Global Journal of Engineering Education

Increasing access to hydrologic modelling through a two-phase course

Fariborz Daneshvar†, Jane R. Frankenberger†, Katy E. Mazer†, Laura C. Bowling† & Edwin F. Bocardo Delgado‡

Purdue University, West Lafayette, Indiana, United States of America†
Universidad Nacional de San Agustín, Arequipa, Peru‡

ABSTRACT: The soil and water assessment tool (SWAT) is a popular hydrologic model, but learning to use it effectively is challenging. In this study, a two-phase course was developed for teaching SWAT to students and faculty in Peru. The initial on-line course provided basic knowledge of SWAT, and participants who successfully completed it were qualified to participate in an in-person workshop, where they learned to adjust SWAT for regional studies and improve model performance. Evaluations were conducted at the end of both phases to determine course outcomes and the effectiveness of the two-phase approach. Results showed that both on-line and in-person phases were beneficial and complementary. The on-line course provided a low-cost, self-paced introduction and its required completion before the workshop increased efficiency of the in-person phase. The workshop was advantageous for learning objectives related to preparing and using local data, since questions became more frequent as the training proceeded from general concepts to site-specific application. The two-phase approach was beneficial for SWAT training and increased participants' access to this hydrological model.

Keywords: SWAT, hydrologic modelling, on-line training, workshop

INTRODUCTION

Hydrologic models are effective tools for evaluating the response of hydrologic systems to land and climate variations [1]. One of the most widely used is the soil and water assessment tool (SWAT), a watershed scale model developed by the United States Department of Agriculture [2]. SWAT simulates long-term impacts of land use, land management, and climate change on hydrology and water quality, and is widely used around the world to improve water resource decisions [2][3]. It is a comprehensive semi-distributed model that incorporates detailed information on topography, vegetation, soil, weather and land management practices within the watershed to simulate daily and sub-daily processes [4], using open source code with free geographic information system interfaces available for both ArcGIS and QGIS.

SWAT has been used in a wide range of water management studies conducted by university researchers, industrial and government agencies [5] resulting in more than 3,300 peer-reviewed journal articles [6]. Because of its widespread use and applications, the ability to use SWAT effectively is valuable for hydrologists and engineers around the world.

However, learning to use SWAT is difficult due to the variety and number of input files, range of optional features and required decisions to be made by users [4]. SWAT developers and expert users conduct irregular training workshops, especially during research conferences [7], but these trainings are costly and audiences are limited to specific groups of researchers. While the use of SWAT is taught in some university courses, students at universities without such courses have difficulty accessing training. In addition, SWAT users outside the US face additional challenges in learning to set up SWAT simulations, because the databases provided with the model use United States data, and modifying the databases for international use is an additional skill not often taught.

On-line training can provide an accessible alternative to in-person courses and workshops. In addition to expanding the geographic reach of a course's audience, on-line training is particularly useful for skills that people learn at different rates, because it allows self-pacing [8][9]. It takes into account differences in students learning preferences and provides more opportunities for their involvement in course discussions in forums [9][10]. It also provides the opportunity for learners to select what is most applicable to them, which is useful since all SWAT users do not need to learn all model features, many of which are optional depending on the specific application [4]. However, on-line training cannot provide all the advantages of in-person courses, especially for skills that require hands on experiences and face-to-face conversations [9]. A two-phase course, consisting of on-line training followed by in-person, can maximise the benefits of both types of learning. Studies have also revealed that using a time gap in the training process (called spaced training) will increase long-term retention of skills and knowledge [11-13].

A collaborative project between Purdue University in Indiana, USA, and the Universidad Nacional de San Agustín (UNSA) in Arequipa, Peru, identified the need for building capacity to use the SWAT model among students and faculty at the UNSA. Hydrologic modelling is used by a growing number of UNSA students in conducting research for their thesis required for obtaining a professional degree, and faculty who supervise the research will benefit from a deeper understanding of SWAT for effective advising and assessment. The certificate earned from the course will also benefit UNSA faculty by allowing them to demonstrate knowledge of this tool and its effectiveness in decision-making.

