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Simulation of Soil Water Infiltration with Integration, Differentiation, Numerical Methods and Programming Exercises*

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Students in a water resources engineering course consider the infiltration of water into soils, a topic through which instructors can reinforce many fundamental engineering principles. In this paper, undergraduates used two 80 minute classes to explore Green-Ampt infiltration through integration, differentiation, Newton-Raphson numerical methods and Visual Basic programming. Students used calculus software to check solved problems, programming software to modify and execute model code, and spreadsheet software to examine model outputs. Outputs included tables and graphs showing infiltration for a single precipitation event. Student assessment of the lesson is used to complement measurement of curricula outcomes and satisfy the US Accreditation Board of Engineering Technology criteria.

Keywords: MathCAD; Excel; Visual Basic for Applications; Student Assessment of Learning Gains

INTRODUCTION

WATER INFILTRATION into the porous soil matrix is a standard curriculum topic for undergraduate and graduate water resources engineering, and is fundamental to site assessment design and remediation research projects. In this paper, State University of New York College of Environmental Science and Forestry (SUNY ESF) students enrolled in Engineering Hydrology and Hydraulics (FEG 340) were exposed to the multi-step Green-Ampt infiltration method, introduced in their course text by Chin [1]. This lesson involved two 80-minute class periods, and served to prepare students in their design of an urban stormwater bioretention device. Implementation of the Green-Ampt method required utilization of integration, differentiation, numerical methods, and computer programming. Student assessment of the lesson was collected, complemented College reporting to the Accreditation Board of Engineering Technology (ABET) on achieving learning outcomes, and has been used to improve the pedagogical approach.

INFILTRATION THEORY

Engineering methods for modelling infiltration are wide ranging, and students in FEG 340 were exposed to empirically-based methods of the Curve Number formula and the Horton exponential decay equation, as well as to the physically-based Green-Ampt equation [1]. The Green-Ampt conceptual model for infiltration originates nearly a century ago [2], and was since rigorously derived by Phillip [3]. Many water resource engineering textbooks mention the Green-Ampt infiltration formulations, but none of those reviewed by the Author provide a complete sequence of derivation together with numerical and programming methods for automated solution [1, 4-7]. This paper intends to present this complete sequence.

The theory for Green-Ampt involves conceptualization of a sharp wetting front dividing saturated soil above from initial unsaturated conditions below. Fundamental to Green-Ampt infiltration theory is the condition that infiltration rate, f (m s^{-1}), proceeds at the rainfall rate, i, when the surface is not ponded, and at the limiting potential rate, f_p, otherwise. This critical ponding condition is determined by the time to ponding, t_p, and is expressed as:

$$f = \left| \begin{array}{lll} i & \text{if} & t < t_p \\ f_p & \text{if} & t \geq t_p \end{array} \right. \tag{1}$$

Ponding occurs when rainfall rate is greater than hydraulic conductivity, K (m s^{-1}), and rainfall length and cumulative infiltration exceed available moisture storage.

Of interest in this exercise is simulating infiltration under ponded conditions, where $f = f_p$. To begin, we accept the phenomena of water flux, q (m s^{-1}), through a soil matrix has physical equiva-

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lence to f_p. As discovered by Henri Darcy in Dijon, France, this water flux is proportional to the change in hydraulic, or piezometric, head, h (m) per distance, z (m), where K is the constant of proportionality. Darcy's Law is given as:

$$q = -K \cdot \frac{h_1 - h_2}{z_1 - z_2} \tag{2}$$

Darcy flux, q, is positive upwards, while infiltration flux, f, is positive downwards, and the two are equated as $f_p = -q$.

Piezometric head, h, in keeping with hydrostatic definitions, is the sum of the pressure head, p (m), and the elevation head, z (m), as shown in the equation below.

$$h = p + z \tag{3}$$

Substituting the condition $f_p = -q$ and equation (3) into equation (2) gives the following.

$$f_p = K \cdot \frac{(p_1 + z_1) - (p_2 + z_2)}{z_1 - z_2} \tag{4}$$

When pressure head is atmospheric, it is set to 0, greater than atmospheric is positive, and less than atmospheric is negative Matric suction head, -ψ (m). Setting the reference datum for this system, from which to measure for variable z, is an arbitrary decision, but in this example zero elevation is taken at the ground surface, where it is negative elevation down through the profile.

