Framing Human-Environment Connections through Waterscapes: A Geographic Lens for Teaching and Learning about Water Resources

Kim N. Irvine
Thammasat University

Chew-Hung Chang*
Nanyang Technological University

Tricia Seow
Nanyang Technological University

Diganta Das
Nanyang Technological University

Huu Ho Loc
Asian Institute of Technology

* *corresponding author*

Abstract

The concept of "waterscapes" is examined, with a focus on applications in secondary schools and the pedagogy for undergraduate geography students. The waterscape emphasis on external flows of capital, political relations, and policy that interact with the physical watershed, as well as the hydrosocial cycle, are particularly well suited to support teacher pedagogical content knowledge because of the flexibility in interpreting and applying concepts using what we have termed "the shallow sustainability approach". Employing case studies from the Singapore geography curriculum, we explore new pathways for the traditional interpretation of waterscapes that include linking mathematical modelling of hydrologic systems with rich local narratives.

Keywords: waterscapes, hydrosocial cycle, socio-hydrology, IWRM, WSUD, water resource management, water resource education

Introduction

> *...the study of water provides a logical link between an understanding of physical and social environments.*
>
> R.J. Chorley and R.W. Kates (1971, p. 3)

Characterizing human-environment interactions is a cornerstone of geographic research and education (Bednarz, 2006; Grindsted, 2013; Turner, 2002; Zimmerer, 2010) and in particular, we note the importance of Pattison's "four traditions of geography", originally published in 1964, and revisited again in 1990 (Pattison, 1990) that addressed the centrality of human-environment interaction in modern geography. Subsequently, the National Geography Standards released under the auspices of the National Council for Geographic Education in the U.S. included "Environment and Society", in which Standard 14 - *How human actions modify the physical environment*, Standard 15 - *How physical systems affect human systems*, and Standard 16 - *The changes that occur in the meaning, use, distribution, and importance of resources* are particularly pertinent to our discussions (Heffron & Downs, 2012). While the human-environment interaction is a central theme of geography, it is reflected using different philosophical and technical approaches as diverse as neoliberalism and Marxism, qualitative ethnographies and quantitative geospatial analysis and big data (e.g., Bakker, 2010; Castree, 2002; 2010; Church, 2010; DeLyser & Sui, 2014; Yang *et al.*, 2015;). Water is essential for life and as such provides a rich context by which to explore human-environment relations, per our opening quote.

The objective of this paper is to discuss and expand the concept of waterscapes as a pedagogical approach to facilitate a deeper understanding of the human-water environment interaction related to water resource assessment and management. Using case examples from secondary and undergraduate geography courses in Singapore to integrate aspects of content and Shulman's ideas regarding pedagogical content knowledge (PCK) (1986), we illustrate the value and relevance of waterscapes as a new lens to explore water resource issues within a geography curriculum. In essence, we see waterscapes as a new way of thinking about how we assess, manage, and teach about water resources that more explicitly incorporates the centrality of human-environment interaction and is distinctly geographical. However, we also conclude that there is a need to consider alternative interpretations and expand the concepts of waterscapes, thereby enhancing the utility of the concept within the pedagogical toolbox. In this, we suggest some pathways forward.

We begin this paper by providing a brief outline of three different conceptual approaches to water resource assessment and management, integrated water resources management (IWRM), socio-hydrology, and waterscapes. We follow this with a brief overview of pedagogical content knowledge (PCK) which is used to frame the discussion of the nexus between water resource management principles and PCK, as presented in the third section of the paper. Finally, a case study approach is used to explore how waterscapes can provide new ways of looking at water resource issues within a geography curriculum.

Current principles, practices, and paradigms of water resource assessment and management

In this section we discuss three different approaches to water resource assessment and management, namely, IWRM, socio-hydrology, and waterscapes. IWRM has been applied throughout the world (Borchardt *et al.*, 2016; Charnay, 2011; Giordano & Shah, 2014; Mekong River Commission, 2016) and the management framework is explored explicitly in university curricula, but generally at the graduate level and more as a planning and management topic with distinctly technical underpinnings (Bourget, 2006; Jonker, 2005; Powell & Larsen, 2013). Individual components of IWRM (e.g., water source and catchment conservation; valuing water resources economically and socially) are found within secondary school and undergraduate curricula (Hirsch & Lloyd, 2005; Irvine *et al.*, 2015a; Shah & Treby, 2006). The waterscape concept was first formally outlined by Swyngedouw (1999) and more recently, the field of socio-hydrology has begun to evolve (e.g., Di Baldassarre *et al.*, 2015; Loucks, 2015; Sivapalan *et al.*, 2014; Troy *et al.*, 2015).