The goal of providing high quality SWAT training to UNSA faculty and students, while minimising travel costs suggested the two-phase approach, consisting of an on-line course followed by an in-person workshop. The goals were to 1) develop and deliver an effective introductory SWAT course; and 2) evaluate the effectiveness of the two-phase approach for increasing access to hydrologic modelling.

COURSE STRUCTURE

The course included two phases: on-line learning and an in-person workshop (Figure 1). The introductory on-line course provided self-paced introduction and prepared trainees for the advanced workshop, where they had a chance to focus on SWAT application in their region and model performance improvement. Participants who successfully completed the on-line course (Phase 1) were qualified to attend the in-person workshop (Phase 2), where they learned more about the model features and how to adjust it for their own regional studies.

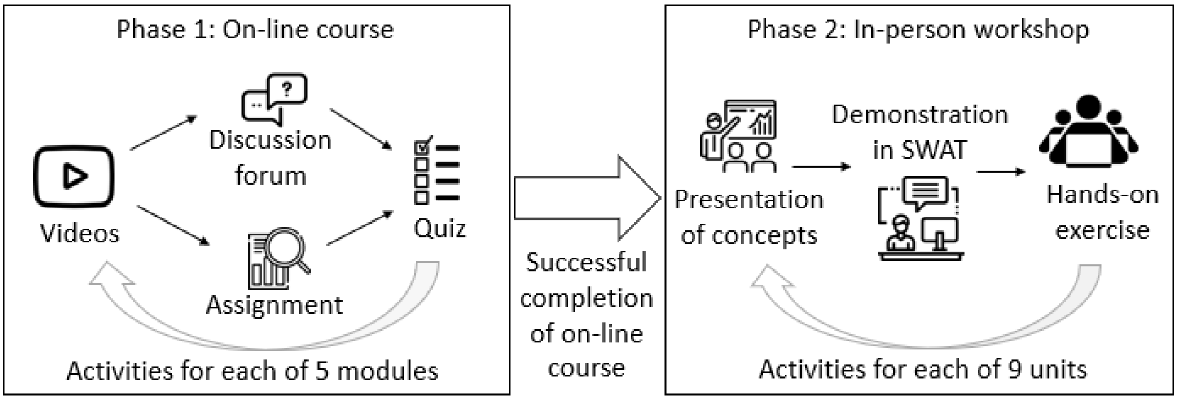

Figure 1: Two-phase course structure and activities.

Six learning objectives were covered in five on-line modules in Phase 1 and in the Phase 2 in-person workshop. Table 1 shows how the modules and workshop activities mapped to the learning objectives of the course. Each learning objective was covered in at least two modules and four out of six were covered in the workshop as well.

Table 1: Course learning objectives, and mapping of on-line modules and workshop to the objectives.

Learning objectives: after completing this course, participants will be able to:	Phase 1: on-line course modules	Phase 2: workshop
1. Describe basic SWAT model structure and capabilities	1, 3, 4	
2. Understand hydrological and meteorological concepts of the SWAT model	2, 3	
3. Develop the geographic representation required for a SWAT model	1, 2, 3, 5	1, 2, 3, 4
4. Create SWAT input files and run a simulation	1, 2, 3, 4, 5	5, 6
5. Analyse outputs and understand procedures for improving performance	4, 5	7, 8
6. Access and use SWAT on-line resources and user communities around the world to continue to learn after the course is completed	1, 2, 3	9

The on-line course included five modules offered for one week each. Modules 1 - 4 introduced new concepts and skills, while the objective of Module 5 was for participants to integrate their knowledge from previous modules to develop a SWAT model for a small watershed in the Arequipa region of Peru, based on a prepared dataset. The course was offered through a Moodle 3.5 platform. Participants who completed all tasks of the five modules received a certificate of completion.

Each module of the on-line course included four types of learning activities (Figure 1):

1) *Instructional videos* ranged in length from 5 to 12 minutes, and were made in English with Spanish closed captions to make them accessible for Peruvian audiences. These videos are also posted on the main page of the SWAT Web site and are accessible for public use [14].

