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Concept Inventory for Engineering Hydrology – Development and Implementation

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Abstract

Concept inventories assess students' understanding of foundational concepts, and have been developed for a variety of engineering disciplines. Concept inventories can be used at the beginning of a course to identify commonly-held misconceptions, existing areas of conceptual strength, and to assess mastery of the foundational concepts by students at the end of a course. Courses in engineering hydrology are typically offered to students at the senior level, and are unique among many senior-level courses in that there are few prerequisite courses that directly introduce and provide background for many of the concepts that will be studied. Although courses in fluid mechanics or hydraulic engineering may be identified on paper as prerequisites, neither generally address the aspects of atmospheric science, subsurface water movement, and watershed modeling that are foundational in hydrology. Therefore, it is particularly useful at the beginning of a course in engineering hydrology for an instructor to have a clear understanding of which foundational concepts students may already understand, and likewise where there are significant conceptual gaps that need particular attention. Concept inventories can be useful in identifying both, and also for assessment purposes at the conclusion of a course to identify student-learning gains and assess the efficacy of meeting learning objectives.

A multiple-choice concept inventory was developed for a senior-level undergraduate engineering course in hydrology, and was administered to students at two institutions. Results demonstrate statistically significant gains in conceptual understanding of several topics, and help illustrate an approach that can be taken to support outcomes assessment through concept inventories.

Introduction

Helping students to develop a solid understanding of fundamental concepts is a key objective in any engineering course. Conceptual mastery enables engineering students to understand when certain equations may be used reliably in analysis and design, for example. Furthermore, a thorough grounding in fundamental concepts enables engineers to solve new, unfamiliar problems that are beyond the range of existing techniques. In view of this, it is critical that engineering instructors ensure that students go beyond an ability to merely substitute given information into applicable equations, and actually understand subjects more broadly. One tool that can be utilized to assess student understanding, and achievement of learning objectives, is concept inventories.

Concept inventories have been developed to assess student understanding in a variety of subjects, including physics[1], statics[2], biology[3], genetics[4], thermodynamics[5], fluid mechanics[6], light and spectroscopy[7], dynamics[8], chemistry[9], digital logic[10], thermal and transport science[11], geoscience[12], statistics[13], and strength of materials[14], among others. Existing concept inventories vary in length from instruments that can be completed by students in just a few minutes to more detailed tests that require several hours. There is a similar variation in the format that is utilized by concept inventories, with the majority employing a multiple-choice format. A single underlying methodology has not been used in the development of existing concept inventories[15], but many share common structural attributes, such as identifying concepts that students have misconceptions about[16], or including questions that highlight related concepts that are not readily observable[17] by students.

Hydrology courses taken by engineering students are often done so during the students' final year of undergraduate study. Among the courses that engineering students typically take during this final year, hydrology courses are uniquely concept-oriented, in that there are relatively few (if any) directly relevant course prerequisites that prepare students for the material that is covered during the course. The effect of this is that engineering hydrology courses often must begin by addressing fundamental principles in atmospheric and earth science before students are prepared to meaningfully apply analytical methods for such purposes as generating runoff hydrographs and estimating peak flowrates and runoff volumes. In view of the special prominence of conceptual understanding to students in engineering hydrology courses, it is particularly important for instructors to have direct measures of students' proficiency in the range of topics covered, such as: the hydrologic cycle, the origin and mechanisms of precipitation, causes and influencing factors of evaporation, infiltration of precipitation into the subsurface, watershed characteristics, and others.

The primary research question addressed by this project was, "can a concept inventory be used for direct assessment of an engineering hydrology course?" To answer this question, a concept inventory was developed and pilot tested in two undergraduate engineering hydrology courses, with the results of this pilot-testing described herein. A secondary research question addressed by this project was, "how does student performance on a concept inventory (both beginning-of-semester and end-of-semester) relate to their ultimate final grade in the course?" In other words, student performance on the concept inventory was explored relative to the summative assessment that students are assigned based on their performance on homework assignments, quizzes, exams, etc. The concept inventory was utilized at two universities: Marshall University (MU), a public institution with a total student population of approximately 14,000 with a Carnegie classification of "Master's Colleges and Universities (larger program); and Brigham Young University (BYU), a private not-for-profit institution with a total student population of 34,000 and a Carnegie classification of "Research Universities (high research activity)".

One significant motivation for and utility of this project is to explore the utility of a concept inventory for purposes of outcomes assessment. At Marshall University the outcomes of the engineering hydrology course in which this concept inventory was used are:

1. Application of hydrologic principles such as precipitation, evaporation, and infiltration in solving engineering analyses.
2. Conduct analysis of urban and rural watersheds using hydrographs, land use and soil type abstraction estimations, and flow routing.
3. Apply principles of probability and frequency analysis in organizing hydrologic data.
4. Analyze and design stormwater control systems, such as storm sewers, detention ponds, culverts, and street inlets.