From equation (4) we need to have values for Zones 1 and 2, noted in the sub-scripts of the p and z terms. Zone 1 is set at the ground interface, and Zone 2 at the wetting front interface, where the infiltration is changing initially unsaturated soil into saturated soil (see Figure 1). Then, in Zone 1, the depth of ponded water, L_p, is substituted for pressure head, and 0 is substituted for elevation. In zone 2, at the wetting front, the Matric suction length, $-\psi_{wf}$, is substituted for pressure head, and the wetting front depth, $-L_s$, is substituted for elevation. These substitutions are given below.

$$p_1 = L_p \tag{5}$$

$$z_1 = 0 \tag{6}$$

$$p_2 = -\psi_{wf} \tag{7}$$

$$z_2 = -L_s \tag{8}$$

Figure 1 defines these terms schematically. Placing the defined terms of equations (5) to (8) into equation (4) gives:

$$f_p = K \cdot \frac{L_p - \left(-\psi_{wf} - L_s\right)}{L_s} \tag{9}$$

Typically, ponded depth is considered negligible compared with the absolute values of Matric suction and length of saturation ($L_p << |\psi_{wf} + L_s|$) [4]. This presumption is used here to drop the L_p term; otherwise the equation becomes cumbersome for an undergraduate course demonstration. Without the L_p term, equation (9) becomes:

$$f_p = K \cdot \left(\frac{\psi_{wf} + L_s}{L_s}\right) \tag{10}$$

Wetting front depth L_s is then substituted with terms measurable in the field. It is set as equivalent to the cumulative infiltration length, F (m), divided by the change in soil moisture $\Delta\theta$, given as:

$$L_s = \frac{F}{\Delta\theta} \tag{11}$$

Incorporating equation (11) into equation (10) and multiplying by $\Delta\theta$ gives:

$$f_p = K \cdot \left(\frac{\psi_{wf}\Delta\theta + F}{F}\right) \tag{12}$$

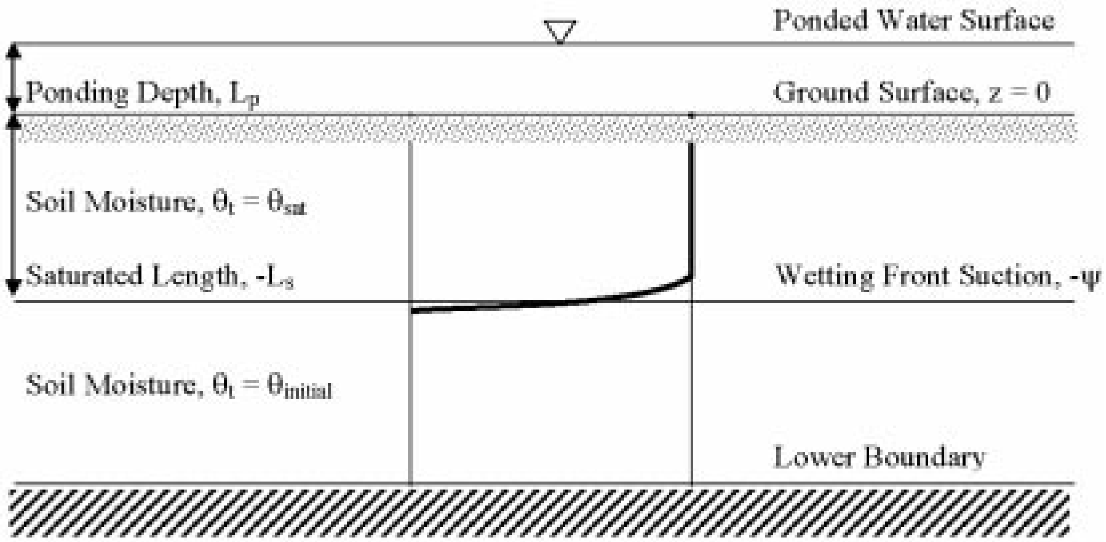


Fig. 1. Green-Ampt soil profile, with soil layers identified on the right-hand side, and soil moisture variables identified on the left-hand side of the diagram. The middle diagram shows the wetting front.

Equation (12) is further rearranged by setting infiltration rate, f_p, equal to the derivative of cumulative infiltration, F, and factoring the quotient F to F equal to 1.

$$f_p = \frac{dF}{dt} = K \cdot \left(\frac{\psi_{wf} \Delta\theta}{F} + 1 \right) \quad (13)$$

It is important to recall, this equation holds for conditions where ponded water is present, but its length is significantly less than the wetting front and suction lengths. The above derivation work was to provide a conceptual background for solution and simulation use of the Green-Ampt equation.

METHODS

In the classroom exercises, students are initially exposed to the graphical theory of Green-Ampt infiltration, with a discussion of Figure 1 and review of equations (1) to (13). Subsequently, the students are asked to perform four tasks that lead toward concept simulation.