2) *Assignments* were developed to encourage and monitor participants' progress in the course. Assigned tasks included running the model and providing screenshots, as well as questions on findings of completed steps.
3) *Discussion forums* allowed participants to share their thoughts and post their questions.
4) *A quiz at the end of each module* assessed participant understanding about major concepts related to the learning objectives of the module.

The four activities are described for one representative module in Table 2.

Table 2: Course activities for an example learning module.

Type of activity	Example for Module 4: simulation and output analysis
Instructional videos	• Run simulation and view outputs (9:02 minutes). • Analyse and improve SWAT model performance (7:34 minutes).
Assignment	• Run the model for two years, and save simulation output monthly, and plot monthly outflow for a specific stream reach. • Modify the curve number (a soil and land-use specific parameter) by reducing it 10%, then plot and compare the modified monthly outflow for the same reach. • Submit a screen capture of the hydrology tab of the output visualisation tool (SWATCheck) after the curve number is updated.
Discussion forum	• What do you think you are missing to run your own SWAT model? • Now that you have run SWAT, how do you think it could be useful?
Quiz questions (multiple choice)	• Why it is a good idea to have a warm-up period (NYSKIP) for a SWAT simulation? • What are benefits of writing output files into the database?

A two-day workshop conducted in Arequipa, Peru, for participants who completed the on-line course built on the introductory skills developed in the on-line course. The workshop included three activities for each of ten topics: 1) presentation of concepts; 2) demonstration in SWAT; and 3) hands on exercise (Figure 2). Short (less than 10 minutes) presentations reviewed major concepts from the on-line phase and also introduced new concepts including reservoir simulation in SWAT, determination of appropriate data sources, data preparation and output analysis. Presentations were followed by demonstrations in SWAT and hands on exercises, where students completed steps on their own personal computers. Step-by-step handouts and flash drives loaded with all required inputs were also provided to ensure that participants would be able to complete all tasks in case no Internet was available during the workshop and for future use.

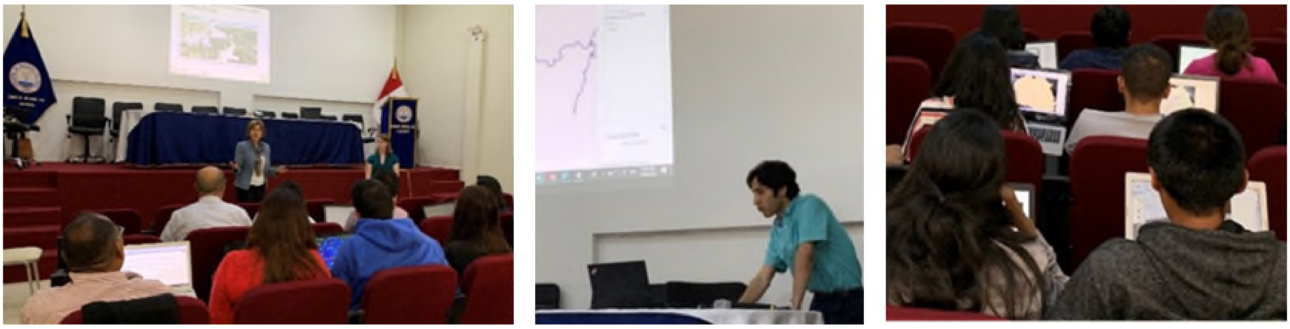

Figure 2: Three steps for each workshop unit including; left: presentation; middle: demonstration; and right: hands on.

The focus of the workshop was the preparation and use of local data in the SWAT model. Identifying data that could be used to parameterise and evaluate SWAT for a watershed in Peru was a major challenge, due to the lack of available weather and streamflow data in unregulated watersheds. Most streamflow measurements are downstream of dams, due to the importance of reservoirs in water management in Peru. Water balance analysis of a reservoir was conducted to estimate naturalised streamflow into the reservoir, providing data that was adequate for realistic model validation. Presentations on the difficulty of identifying data provided a realistic view of a major modelling challenge in this region.

EFFECTIVENESS EVALUATION OF THE TWO-PHASE APPROACH

Anonymous evaluations were conducted during and after the on-line course, and also at the end of the in-person workshop. Evaluations were reviewed and approved by Purdue University Human Research Program Institutional Review Board (IRB protocol #1902021719).