At Brigham Young University the outcomes are:

1. Understand and apply climatological principles relating to the hydrologic cycle and its occurrence and interaction with the biosphere of the earth.
2. Understand and solve problems for precipitation/runoff situations; including generation of the flow rates at desired points in a watershed.
3. Design and make calculations of flowrate hydrographs, reservoir storage, and water demand relationships in a stream.
4. Understand and be able to make calculations related to groundwater flow, well flow analysis and design, and drainage of saturated soils.
5. Design and apply statistical methods to generate hydrologic intensity and frequency distributions.

Development of the hydrology concept inventory was guided in part by a desire to ultimately use the concept inventory for direct assessment of outcome achievement.

Methods

The 21 question concept inventory is included at the end of this paper as Appendix A. As illustrated in Table 1, the questions in the inventory include questions that are primarily conceptual (C) in nature, primarily knowledge (K) based, and mixed (M) between conceptual and knowledge based. Students do not know while they are taking the inventory whether a certain question is classified as conceptual, knowledge based, or mixed. However, the distinction has been made during the inventory design stage, and is presented herein, in order to help ensure that the inventory includes a broad range of both topics and also question types.

Conceptual questions are those in which a student may be able to apply basic reasoning and information from previous personal experiences or past courses to determine the correct answer to the question. Using question #8 as an example, a student who already understands (or is able to correctly reason) that a rougher surface will reduce the velocity of water flowing over that surface. That same student may then be able to apply that understanding to choose the runoff hydrograph that exhibits a flow delay. Thus, even at the beginning of the semester before a student has learned anything about hydrographs, that student may be able to reason their way through a conceptual question. Eight of the inventory's 21 questions are conceptual in nature.

Knowledge based questions, by contrast, are those in which the key information needed to answer the question correctly will be presented for the first time during the engineering hydrology course. The question is still conceptual in nature, it is just that at the beginning of the semester a student is not likely to already know a key point of terminology that is required to express or understand the concept. What is meant by the phrase "aquifer drawdown", for example (i.e., question #5), is not something that a student will be able to apply reasoning to in order to ultimately identify the correct answer choice from among the options. Instead, drawdown is something that most students will learn about for the first time during the course. Nine of 21 questions are categorized as knowledge based.

Mixed questions are those that contain some characteristics of both a knowledge based question and a conceptual question. The cause of precipitation, for example (i.e., question #3) is something that students may have some limited previous exposure to, and is likewise something that students may be able to use reason to eliminate one or more of the answer options. However, the depth of detail contained within the questions means that most students will be unable to identify the correct answer until after having been exposed to the related content during the semester.

Table 1 – Relationship between concept inventory question, topic, question type, and course outcome.

Question	**Topic**	**Question Type** (Conceptual, Knowledge, Mixed)	**MU: Related Course Outcome**	**BYU: Related Course Outcome**
1	Runoff: urbanization	C	2	2
2	Culvert	K	4	-
3	Precipitation: cause	M	1	1
4	Runoff: moisture condition	C	2	2
5	Wells	K	1	4
6	Flood control: floodplain management	K	4	-
7	Evaporation	C	1	1
8	Runoff	C	2	2
9	Subsurface flow: Darcy's law	M	1	4
10	Watersheds	K	2	2
11	Runoff: hydrographs	K	2	3
12	Runoff: hydrographs	K	2	3
13	Runoff: time of concentration	K	2	3
14	Infiltration	C	1	4
15	Runoff: quantity	M	2	2
16	Precipitation: temporal distribution	C	1	1
17	Flood control: detention pond	C	4	3
18	Runoff: land cover	M	2	2
19	Subsurface flow: base flow	K	1	4
20	Reservoirs	K	4	3
21	Precipitation: probability	C	3	5

Students at Marshall University were administered the concept inventory on paper, during class time during both the beginning-of-semester pre-test, and the end-of-semester post-test. At Brigham Young University the questions were put online and the concept inventory was administered at the beginning of the first day of class by a web survey.

Since the concept inventory was still under development during the Fall 2014 semester, only the first six questions of the inventory were administered to Marshall University students both at the beginning and end of the semester. That experience led to the expansion of the concept inventory to its current makeup of 21 questions. All 21 questions were then administered to Brigham Young University students at the beginning of the Spring 2015 semester. However, since that semester is still in progress the end-of-semester performance will not be available for analysis in this paper but will be reported on in the conference presentation. Performance on the concept inventory for both student pools is reported herein, but analysis of the statistical significance of pre- and post-test performance is limited to the Marshall University student pool for the first six questions.

One unusual aspect of the student pool at Marshall University during the Fall 2014 semester was a large number of transient, non-degree seeking international students enrolling in the course. Only three of these 13 international students had completed the prerequisite course at Marshall University, and several of these students were still enrolled in intensive English language preparatory courses. These international students tended to struggle with the concept inventory, perhaps due to the combined effects of language difficulties and differences in prerequisite courses they had taken at their home institution.