Task one for students is integration of equation (13), between two time steps. Integration of equation (13) will solve for F, and is approached by collecting like terms through cross-multiplication, giving:

$$\int_{F_{t-1}}^{F_t} \frac{1}{\left(\frac{\psi_{wf}\Delta\theta}{F} + 1\right)} \cdot dF = \int_{t-1}^{t} K \cdot dt \quad (14)$$

Integration of the right-hand side (RHS) is likely most familiar to students, where the anti-derivative is needed. A test of proper integration is to take the derivative of the result, and check that it gives you what had been on the RHS of equation (14).

$$\int_{t-1}^{t} K \cdot dt = K \cdot t - K \cdot (t-1) = K \cdot \Delta t \quad (15)$$

Integration of the left-hand side (LHS) of equation (14) may require students to revisit their calculus manuals or reference handbooks for integration. Calculus software programs, such as MathCAD® with the symbolic evaluation, can also be used. This software was used to check work in the SUNY ESF FEG 340 course, and corroborate the solution to the LHS of equation (14).

$$\int_{F_{t-1}}^{F_t} \frac{1}{\left(\frac{\psi_{wf}\Delta\theta}{F} + 1\right)} \cdot dF = \left[F_t - \psi_{wf}\Delta\theta \cdot \ln\left(\psi_{wf}\Delta\theta + F_t\right)\right] - \left[F_{t-1} - \psi_{wf}\Delta\theta \cdot \ln\left(\psi_{wf}\Delta\theta + F_{t-1}\right)\right] \quad (16)$$

The RHS and LHS, given in equations (15) and (16), can be combined to provide a solution for cumulative infiltration at time, t:

$$F_t = \psi_{wf}\Delta\theta \cdot \ln\left(\psi_{wf}\Delta\theta + F_t\right) + F_{t-1} - \psi_{wf}\Delta\theta \cdot \ln\left(\psi_{wf}\Delta\theta + F_{t-1}\right) + K \cdot \Delta t \quad (17)$$

Equation (17) can be rearranged and simplified, collecting like terms and reworking the subtraction of natural logarithms to division of these terms,

$$F_t = F_{t-1} + \psi_{wf}\Delta\theta \cdot \ln\left[\frac{\psi_{wf}\Delta\theta + F_t}{\psi_{wf}\Delta\theta + F_{t-1}}\right] + K \cdot \Delta t \quad (18)$$

After completion of task one the students should reflect on their accomplishment, i.e. applying calculus integration theory to solve part of an engineering problem.

Task two for students is to identify a numerical method to solve equation (18). Cumulative infiltration at time t, F_t, is on the LHS and is also operated upon on the RHS of equation (18), making it an implicit function. To solve for F_t on the LHS, the equation requires the value of F_t on the RHS. Additionally, the RHS needs a cumulative infiltration value from the previous time step, and other known terms, such as Matric suction length and hydraulic conductivity. Rearranging equation (18) into a root function is one method to solve for cumulative infiltration. By subtracting the LHS from the RHS, the equation will give a value of zero when F_t has the proper value. This arrangement can be written as a new operator on F_t, given as function:

$$g(F_t) = F_t - F_{t-1} - \psi_{wf}\Delta\theta \cdot \ln\left[\frac{\psi_{wf}\Delta\theta + F_t}{\psi_{wf}\Delta\theta + F_{t-1}}\right] - K \cdot \Delta t \quad (19)$$

Equation (19) should give a value of 0 when the exact root for F_t has been found. Students are told a numerical technique will help in finding this root.

Figure 2 shows the self-correcting, iterative procedure to find F_t given a previous estimate, F_{est}. At point *a* the initial F guess generates a value of the *g(F)* function on the y-axis. The tangent at the *g(F)* value redirects the second *F* guess toward the location of the root, where the function *g(F)* intersects the x-axis at zero, at point *d*. The procedure works equally well for negative valued functions. Students should be asked how to obtain the tangent of a function, and guided toward the use of derivatives.

The Newton-Raphson equation represents this graphical approach by using the root function and its derivative, $g'(F_{est})$, and is given as:

$$F_t = F_{est} - \frac{g(F_{est})}{g'(F_{est})} \quad (20)$$

This numerical approach is an iterative-based method for finding roots of an equation, based on an initial estimate or previously computed value, F_{est}. Students should recognize that equation (20) will be used more than once, similar to the iteration in Figure 2. When F_{est} approaches the root value, the numerator in equation 20 goes toward zero. As this happens, the adjustment to