Overall, the on-line course was effective and met students' expectations. The final evaluation of the on-line course, completed by 19 participants (including 4 faculty, 11 graduate and 4 undergraduate students), showed that all participants were at least somewhat satisfied with the course and found that it was effectively designed to meet learning objectives. For almost all learning objectives, 70% or more selected *very comfortable* or *comfortable* completing objectives by the end of the course (Figure 3). Statements about on-line course effectiveness included the following:

- *This is the first time that I've used SWAT and I have noticed that the sequences for inputting data are simple and logical. The videos are very accurate and precise. I have been able to watch the videos many times and I now know how SWAT is structured.*
- *The videos were clear. The step-by-step instructions were very useful.*

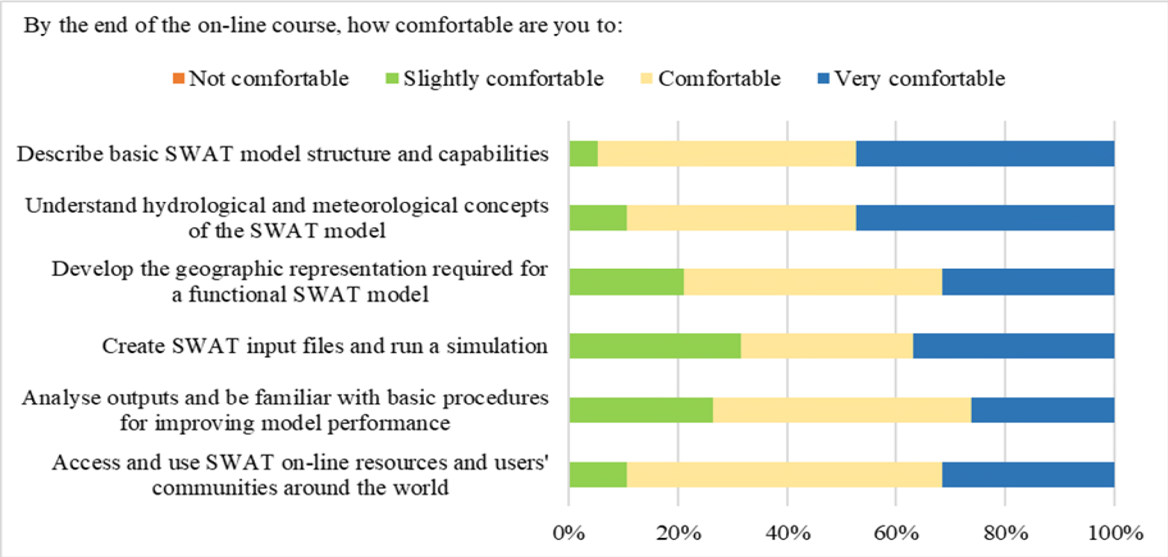

Figure 3: Participants' comfort with the learning objectives provided in the end of the on-line course (%).

At the end of the on-line course, participants' responses to appropriateness of the on-line method for teaching SWAT were mixed, where 84% found it somewhat appropriate, while 16% were neutral about it. However, 90% of participants said that it would be difficult for them to learn SWAT without this on-line course and 89% noted that they would use course materials frequently in future, which shows that the on-line course increased their access to SWAT. Spanish closed captions also made instructional videos more accessible for Peruvian audiences, and 90% of participants believed that not only did it make watching videos easier for them but also increased their understanding of course materials.

The evaluations conducted after each learning module showed that most participants were at least somewhat comfortable with the skills defined in the module-specific learning objectives (Table 3).

Table 3: Participants' evaluation of the success of meeting the learning objectives for each module.

