperative-teaching strategies, students collected and analyzed data for a single watershed using spreadsheets. The article does not detail the spreadsheet use.

29. Schlische, R. W. and Ackermann, R. V. (1998). Integrating computers into the field geology curriculum. *JGE* **46**: 30–40.

Students in a capstone field course generate geologic maps and topographic profiles from GPS data using several different computer programs. The paper concentrates more on programs such as CANVAS and STEREONET; however, EXCEL is used to create and sort data tables.

30. Shea, J. H. (1993). An exercise for introductory earth science classes on using globular clusters to determine the size of the Milky Way and our position in it. *JGE* **41**: 490–496.

This paper describes a plotting exercise in which students start with coordinates of globular clusters in the Milky Way and then plot their location using a spreadsheet. The coordinates come in either of two forms: (x, y, z) coordinates, which may be used as they are, or equatorial coordinates, which need to be converted to (x, y, z) coordinates before plotting. Students must decide the best way to estimate the size and center of the galaxy (applying different averaging techniques) and decide how close the Earth is to the center of the galaxy.

31. Soreghan, G. S. (1999). A multi-week basin-analysis lab for sedimentary geology. *JGE* **47**: 135–142.

This sedimentary lab involves the analysis of sedimentary facies, paleocurrents, sub-surface data, paleogeography, bio- and magnetostratigraphy, and subsidence curves. The article shows but does not discuss a spreadsheet used for plotting data.

32. Vacher, H.L. (2000). Computational Geology 12 – Cramer's rule and the three-point problem. *JGE* **48**: 522–532.

Applying Polya's heuristic results in several computational solutions to the classic three-point problem (find the attitude of a plane given three points within that plane). A spreadsheet shown and discussed in the article solves the problem in three dimensions using Cramer's Rule. This spreadsheet accepts as input the coordinates of the three points. It calculates the partial derivatives in the x and y directions, the z intercept, and the corresponding strike and dip of the inclined plane.

33. Vacher, H. L. (2001). Computational Geology 14: The vector cross product and the three-point problem. *JGE* **49**: 72–82.

A discussion of the mathematical (and vector) basis for the three-point problem in this paper includes an explanation of how to solve a variant of it using weighted averages in both two and three dimensions. The accompanying spreadsheet calculates the height of an interior point of a triangle first by plugging the coordinates of the interior point into the slope-intercept form of the equation for the plane, then by a weighted average.

34. Vacher, H. L. (2001). Computational Geology 15: More mapping with vectors. *JGE* **49**: 190–192.

The first part of this paper describes the trigonometric solution to a triangulation problem and demonstrates a spreadsheet to convert between bearings and azimuths. A second section of the paper includes a spreadsheet that calculates the coordinates of points on a map. Both spreadsheets include cell values and formulas.

35. Vacher, H. L. (2002). Computational Geology 22: Pie slices and circular arcs. *JGE* **50**: 610–619.

The discussion of a word problem concerning fractions of a circle relates to such fundamental ideas as the definition of a radian and historical use of pie slices and arcs by Kepler and Eratosthenes. A rigorous examination of solutions to this problem includes solving the word problem using a spreadsheet. The paper discusses the equations used in the spreadsheet and gives a spreadsheet table of values.

36. Vacher, H. L. (2003). Computational Geology 23: The earth is curved! *JGE* **51**: 127–139.

As part of a discussion of the curvature of the earth, a spreadsheet is used to find true altitude from apparent altitude. The paper discusses parallels, meridians, and the history of navigation. Discussion of the calculations with the spreadsheet includes a table of values.

37. Vacher, H. L. (2003). Computational Geology 25 – Quantitative literacy – Drug testing, cancer screening, and the identification of igneous rocks. *JGE* **51**: 337–346.

A discussion of probability, or more specifically, the "mathematics of false positives," is an often-overlooked mathematical concept that has applications in many different areas. Spreadsheets calculate the uncertainty of test (or diagnostic) results given the base rate (or prevalence) and the accuracy of the test. The paper shows the spreadsheets and gives the matrix of formulas used to create them.

38. Vacher, H. L. (2003). Computational Geology 26 – Mathematics of radioactivity – When the Earth got old. *JGE* **51**: 436–445.

A brief history of radiometric dating leads into a discussion of the Rutherford equation $dN/dt = -\lambda N$, the concept of half-life, and the dating of rocks using the concept of radioactive decay. Spreadsheets in the article demonstrate both Boltwood's and Rutherford's historic calculations of huge geologic ages. Discussion of the spreadsheets includes the equations.

References

[1] Baker, J. E., and Sugden, S.J. (2003). Spreadsheets in Education: The First 25 Years. *Spreadsheets in Education* **1**(1): 18–43.