The number of students answering each question on the concept inventory correctly at the beginning and end of the semester was analyzed using a one-tailed Z-test to determine whether the difference is statistically significant. The Z-test statistic is calculated by first determining the Pooled Sample Proportion, P (Equation 1), then calculating the Standard Error, SE (Equation 2), and finally the Z-test Statistic, Z (Equation 3).

$$P = \frac{P_1 n_1 + P_2 n_2}{n_1 + n_2} \qquad \text{(Equation 1)}$$

$$SE = \sqrt{P(1-P)\left(\frac{1}{n_1} + \frac{1}{n_2}\right)} \qquad \text{(Equation 2)}$$

$$Z = \frac{P_1 - P_2}{SE} \qquad \text{(Equation 3)}$$

Where:

P_1 = Sample proportion from population 1 (i.e., beginning of semester)
P_2 = Sample proportion from population 2 (i.e., end of semester)
n_1 = Size of sample 1 (i.e., beginning-of-semester; 19)
n_2 = Size of sample 2 (i.e., end-of-semester; 21)

A 95% confidence level (i.e., $\alpha = .05$) was selected such that when a significant difference of "yes" is indicated, there is a 95% probability that it is correct to reject the null hypothesis that the two groups are the same – that the proportion of students answering the question correctly is the same between the pre- and post-test. When a significant difference of "no" is indicated, this means that there is less than a 95% probability that the two groups are actually different.

The significance of differences in overall student score for the six common questions of the pre- and post-test were determined using a one-tailed t-test (Equation 4).

$$t = \frac{\bar{x} - \mu_0}{s / \sqrt{n}} \qquad \text{(Equation 4)}$$

Where:

$\bar{x}$ = Mean score on concept inventory, end-of-semester
μ_0= Mean score on concept inventory, beginning-of-semester
s = Standard deviation, end-of-semester
n = Number of students, end-of-semester

The internal consistency of the concept inventory was evaluated with the Kuder-Richardson Formula 20 approach (Equation 5).

$$\rho_{KR20} = \frac{k}{k-1}\left(1 - \frac{\sum_{j=1}^{k} p_j q_j}{\sigma^2}\right) \qquad \text{(Equation 5)}$$

Where:

ρ_{KR20} = Kuder and Richardson Formula 20 test statistic
k = number of questions in concept inventory
σ^2 = variance of the total scores of all people taking the test
p_j = number of people who answered question j correctly
q_j = number of people who did not answer question j correctly

Results and Discussion

For the six questions included during the beginning-of-semester pre-test, the average score of students at Marshall University was 38.6%. For the same six questions, the end-of-semester post-test average score was 64.3%, an increase of 25.7%. The one-tailed t-test indicates that this increase is statistically significant ($t=4.99$; $p<.01$). As shown in Table 2, the percent of students answering correctly increased on all but one question. The increase in student performance was statistically significant for three of six questions, and for the one question where student performance decreased (i.e., question #6, the decrease was not statistically significant. For the 20 questions taken by Marshall University students on the end-of-semester post-test, the average score was 66.4%.

At Brigham Young University, the average score was 59.0% for the full 21-question concept inventory when taken at the beginning of the Spring 2015 semester. When end-of-semester results are available, they will be included in the presentation that accompanies this conference paper.

Table 2 – Summary of student performance on concept inventory.

Question	Topic	Fall 2014 - INST 1				Spring 2015 - INST 2
		% of Students Answering Correctly		Z	Sig Diff	% of Students Answering Correctly
		Pre-	Post-			Pre-
1	Runoff: urbanization	63	71	-0.56	No (p=.288)	77
2	Culvert	53	90	-2.68	Yes	72
3	Precipitation: cause	32	86	-3.49	Yes	64
4	Runoff: moisture condition	26	67	-2.55	Yes	69
5	Wells	37	57	-1.28	No (p=.100)	67
6	Flood control: floodplain management	21	14	0.563	No (p=.288)	28
7	Evaporation	-	14	-	-	5
8	Runoff	-	86	-	-	85
9	Subsurface flow: Darcy's law	-	90	-	-	85
10	Watersheds	-	95	-	-	87
11	Runoff: hydrographs	-	71	-	-	69
12	Runoff: hydrographs	-	52	-	-	15
13	Runoff: time of concentration	-	67	-	-	21
14	Infiltration	-	86	-	-	62
15	Runoff: quantity	-	48	-	-	67
16	Precipitation: temporal distribution	-	67	-	-	59
17	Flood control: detention pond	-	71	-	-	67
18	Runoff: land cover	-	71	-	-	77
19	Subsurface flow: base flow	-	81	-	-	56
20	Reservoirs	-	43	-	-	44
21	Precipitation: probability	-	-	-	-	62

Figure 1 shows a general trend of increasing course grade with increasing beginning-of-semester concept inventory performance. As evidence by the broad scatter within this trend (and the correspondingly low R^2 value of 0.43), there is substantial variance with such a one-parameter linear model. Similarly, as shown in Figure 2, there is a general relationship between increased performance on the end-of-semester concept inventory and course grade, but substantial variance within this trend ($R^2 = 0.43$). By comparison, one of the older and better developed concept inventories, in calculus-based physics, has been investigated relative to correlation with course grade, with an R^2 of 0.51 for that study[18].