By the end of the module, how comfortable are you completing the following tasks?	Not comfortable %	Slightly comfortable %	Comfortable %	Very comfortable %
1.1. Interacting with the SWAT Web site and the on-line SWAT community	-	26	52	22
1.2. Downloading and installing SWAT	-	33	67	-
1.3. Setting up a SWAT project	-	9	59	32
2.1. Delineating a watershed and sub basins	-	27	41	32
2.2. Overlaying soil, land use and slope layers	9	23	45	23
2.3. Making decisions about HRU definition to effectively model a watershed	5	36	55	5
3.1. Inputting weather data for SWAT	-	25	56	19
3.2. Understanding what information is found in input files that are required by SWAT	-	25	63	13
3.3. Writing and editing SWAT input files	19	19	50	13
4.1. Running SWAT for a given situation	-	43	57	-
4.2. Knowing tools that can help analyse SWAT output performance	-	43	57	-
4.3. Modifying SWAT inputs to improve performance	-	29	71	-
5.1. Integrating skills from previous modules to run SWAT on their own	6	33	33	28
5.2. Managing the model for a new location/watershed	11	39	22	28

Overall, participants were more comfortable in completing tasks of the first four modules, which included step-by-step trainings on SWAT, than tasks of the fifth module, which required them to integrate their knowledge from previous modules and apply it to a new region. This increase in difficulty partially stemmed from problems encountered in the simulation, which were difficult to address in the on-line course format, because it was difficult to give immediate feedback. This supports the need for the in-person workshop, which provides an opportunity for more interaction among participants and instructors to resolve unexpected problems faster.

Participants were also asked how much time they spent on each module. The target time requirement for each module was 2 to 3 hours, and although many were within this range, about 40% of participants spent more than three hours to complete each module (Figure 4). Overall, participants spent 10 to 15 hours on the on-line course, showing the advantage of this approach in terms of minimising costs compared to in-person training, especially for teaching abroad. Around 20% spent less than 2 hours on most modules, with some spending less than one hour, which suggests another advantage of on-line training by allowing self-pacing, so that each participant could spend the time he or she needed, while not slowing down the class.

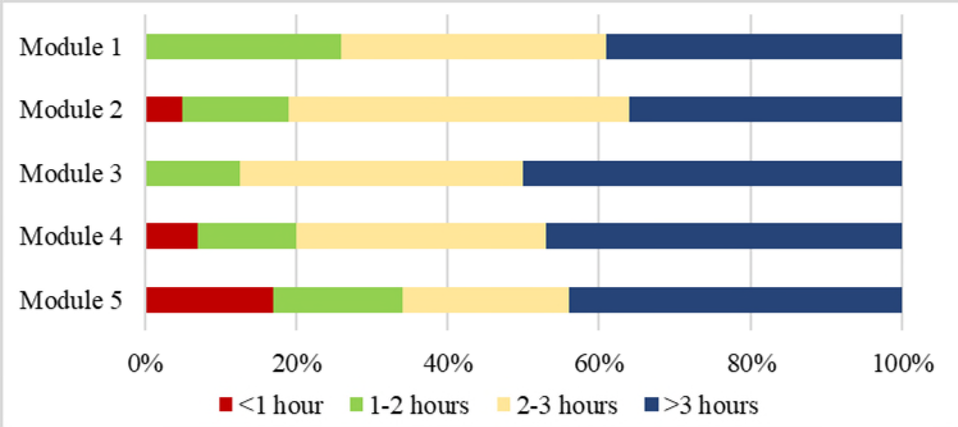

Figure 4: Time spent completing each module by percentage of respondents.

Seventeen participants who successfully completed both phases filled out final evaluations about the whole course at the end of the second phase (the workshop). Participants appreciated that the workshop allowed for more interaction and opportunities to ask questions. A typical comment about the benefits of the workshop was that: *All questions were answered and we gained a better understanding of SWAT.*

At the end of the workshop, 100% of participants stated that they were satisfied with both on-line and in-person phases and found both phases beneficial, unlike at the end of on-line course, when 16% were neutral about on-line course effectiveness for SWAT training (Figure 5). They also unanimously agreed that future in-person workshops should be preceded by an on-line training (Figure 5). This increase in appreciation of the on-line course at the end of the in-person workshop highlights the benefits of the two-phase approach. On-line training was beneficial, as it prepared them for the workshop where they learned how to develop a model on their own and adjust it for their regional studies.