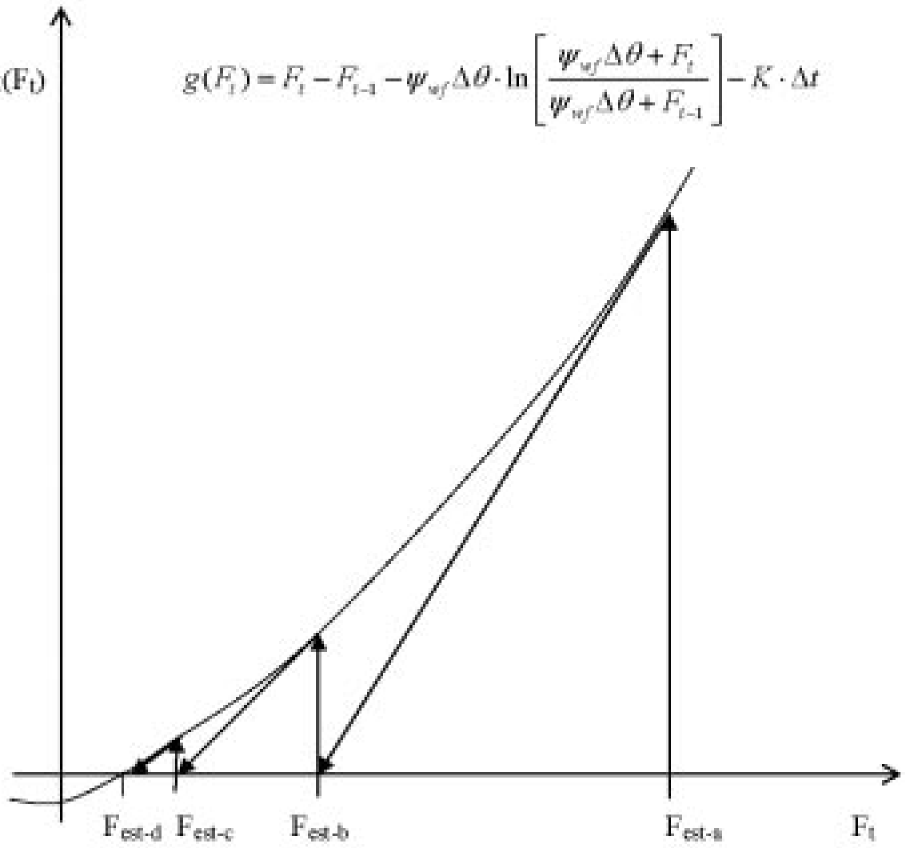


Fig. 2. Graphical illustration of the Newton Raphson technique on the root function as it moves from an initial estimate for cumulative infiltration at $F_{est\text{-}a}$ through iteration toward a final acceptable estimate at $F_{est\text{-}d}$.

F_{est} becomes incrementally smaller, and the difference between two consecutive estimates approaches zero.

Programs that use the Newton-Raphson procedure rarely require an exact root, and instead each solution estimate in the iteration sequence is compared to the prior sequence to determine if the net improvement approaches a threshold near zero. This threshold is typically set by the program modeller or user, and represents the needed level of precision. At the close of this task, students should reflect on their exposure to a numerical method for implementing a graphical exercise and solving an estimation problem. The students should also be challenged to provide algebraic values for equation (20).

Task three for students is to take the derivative of equation (19) with respect to F_t, such that they can later implement the numerical method represented by equation (20). While equation (19) looks complex, the differentiation of terms that do not operate on F_t or contain F_t go to zero, and the remaining terms are readily addressed by standard calculus references.

Students should recall the integration of an inverse fraction in equation (16) led to the natural logarithm, and the Fundamental Theorem of Calculus requires that the differentiation of a natural logarithm will lead to an inverse fraction. Again, at SUNY ESF we used MathCAD to check our work. Differentiation of g(F) is given as:

$$\frac{dg}{dF_t} = \frac{d}{dF_t}\left(F_t - F_{t-1} - \psi_{wf}\Delta\theta \cdot \ln\left[\frac{\psi_{wf}\Delta\theta + F_t}{\psi_{wf}\Delta\theta + F_{t-1}}\right] - K \cdot \Delta t\right) = 1 - \frac{\psi_{wf}\Delta\theta}{(\psi_{wf}\Delta\theta + F_t)} \qquad (21)$$

Before proceeding to task 4, students should again reflect on how their knowledge of differentiation in calculus was used to establish an engineering equation and provide input for a useful numerical method.

Task four for students is to review the above accomplishments, conceptualize how they fit together to estimate infiltration, and construct a programming plan for the simulation of infiltration. This is a good place to break for the first class, and allow students homework time to prepare for the second class.

Students in the SUNY ESF curriculum have taken an introduction to programming before this class, yet are reminded that pseudocode precedes the actual computer program. Pseudocode is not compilable or executable, but instead organizes the simulation logic and algorithms in a written outline format that can be readily converted to programming statements. Further, students should be directed to avoid 'goto' type control structures, simplifying programs to no more than the sequence structure, the selection structure and the repetition structure.