In view of the limited number of students for whom both course grade and concept inventory performance was available, this study is not able to definitively characterize a relationship between the two. Likewise, since only two institutions were included in this study (i.e., a small teaching-emphasis program and a larger program with a greater emphasis on research), it is probable that students at other types of programs would exhibit different relationships between course grade and concept inventory performance. Nevertheless, regardless of the student pool, a hydrology concept inventory can play a valuable role in assessing student understanding before a course begins, and quantifying gains in student learning during the semester.

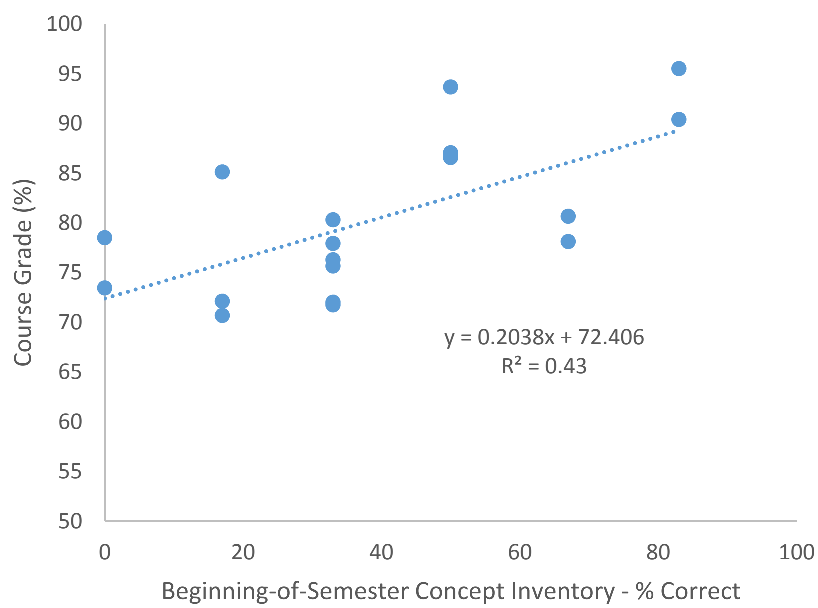

Figure 1 – Relationship between beginning-of-semester concept inventory performance and final grade in an engineering hydrology course.

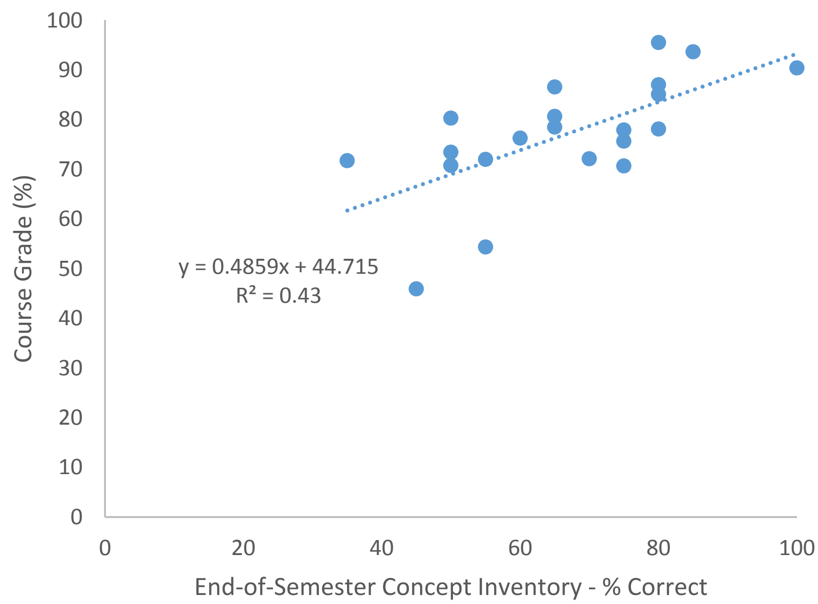

Figure 2 – Relationship between beginning-of-semester concept inventory performance and final grade in an engineering hydrology course.

With regards to the relationship between performance on the concept inventory and ultimate performance in the course, two comparisons were made for students at Marshall University.

The Kuder-Richardson Formula 20 test statistic computed for the Fall 2014 end-of-semester administration of the concept inventory at Marshall University is 0.670, which approaches the threshold of 0.70 that indicates good reliability and internal consistency of a test. The Kuder-Richardson Formula 20 test statistic is biased in favor of instruments with more items, and thus increasing the number of questions on the concept inventory would likely increase the test statistic. The influence of a significant proportion of non-native English speaking students may also have contributed to the test statistic falling slightly below 0.70.