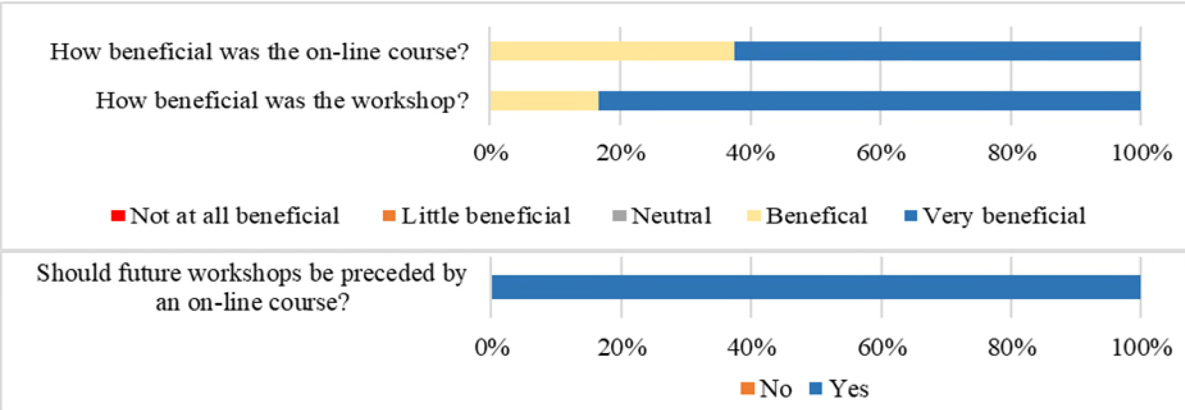

Figure 5. Participants' responses to effectiveness of the two-phase approach at the end of workshop (%).

Answers to open-ended statements showed how the on-line course and the workshop provided complementary benefits, combining self-pacing and remote access in the on-line course with the ability to discuss questions in the workshop.

1. The on-line course was beneficial because:

- *I had the videos at hand and I was able to pause them and repeat them at my own pace.*
- *It helped us to have a better basic understanding of the software and be able to run the model more quickly.*
- *You could understand the majority of advancing in the in-person course and you could complete those steps more quickly and learn or understand more things that were explained in the in-person workshop.*

2. The workshop was beneficial because:

- *It complemented the on-line course. We were able to solve errors quickly consulting directly with those in charge of the course. We were able to learn things that we couldn't learn during the on-line course.*
- *It resolved many of our concerns and helped us to better understand the SWAT application.*
- *We worked with a local case, which was more beneficial and understandable in our case.*

3. Future workshops should have a former on-line training because:

- *It accelerates the workshop.*
- *We came to the workshop prepared and it was easy to understand the workshop presentations.*
- *In the on-line course, we had time to learn the steps to follow and the tools to use, and to familiarize ourselves with problems that occur. The problems could then be solved in the in-person workshop.*

The effectiveness of the course is also demonstrated by the fact that professors and students of specialties including civil engineering, agricultural engineering, biology, environmental engineering, chemistry among others have expressed interest in participating in a similar course in the future, which could potentially be offered as an elective course in the fifth year of study. Informal comments suggested that the use of regional examples and the fact that the elements taught could easily be transferred to other scenarios made the course particularly beneficial.

CONCLUSIONS

SWAT is one of the most widely-used hydrologic models, but it can be challenging to learn and use. Evaluation results showed that both on-line and in-person phases were beneficial and complementary. Participants stated that the on-line course was appropriate for learning SWAT and it would be difficult for them to learn it without the on-line course.

In addition, the on-line course accelerated the in-person workshop by providing a self-paced introduction for foundational knowledge. The workshop enabled them to focus on region-specific SWAT application and model performance improvement. The interactive nature of the workshop setting facilitated problem solving to effectively run the model. Because of the complementary benefits, participants unanimously agreed that future workshops should be preceded by an on-line course.

ACKNOWLEDGEMENTS

This work was supported and funded by the Arequipa Nexus Institute for Food, Energy, Water and the Environment at Purdue University.