Students should be told the following to guide their work. Pseudocode for simulation of infiltration begins by understanding that outputs include infiltration rate and cumulative infiltration, and inputs will include rainfall rate and soil physical properties. They must provide unit dimensions for program inputs, outputs and variables, gather all needed parameter initial values (e.g. $K,\ _{wf},$), and set the number of time steps for the routine.

```
Dimensionalize variables

Main Routine: Soil Infiltration
Get Model Parameters
Loop through simulation time
        Get Precipitation
        Get Infiltration
        Put model results
Next loop

Sub Routine: Model Parameters
Set ponded depth, hydraulic conductivity, soil suction, soil storage, time delta, end time

Sub Routine: Precipitation
Read precipitation rate
Set precipitation length

Sub Routine: Infiltration
Check if ponded water
If water is ponded then
        Ponded depth is incremented by precipitation length
        Time to ponding is zero
        Compute infiltration with Green-Ampt Newton-Raphson routine
If no water is ponded then
        Check precipitation rate
        If precipitation rate less than or equal to hydraulic conductivity then
                Infiltration is incremented by precipitation length
        If precipitation rate greater than hydraulic conductivity then
                Check how close soil storage is to saturation
                If infiltration to saturate is zero then
                        Ponded depth is incremented by precipitation length
                        Time to ponding is zero
                        Compute infiltration with Green-Ampt Newton-Raphson routine
                If infiltration to saturate is greater than precipitation length then
                        Infiltration is incremented by precipitation length
                If infiltration to saturate is less than precipitation length but more than zero then
                        Infiltration is incremented by infiltration to saturate length
                        Ponded depth is incremented by precipitation – infiltration to saturate lengths
                        Time to ponding is infiltration to saturate divided by precipitation rate
                        Compute infiltration with Green-Ampt Newton-Raphson routine

Sub Routine: Green-Ampt Newton-Raphson
Generate estimate for cumulative infiltration
Loop through convergence test
        Compute infiltration root function
        Compute derivative of root function
        Compute infiltration using Newton-Raphson equation
        If computed infiltration is very close to previous estimate then
                Ponded depth is decreased by infiltrated length
                Stop looping
        If computed infiltration is not close enough to previous estimate then
                Stop looping if passed through too many times
        Set estimate of cumulative infiltration to computed infiltration
Next loop

Sub Routine: Model Results
Write cumulative infiltration, infiltration rate, ponded depth
```

Fig. 3. Pseudocode for infiltration using the Green-Ampt model.

Table 1. Infiltration model output from a simulation with 20 mm of initially ponded water, and a simulation with 0 mm of initially ponded water, showing precipitation rate, P (mm/hr), time (hr), instantaneous infiltration, f (mm/hr), cumulative infiltration, F (mm) and ponded depth (mm).

Data Input		Initially Ponded at 20 mm			Initially Ponded at 0 mm		
P (mm/hr)	Time (hr)	f (mm/hr)	F (mm)	Pond (mm)	f (mm/hr)	F (mm)	Pond (mm)
7	0.17	72.88	12.39	8.80	7.00	1.19	0.00
21	0.34	34.75	18.30	6.46	21.00	4.76	0.00
34	0.51	28.55	23.15	7.39	34.00	10.54	0.00
26	0.68	25.36	27.46	7.50	26.00	14.96	0.00
23	0.85	23.34	31.43	7.44	23.00	18.87	0.00
28	1.02	21.91	35.15	8.48	13.93	21.24	0.00
20	1.19	20.83	38.70	8.33	20.00	24.64	0.00
18	1.36	19.99	42.09	8.00	18.00	27.70	0.00
14	1.53	19.30	45.37	7.10	14.00	30.08	0.00
22	1.70	18.73	48.56	7.65	5.00	30.93	0.00
25	1.87	18.25	51.66	8.80	22.07	34.68	0.50
13	2.04	17.83	54.69	7.98	20.96	38.24	0.00
11	2.21	17.46	57.66	6.88	11.00	40.11	0.00
6	2.38	17.14	60.57	4.99	6.00	41.13	0.00
18	2.55	16.85	63.44	5.18	18.00	44.19	0.00
23	2.72	16.60	66.26	6.27	18.93	47.41	0.69
4	2.89	16.37	69.04	4.17	18.41	50.54	0.00
5	3.06	16.16	71.79	2.27	5.00	51.39	0.00

Students should be told their program will pass through time, and for each time step get precipitation data, compute infiltration and put infiltration results into storage. In the precipitation routine, rainfall rate will be read and converted to a length based on the time step. In the infiltration routine, it is important to determine if ponding has occurred, as queried in equation (1), such that the appropriate infiltration rate is selected.

Infiltration simulation starts by checking if water is ponded on the surface, and if not, whether rainfall rate is greater than hydraulic conductivity and soil storage, S_t, is exceeded. In either case, the program should implement equation (20), using equations (19) and (21) to fill in the RHS, to solve for cumulative infiltration; otherwise the precipitation length should be infiltrated.