The Kuder-Richardson Formula 20 test statistic for the beginning-of-semester administration at Marshall University is 0.376 and is 0.476 for Brigham Young University. The inventory only consisted of six questions during the pre-test administration at Marshall University during the Fall 2014 semester, and that may partly explain the lower statistic for that administration. However, these results do suggest less reliability (i.e., correlation between a test-taker's performance on each test item relative to their overall test performance) when the concept inventory is used as a pre-test. Before students have received instruction in a course, it follows that performance on a concept inventory will, in fact, be less uniform on a pre-test than on a post-test.

As a direct indicator of outcomes achievement, a concept inventory has two powerful advantages over other items that are often used for direct measures, such as homework assignments or exam questions. First, the concept inventory has a binary "right or wrong" answer, which is not subject to interpretation or partial credit. Subjective assessments that include partial credit can vary over time (e.g., from semester to semester), whereas a fixed indicator such as a concept inventory is more reliable when it is desirable to monitor outcomes achievement over time. Gathering data for accreditation purposes is an example of one such instance where it may be worthwhile to have fixed direct assessment indicators to supplement other direct assessment data that is gathered. Another advantage of using concept inventories for outcomes assessment is that when administered twice during a semester (e.g., at the beginning and at the end), one is able to illustrate the 'value added' during the course. As shown in Table 2, and emphasized by the previously-described statistical analysis, the results on a concept inventory are able to prove that students know more at the end of the semester than they did at the beginning. This same proof cannot be generated by other direct measures that only assess student performance at the end of the semester.

Conclusion

Development of a concept inventory in engineering hydrology showed (1) the utility of a concept inventory for direct assessment purposes, and (2) a relationship between a students' concept inventory performance and ultimate course grade, albeit with substantial variance and drawn from a small pool of students during this first implementation. For an instructor who wishes to identify which hydrology concepts are most commonly misunderstood by students, a concept inventory is a useful tool to obtain a broad estimation of students' beginning-of-semester awareness of the foundational concepts that exist within a course. Similarly, for purposes of evaluating how a course might need to be changed in the future in order to better ensure that students are able to achieve the course outcomes, a concept inventory can identify which topics students continue to struggle with at the end of the semester. This information enables instructors to make changes in their approach or emphasis in teaching these topics during subsequent semesters.

Continued refinements to the concept inventory are planned over the coming semesters, including the addition of questions that relate to storm return period, probability distribution, and risk assessment. Instructors who are interested in using the engineering hydrology concept inventory in their courses are welcome to contact the authors to obtain the latest version of the inventory, and the key with which to grade it.

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Appendix – Concept Inventory Questions

Note: for a copy of the key to this concept inventory, please email one of the authors.

1. When a previously-forested area is urbanized, what effect does it have on stormwater runoff?
    a. The peak flow rate during a storm will **increase** and the time to peak will **decrease**.
    b. The peak flow rate during a storm and the time to peak will stay the **same**.
    c. The peak flow rate during a storm will **increase** and the time to peak will **increase**.
    d. The peak flow rate during a storm will **decrease** and the time to peak will **decrease**.
    e. The peak flow rate during a storm will **decrease** and the time to peak will **increase**.

2. What is a culvert?
    a. A pipe used to convey wastewater from an aeration pond to a settling basin.
    b. A pipe used to carry drinking water from the disinfection chamber to the storage tank.
    c. A conduit for conveying stormwater runoff under a roadway.
    d. A conduit for carrying sediment downstream during high flow events that may suspend the bed load.
    e. An earth-lined channel to carry irrigation water to agricultural areas.

3. What causes precipitation?
    a. When a humid airmass is forced to fall through the atmosphere.
    b. When air rises through the atmosphere, cools, and becomes oversaturated with moisture.
    c. When dust particles in the air act as a nuclei for electrical attraction.
    d. When two cloud systems collide in a region of relatively high barometric pressure.
    e. When water evaporates from the ocean, streams, lakes, and the temperature rises to above the dewpoint.

4. How can the sequence of storms over time (i.e., *antecedent moisture condition*) affect stormwater runoff quantity?
    a. If it was very **dry** in the days prior to a storm then there will be **greater**-than-usual runoff during that storm.
    b. If it was very **wet** in the days prior to a storm then there will be **less**-than-usual runoff during that storm.
    c. If it was very **dry** in the days prior to a storm then there will be **less**-than-usual runoff during that storm.
    d. If it was very **wet** in the days prior to a storm then the amount of storm runoff will be **unchanged** for that storm.
    e. If there was a **typical** amount of precipitation in the days before a certain storm, then the runoff from that storm will be **less** than when the prior moisture conditions were relatively **dry**.