[2] Beare, R. (1992). Software tools in science classrooms. *Journal of Computer Assisted Learning* **8**: 221–230.

[3] Beare, R (1993). How spreadsheets can aid a variety of mathematical learning activities from primary to tertiary level. *Technology in Mathematics Teaching: A Bridge Between Teaching and Learning.* B. Jaworksi. Birmingham, U.K.: 117–124.

[4] The Digital Library of Earth Science Education, http://serc.carleton.edu/quantskills/index.html.

[5] Dutch, S. I. (1991). Geochemical calculations using spreadsheets. Journal of Geoscience Education **39:** 127–132.

[6] Freeze, R.A., and Witherspoon, P.A. (1966). Theoretical analysis of regional groundwater flow: 1, Analytical and numerical solutions to the mathematical model. *Water Resources Research* **2**: 641–656.

[7] Freeze, R.A., and Witherspoon, P.A. (1967). Theoretical analysis of regional groundwater flow: 2, Effect on water-table configuration and subsurface permeability variation. *Water Resources Research* **3**, 623–634.

[8] Friedlander, A. (1998). An EXCELlent bridge to algebra. *Mathematics Teacher* **91**: 382–383.

[9] Ganter, S.L. and Barker, W. (2004). Curriculum Foundations Project: Voices of the Partner Disciplines, The Mathematical Association of America, 215 pp. http://www.maa.org/cupm/crafty/Chapt1.pdf.

[10] Goforth, T.T. and Dunbar, J.A. (2000). Student response to quantitative aspects of instruction in an introductory geology course. *Mathematical Geology* **32**: 87–202.

[11] Harbor, J. M. and Keattch, S. E. (1995). An undergraduate laboratory exercise introducing form-development modeling in glacial geomorphology. *Journal of Geoscience Education* **43**: 529–533.

[12] Hughes-Hallet, D. (2003). The role of mathematics courses in the development of quantitative literacy. In: Madison, B.L. and Steen, L.A. (eds.), Why Numeracy Matters for Schools and Colleges, National Council on Education and the Disciplines, The Woodrow Wilson National Fellowship Foundation.

[13] *Journal of Geoscience Education*, www.nagt.org/jge.html.

[14] National Association of Geoscience Teachers, http://www.nagt.org.

[15] National Council of Teachers of Mathematics, http://www.nctm.org.

[16] Olsthoorn, T. N. (1985). Computer notes – the power of the electronic worksheet: Modeling without special programs, *Ground Water* **23**: 381–390.

[17] Ousey, Jr., J. R. (1986). Modeling steady-state groundwater flow using microcomputer spreadsheets. *Journal of Geoscience Education* **34**: 305–311.

[18] Relf, S., and Almeda, D. (1999). Exploring the birthdays problem and some its variants through computer simulation. *International Journal of Mathematical Education in Science and Technology* **30**: 81–91.

[19] Richardson, R. M. and McCallum, W. G. (2003). The third R is literacy: In: Madison, B.L. and Steen, L.A. (eds.), *Why Numeracy Matters for Schools and Colleges*, National Council on Education and the Disciplines, The Woodrow Wilson National Fellowship Foundation.

[20] Shea, J.H. (1990). Mathematics in physical-geology textbooks: *Journal of Geoscience Education*, **38** (2): 138–148.

[21] Shea, J. H. (1993). An exercise for introductory earth science classes on using globular clusters to determine the size of the Milky Way and our position in it. *Journal of Geoscience Education* **41**: 490–496.

[22] Steen, L.A. (ed.) (1997). *Why Numbers Count: Quantitative Literacy for Tomorrow's America*, New York, College Entrance Examination Board, 194pp.

[23] Steen, L.A. (ed.) (2001). *Mathematics and Democracy: The Case for Quantitative Literacy*, 121pp.

[24] Steen, LA. (2004). Quantitative Literacy: Why numeracy matters for schools and colleges. URL: http://www.maa.org/features/QL.html.

[25] Vacher, H.L. (1998). Computational Geology 1 – Significant figures! *Journal of Geoscience Education* **46**: 292–295.

[26] Vacher, H.L. (2000). Computational Geology 12 – Cramer's rule and the three-point problem. *Journal of Geoscience Education* **48**: 522–532.

[27] Vacher, H. L. (2000). Computational Geology 13 – Geological-mathematical activities for college students in the Journal of Geoscience Education, 1990-1999. *Journal of Geoscience Education* **48**: 682–691.

[28] Vacher, H.L. (2001). Better math, better geology (Geoscience Education column), *Geotimes*, **46**: 13.

[29] Wagner, J.R. (2000). Sneaking mathematical concepts through the back door of the introductory geology classroom. *Mathematical Geology* **32**:217–229.