Soil water storage for the current time step is assessed using knowledge of cumulative infiltration from the previous simulation time step, along with current rainfall rate and soil physical parameters defined earlier. It is computed as:

$$S_t = K \cdot \frac{(\psi_{wf}\Delta\theta)}{(i_t - K)} - F_{t-1} \qquad (22)$$

Output first generates cumulative infiltration and ponded depth, and infiltration rate is computed as the incremental increase in cumulative infiltration per time step, given as:

$$f = \frac{F_t - F_{t-1}}{\Delta t} \qquad (23)$$

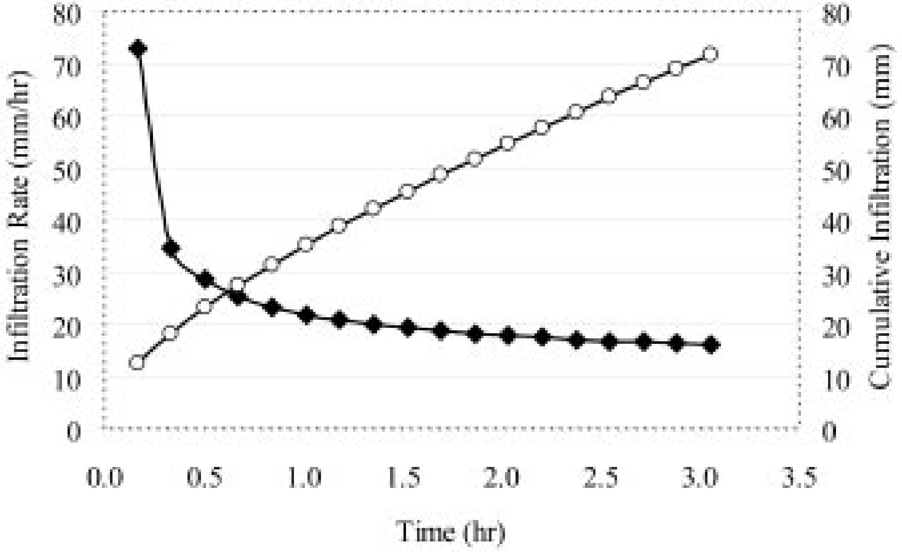
The entire pseudocode structure is presented in Figure 3.

Actual implementation of the simulation is completed by the class using a mostly prepared Excel sheet, saved to the course website. The extent of algorithm preparation is based on class time and student experience with programming. Students could be given a working model, or be asked to insert or complete a few lines of code. Precipitation data for each time step, and an embedded chart that plots instantaneous and cumulative infiltration, are provided in the Excel sheet.

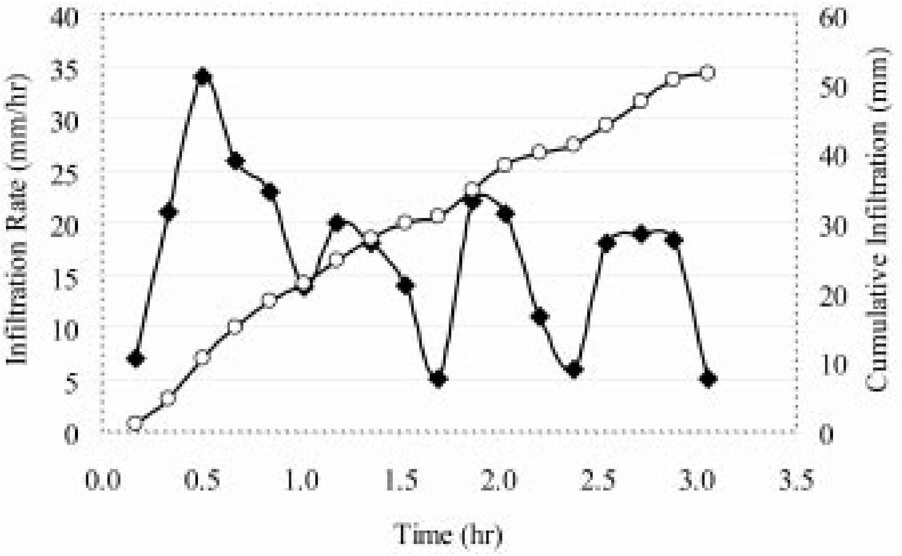
In the class exercise, a seven-year recurrence interval storm delivers 5.4 cm of precipitation in three hours to a sandy loam soil. Two simulations are run, first with 20 mm of antecedent ponded depth and second with 0 mm of antecedent ponded depth.

The students are instructed or reminded how to open the Visual Basic® (VB) Editor in Microsoft Excel® and view the VB for Applications code. The full code is attached in the Appendix, and the Excel program is available from the author. Once the program has been run, the students explore both tabular and graphical simulation output to better appreciate what they are predicting. Table 1 reports the input and output for the simulations with and without ponding, and Figure 4 illustrates the time series evolution of infiltration under both simulation scenarios.