5. What is aquifer drawdown?
    a. A decrease in well yield, generally observed only after many years of over-pumping.
    b. An increase in the amount of water that can be drawn from a groundwater well due to water being drawn from an adjacent surface water source.
    c. A decrease in the soil bearing capacity attributable to increased soil moisture content during a storm.
    d. A decrease in the hydraulic head observed at a well due to pumping at the well.

6. Floodway fringe *is*:
   a. Development on floodplains that reduces the flood-carrying capacity and increases flood height and hazard.
   b. The section of the floodplain that could be completely obstructed and still limit water surface elevation increase to 1 ft or less during the 100 year storm.
   c. The stream channel plus the adjacent floodplains that must be kept clear to limit the 100-year flood height increase to 1 foot or less.
   d. The floodplain area which must not experience any development due to risk of water damage.
   e. The process of extracting sediment from the banks of a floodway after high flow events to maintain the waterway for navigation and water conveyance.

7. Yesterday it was windy, relative humidity was 75%, and 150 gallons of water evaporated from a pond. Today it is not windy, and relative humidity is 25%. It was sunny both days, and the temperature was the same.

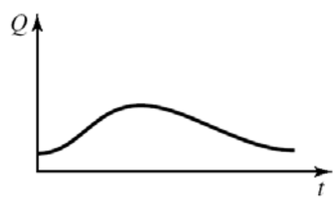
The relative amount of evaporation today:

a) Will be the same as yesterday
b) Will be more than yesterday
c) Will be less than yesterday
d) Cannot be generalized with the available information.

8. During a rainstorm, water flows over the sloped hillside depicted below, and the resulting hydrograph is as shown.

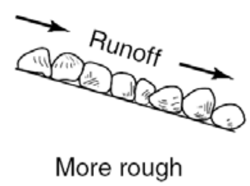
Existing hillside

Hydrograph



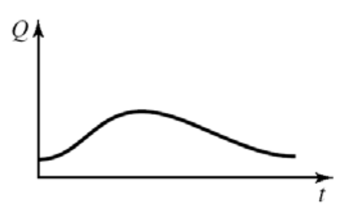
Modified hillside

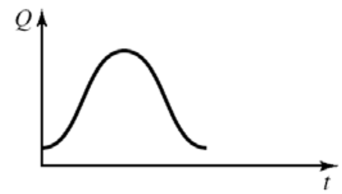
If the existing hillside is modified by adding rough, rocky stones, such as shown:



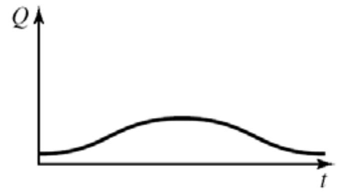
Then the resulting hydrograph is most nearly which of the following?

a)





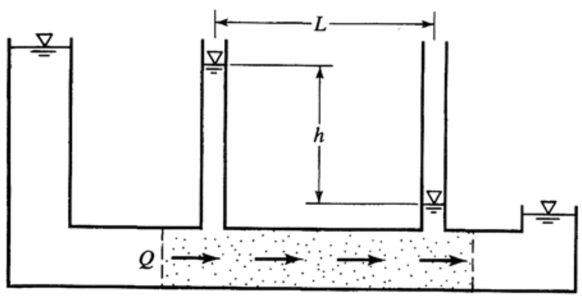
b)



c)

d) No generalization can be made with the available information.

9. The apparatus shown below can be used to characterize the hydraulic conductivity of soil. When it is loaded with sand then Q = 30 L/min. If the sand in the apparatus is replaced with clay:



a) Q will decrease below 30 L/min
b) Q will increase above 30 L/min
c) Q will remain at 30 L/min
d) Q cannot be determined with the available information

10. What is a watershed?
   a. An engineered covering that protects a surface from rain damage
   b. A man-made structure on the land surfaces that changes the course of flow in a river
   c. A political boundary that governs the management of water rights
   d. An impervious land surface
   e. An area of land that all drains to a common point

11. What is a hydrograph?
   a. Any statistical plot of data related to water
   b. Any water observation measurement such as rainfall, stream flow, depth, etc.
   c. A plot of stream discharge over time
   d. A fully submerges land mass
   e. A mathematical matrix used to determine the runoff from rainfall