REFERENCES

1. Devia, G.K., Ganasri, B.P. and Dwarakish, G.S., A review on hydrological models. *Aquatic Procedia*, 4, 1001-1007 (2015).
2. Neitsch, S.L., Arnold, J.G., Kiniry, J.R. and Williams, J.R., Soil and Water Assessment Tool Theoretical Documentation Version 2009. Texas Water Resources Institute (2011).
3. Gassman, P.W., Sadeghi, A.M. and Srinivasan, R., Applications of the SWAT model special section: overview and insights. *J. of Environmental Quality*, 43, **1**, 1-8 (2014).
4. Arnold, J.G., Kiniry, J.R., Srinivasan, R., Williams, J.R., Haney, E.B. and Neitsch, S.L., SWAT 2012 Input/output Documentation. Texas Water Resources Institute (2013).
5. Blackland, Texas A&M Agrilife Research and Extension Center (2019), 16 March 2019, https://blackland.tamu.edu/models/swat/
6. SWAT Literature Database for Peer-Reviewed Journal Articles (2019), 16 March 2019, https://www.card.iastate.edu/swat_articles/
7. Soil and Water Assessment Tool (SWAT). Workshops (2019), 25 March 2019, https://swat.tamu.edu/workshops/
8. Holmes, B. and Gardner, J., *E-learning: Concepts and Practice*. Sage (2006).
9. Arkorful, V. and Abaidoo, N., The role of e-learning, advantages and disadvantages of its adoption in higher education. *Inter. J. of Instructional Technol. and Distance Learning*, 12, **1**, 29-42 (2015).
10. Wagner, N., Hassanein, K. and Head, M., Who is responsible for e-learning success in higher education? A stakeholders' analysis. *J. of Educational Technol. & Society*, 11, **3**, 26-36 (2008).
11. Brown, P.C., Roediger, H.L. and McDaniel, M.A., *Make it Stick*. Harvard University Press (2014).
12. Xue, G., Mei, L., Chen, C., Lu, Z.L., Poldrack, R. and Dong, Q., Spaced learning enhances subsequent recognition memory by reducing neural repetition suppression. *J. of Cognitive Neuroscience*, 23, **7**, 1624-1633 (2011).
13. Kramár, E.A., Babayan, A.H., Gavin, C.F., Cox, C.D., Jafari, M., Gall, C.M., Rumbaugh, G. and Lynch, G., Synaptic evidence for the efficacy of spaced learning. *Proc. National Academy of Sciences*, 109, **13**, 5121-5126 (2012).
14. Soil and Water Assessment Tool (SWAT) (2019), 19 March 2019, https://swat.tamu.edu/

Dr Fariborz Daneshvar is Postdoctoral Research Associate in the Department of Agricultural and Biological Engineering at Purdue University. He is also member of Arequipa Nexus Institute for Food, Energy, Water and the Environment at Purdue University. His research areas are watershed modelling and evaluating ecohydrological impacts of land use, land management and climate change at watershed scale.

Dr Jane Frankenberger is a Professor in the Department of Agricultural and Biological Engineering at Purdue University. Her research focuses on watershed management, nonpoint source modelling and water and nitrate flux to subsurface drainage tiles. She leads an integrated extension and research program focused on building the capacity of agencies, producers, watershed coordinators, communities, and citizens to protect water quality while maintaining agricultural productivity.

Katy Mazer is the project coordinator for the Sustainable Water Management project of the Arequipa Nexus Institute for Food, Energy, Water and the Environment at Purdue University. She has a Masters in Biological and Agricultural from NC State University, as well as experience in Spanish-language water resources extension and education in Latin America.

Dr Laura Bowling is a Professor in the Department of Agronomy at Purdue University. She is the co-director of the Arequipa Nexus Institute for Food, Energy, Water and the Environment at Purdue University and co-PI of the Sustainable Water Management project. Her expertise is in hydrologic model development and application in data scarce and cold environments. She is currently studying agricultural water use and water resource sustainability.

Dr Edwin Bocardo is a Professor in the Biology Department at the Universidad de San Agustín in Arequipa, Peru. He is co-PI in the Sustainable Water Management project of the Arequipa Nexus Institute for Food, Energy, Water and the Environment at Purdue University. His current research focuses on developing curves for ecological flow requirements in watersheds for the myriad riverine ecosystems throughout the Arequipa region.