For the first simulation the table reports how infiltration rate steadily decreases from its maximum, and cumulative infiltration increases to a depth greater than the 54 cm of rainfall. These trends are clear from the associated Figure 4a. For the second simulation, however, Figure 4b provides a wonderful insight to the oscillation of the infiltration rate, where it actually increases at first, and then is later controlled by unsteady rainfall rates. At the close of these simulation exercises, students should reflect on how their calculus exercises and pseudocode development enabled completion of a working infiltration



(a)



(b)

Fig. 4. (a) Figure of infiltration rate (mm hr^{-1}) as a time series, showing the steady decrease, and cumulative infiltration (mm), showing steady increase, for a ponded scenario. (b) Figure of unsteady infiltration rate and cumulative infiltration with the same rainfall input, but without ponding.

model, and how this model can provide predictions for engineering questions.

DISCUSSION

Green-Ampt infiltration parameters, such as K, ψ_{wf}, and θ, are available for different soil types based on work by Rawls et al.,[8], and cited in the Chin [1] textbook used in this course. Table 2 presents parameters for a subset of common soil types. In the attached code, sandy loam parameter values have been entered.

Students might be informed that additional steps are available to relate infiltration to changes in soil moisture. This step is important for simulating the trends recorded by soil moisture probes, and in simulation of observed phenomenon. Volumetric soil moisture for the time step, θ_i (m^3 m^{-3}), is the fraction of water in the porous matrix, and when multiplied by the depth of soil, L_s (m), per unit area, A (m^2), gives the length of water in that soil profile. From this relation, infiltrated lengths can be converted to changes in volumetric soil moisture.

$$\theta_t = \theta_{t-1} + \frac{\Delta F}{L_s} \cdot A \quad (24)$$

with the conditions if θ_t exceeds θ_{sat}, the remainder goes to surface runoff or remains ponded.

$$\theta_t \theta_{sat}, \theta_t = \theta_{sat} \quad (25)$$

Table 2. Green-Ampt hydraulic conductivity, wetting front suction, and volumetric soil moisture parameter values for common soil texture types (Chin, 2000). The change in volumetric soil moisture, $\Delta\theta$, is computed by taking the difference between θ_{sat} and θ_{init}, which is typically at wilting point or higher.

Soil Texture Class	Hydraulic Conductivity K_{sat} (m h^{-1})	Wetting Front Suction Head ψ_{wf} (m)	Volumetric Soil Moisture at Saturation θ_{sat} (m^3 m^{-3})	Volumetric Soil Moisture at Wilting Point θ_{wp} (m^3 m^{-3})
Sandy Loam	0.011	0.110	0.453	0.085
Silt Loam	0.007	0.170	0.501	0.135
Loam	0.003	0.089	0.463	0.116
Clay Loam	0.001	0.210	0.464	0.187
Sandy Clay	0.001	0.240	0.479	0.251

Student feedback on the exercise was collected at the end of the class.

ASSESSMENT

Assessment and feedback are critical for efficient and directed adjustment of teaching, and such assessment can assist in evaluating undergraduate curricula outcomes. For example, in the US, ABET accreditation will review how measurement of student performance in specific exercises supports conclusions about the success of the undergraduate programme and curricula. While the above work is presented as two class lessons, the assessment of these exercises for specific performance criteria will help to satisfy the ABET reporting requirements of the entire undergraduate programme.

At the close of the above lesson, students were asked to provide feedback on instructor created forms posted to the Student Assessment of Learning Gains (SALG) website [9]. SALG kept student response anonymous, and summary reports from the 25 students providing feedback is reported below. Earlier in the semester, students had been invited to participate in an online Index of Learning Styles (ILS) assessment [10]; through this exercise it was confirmed that many students desire visual, active and real-world-based learning. The above lesson attempted to address that learning style, yet retained text-based, reflective and theoretical elements to expand student comfort with non-preferred learning styles.

Responses on the SALG included a 5-point ranking, where 5 is 'very much help', 3 is 'moderate help', and 1 is 'no help'; an area for open comments was also available. Open comments included mostly praise for the exercise, while ranking data placed the exercise just above moderately helpful. Results are shown for the 2005 academic year. Figure 5 reports ranking mean and standard deviation for the master question, 'How did each of the following aspects/activities of