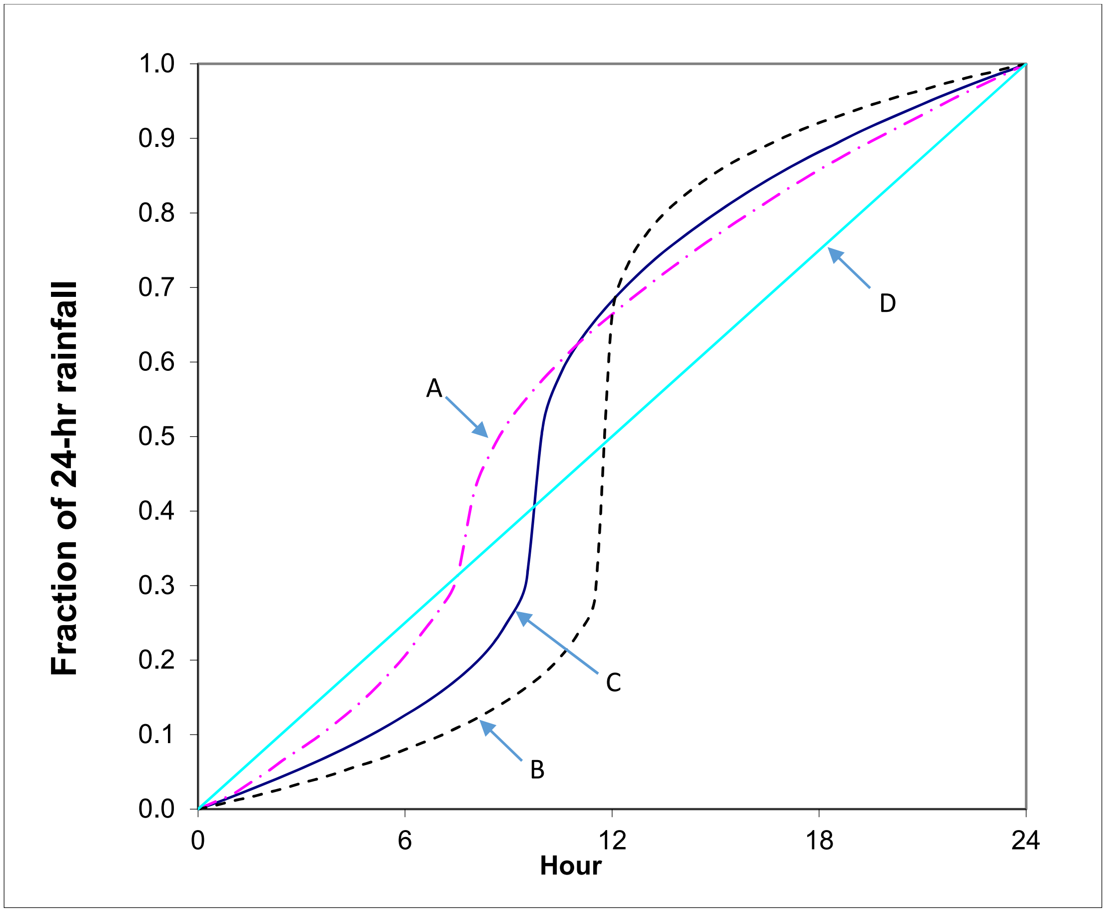
12. What is a unit hydrograph?
    a. A hydrograph normalized to 1 unit of discharge
    b. The hydrograph resulting from 1 unit of area
    c. A hydrograph with standard customary English units
    d. The hydrograph resulting from 1 unit of rainfall
    e. The hydrograph resulting from a 1-hour duration

13. What is the Time of Concentration?
    a. The time required for water to travel from the hydraulically most distant point of the watershed
    b. The time from the beginning of rainfall at which the watershed becomes saturated and produces runoff
    c. The time of concentrated rainfall that causes flooding
    d. The time duration of a flood hydrograph
    e. The time from the beginning of rainfall to measurable discharge at the outlet of a watershed

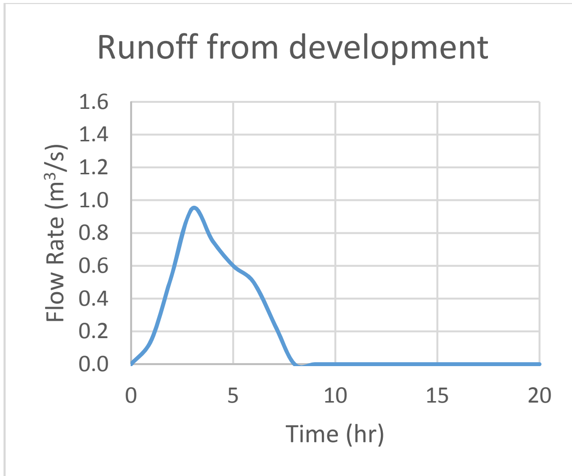
14. Which of the following will lead to an increased rate of infiltration of precipitation into soil during a certain storm?
    a. Compaction of the soil.
    b. Increasing the slope of the ground surface.
    c. A significant rainstorm in the day prior to the storm in question.
    d. Ponding of water at the surface.

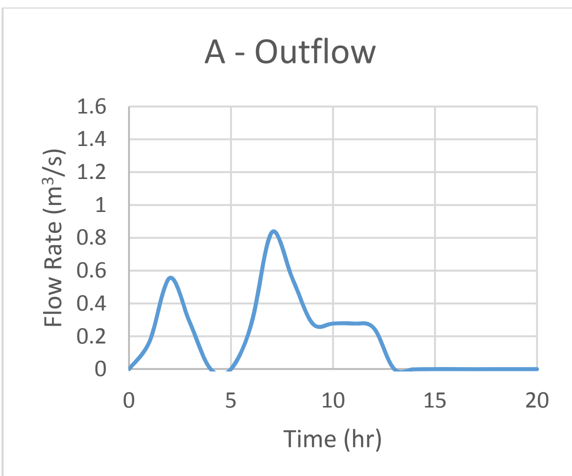
15. During a storm, 1.5 inches of rain falls onto a paved surface. The area of this surface is 2.0 acres. The total volume of water that has fallen onto the surface during this storm is most nearly: (Note: 1 acre = 43,560 ft^2).
    a. 10,890 ft^3
    b. 58,080 ft^3
    c. 65,340 ft^3
    d. 130,680 ft^3

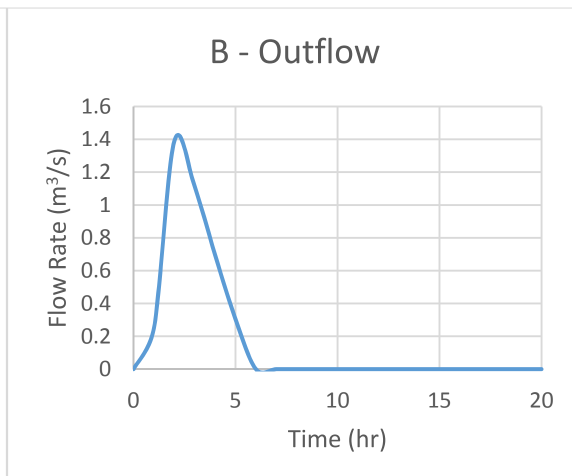
16. The figure provided below shows the fractional rainfall depth as a function of time for four different storms. Which of the storms would be the most likely to cause "flash flooding"?
    a. A
    b. B
    c. C
    d. D

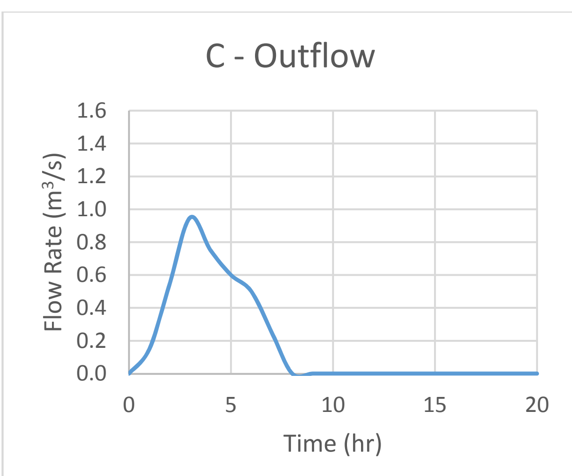

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Fraction of 24-hr rainfall
0
6
12
18
24
Hour
A
B
C
D

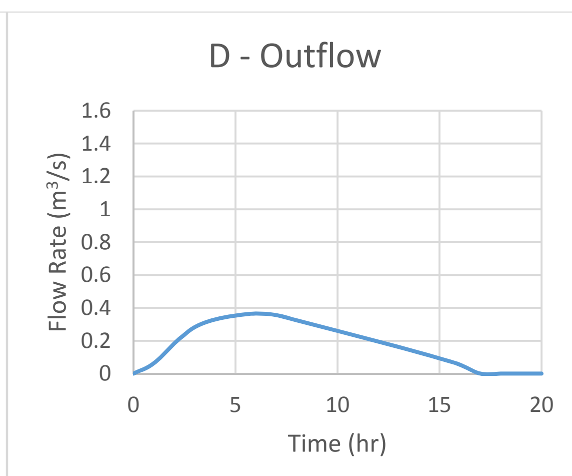
17. Runoff from an urban development is directed to a temporary detention pond before it is ultimately discharged into a nearby stream. A figure depicting runoff flow rate versus time is provided below. Which of the four outflow figures most nearly represents the likely discharge coming out of the detention pond? (Circle one)











18. Which of the following land covers would you expect to produce the least runoff, assuming the same rainfall amount?

a. 

b. 

c. 

19. What is base flow?
    a. Stream flow derived from the first half of the rainfall storm
    b. Stream flow derived from groundwater and delayed surface water runoff
    c. Stream flow derived from the first 1 foot of depth in the stream
    d. Stream flow derived from bank-full depth in the stream

20. What is the dead storage in a reservoir?
    a. The storage volume below all hydraulic structure outlets
    b. The storage volume below the spillway
    c. The storage volume above the spillway
    d. The storage volume that evaporates rather than discharges downstream

21. The peak precipitation intensity for a storm that has an average return period of 25 years __________ the peak precipitation intensity for a storm with an average return period of 5 years.
    a. is greater than
    b. is less than
    c. is equal to
    d. cannot be accurately predicted relative to