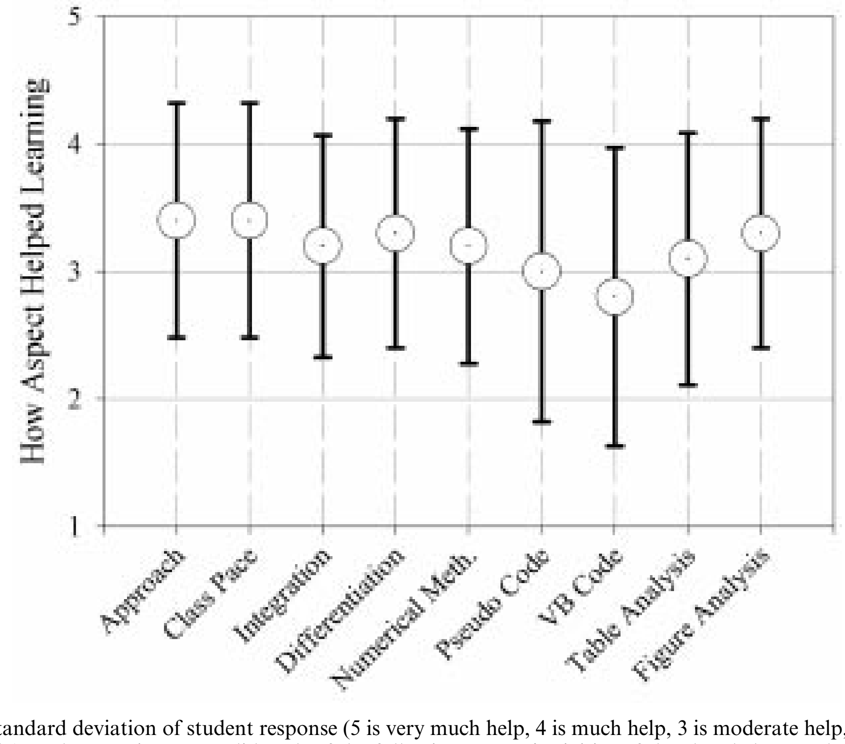


Fig. 5. Mean and standard deviation of student response (5 is very much help, 4 is much help, 3 is moderate help, 2 is a little help, 1 is no help) to the question, How did each of the following aspects/activities of the class help your learning?

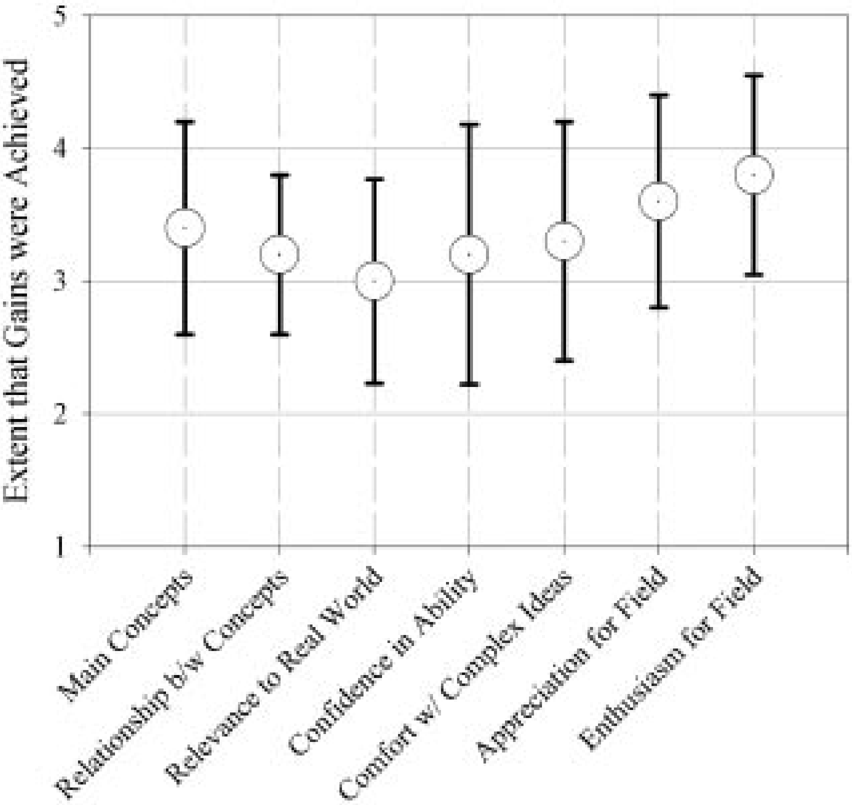


Fig. 6. Mean and standard deviation of student response (5 is very much help, 4 is much help, 3 is moderate help, 2 is a little help, 1 is no help) to the question, To what extent did you make gains in any of the following as a result of the class activity?

the class help your learning?' where the x-axis has sub-categories. One item of interest in this figure is the greater deviation in the lower ranked elements of constructing pseudo code and programming visual basic. Next year I will explore the cause of a lower ranking in these activities, but suspect it may be due to: the relative higher comfort of calculus topics, the relative short duration of earlier programming classes or the fact that the activities were at the end of class when students were tired and possibly feeling rushed. In keeping with ILS expectations, students on average found their learning was assisted more by analysis of the figure than the table.

Figure 6 reports responses to the master question, 'To what extent did you make gains in any of the following as a result of the class activity?' with sub-categories on the x-axis. One trend of interest in this figure is the perceived low relevance of the infiltration activity to the real world as compared with the relatively high ranking for the activity instilling an appreciation and enthusiasm for the field of engineering hydrology. Ironically, the students were asked to undertake this infiltration exercise because it is more representative of real world processes than most other simulation tools. In planning for the next year, I hope to again imbue in the students a positive outlook toward the topic matter, and will work to augment their real and perceived gains in engineering skills.

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