Principles of Integrated Water Resource Management (IWRM)

Irvine *et al.* (2010) summarized the modern development of IWRM and its eight guiding principles. The eight guiding principles are as follows:

1) Water source and catchment conservation and protection are vital.
2) There should be agreement between stakeholders on water allocation within a national framework.
3) Management must be addressed and implemented at the lowest appropriate level.
4) Capacity building is essential to sustainable development and management of water resources.
5) Stakeholders from all sectors must be involved in a participatory process of developing inclusive water resource management policy.
6) Efficient water use is essential and can be considered an important ‘source’ in itself.
7) Water provides essential ecosystem services that should be appropriately valued.
8) Striking a gender balance is essential.

Although widely applied, there also has been considerable debate and criticism of IWRM. A common criticism, one that echoes earlier criticisms of sustainable development concepts, is that the definition of IWRM is too broad to be meaningful (Biswas, 2008; Jewitt, 2002; Medema *et al*., 2008). On the other hand, Anderson *et al*. (2008) argued that while different definitions of IWRM exist, there is a common understanding of its fundamental principles and approaches and that there should be a shift away from debates on definitions but rather towards identifying implementation mechanisms. Giordano and Shah (2014) concluded that "…the current monopoly of IWRM in global water management discourse is shutting out alternative thinking on pragmatic solutions to existing water problems." Cohen and Davidson (2011) suggested that with IWRM "…the conceptual jump from technical tool to governance unit was made without an attendant focus on the broader components of water governance.," while Garcia (2008) identified a number of questions and challenges faced by practitioners in moving from IWRM theory to real world application.

Principles of Socio-hydrology

The socio-hydrology literature tends to be dominated by the engineering and earth system science community who are exploring new approaches to managing water by linking complex system theory, demographics, and to a lesser extent, socio-economics. The social theory components, including geographical aspects of human-environment interactions in the socio-hydrology literature, are still not well-developed (e.g., Di Baldassarre *et al*., 2015; Loucks, 2015; Sivapalan *et al*., 2014; Troy *et al*., 2015; Wesselink *et al*., 2017).

As Wesselink *et al.* (2017) noted:

> The ontological aspiration of scholars in socio-hydrology is to capture the full range of human behavior in the interaction with the natural systems. However, in the methodological implementation of these ideas both the natural and the human dimensions are reduced to fit in a quantitative model. (p. 3)

Di Baldassarre *et al*. (2015), for example, developed an interesting approach that considered a peak-over-threshold time series of high-water levels and property damage to represent floods that were linked to three differential equations representing the temporal change of demography, technology, and society in response to flood conditions. It was concluded that the models successfully captured some of the general societal attributes, but Vogel *et al.* (2015) noted quantitative descriptions of stakeholder and societal behavior remain a great challenge.

Principles of Waterscapes

Perrault *et al.* (2012) succinctly summarized the principles of waterscapes:

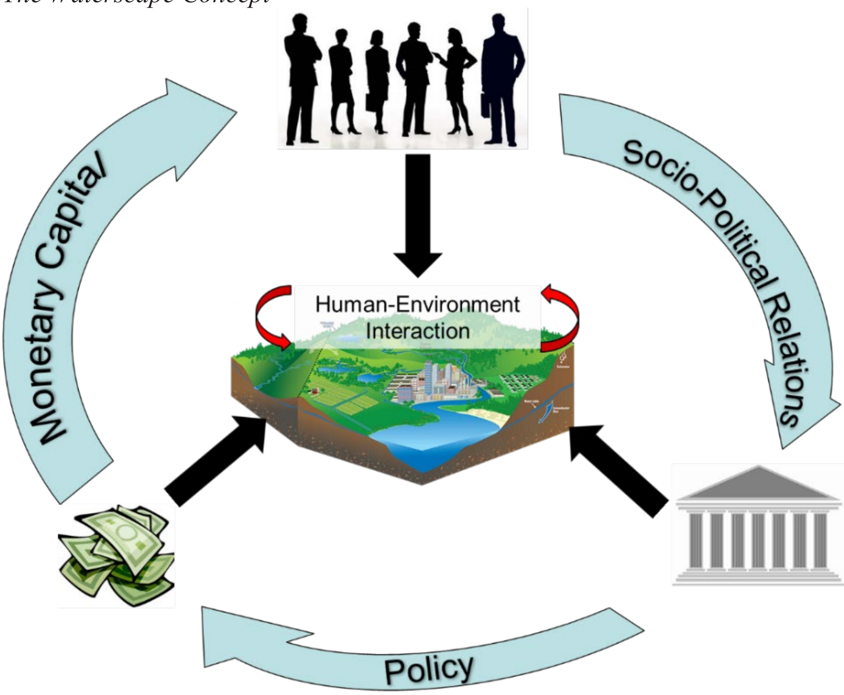
> Waterscapes explore the ways in which flows of water, power, and capital converge to produce uneven socio-ecological arrangements over space and time, the particular characteristics of which reflect the power relations that shaped their production (p. 486)

Importantly, a waterscape extends beyond the physical boundaries of a watershed (Figure 1). In some ways, as noted by Swyngedouw (1999) and reviewed by Irvine *et al*. (2016), waterscapes theory can be linked to concepts of political ecology. Swyngedouw (2009) also observed that "…interventions in the organization of the hydrologic cycle are always political in nature and therefore contested and contestable." Furthermore, our contention is that an important element of the waterscapes framework should be the hydrosocial cycle. Linton and Budds (2014) likely would disagree as they stated, "We propose the hydrosocial cycle as an analytical tool for investigating hydrosocial relations and as a broader framework for undertaking critical political ecologies of water." As we will discuss later, we believe the waterscapes concept to be more encompassing and elegant and therefore, we prefer to consider the hydrosocial cycle as an element within the waterscapes concept. The hydrosocial cycle begins to place a greater emphasis on the role of human involvement with the hydrologic cycle. As noted by Linton (2014):

> The hydrosocial cycle borrows somewhat from the concept of the hydrologic cycle, but modifies it in important ways. While the hydrologic cycle has the analytical effect of separating water from its social context, the hydrosocial cycle represents water as a hydrosocial fact, thus putting people and politics at the center of all water issues. (p. 114)

As such, the hydrosocial cycle addresses Swyngedouw's (1999) concern regarding the dualism of nature and society whereby the inseparable connection between nature and society is not adequately addressed.

Figure 1
The Waterscape Concept



Note. Human-environment interactions within the physical boundaries of the watershed remain central. However, there are policy, monetary, and socio-political currents that interact outside of the watershed boundaries, but which also flow into, and directly impact, the human-environment interactions within the watershed.

We see waterscapes as being characterized by two key changes in the way scientists examine water resources management:

1) The frame of reference has expanded to encompass the "human" aspect of the hydrological cycle, or the hydrosocial cycle, which emphasizes the geographical lens of human-environment interactions and provides us with a new way of thinking about the "what" we are studying. This informs the thinking about "how" we should investigate the hydrosocial cycle and creates a shift into new methods of knowing – surveys and observations will become as important as streamflow measurements or modelling.

2) The scale of analysis is dynamic. It is not fixed at the catchment level but scales up or down according to what needs to be examined, which represents a shift in terms of the way we do things.

Pedagogical Content Knowledge

The paradigm of pedagogical content knowledge (PCK) emerged from issues related to educational quality and the desire for reform in U.S. schools beginning in the early 1980's (Carlsen, 1999; Gess-Newsome, 1999). To address some of these concerns, Shulman (1986, 1987) began a line of research that identified signature characteristics of the teaching profession. Shulman (1986) initially outlined three categories of teacher knowledge: 1) content knowledge; 2) curricular knowledge; and 3) pedagogical content knowledge. Content knowledge pertains to what a teacher may have learned in formal (or informal) settings, such as through the courses in their major at university, while curricular knowledge refers to the tools (e.g., technology) and understanding of how to teach (e.g., teaching strategies for different learners). Pedagogical content knowledge refers to the teacher's ability to translate difficult content material so that it is understandable for the student. It is not sufficient to simply understand the content of the discipline; the teacher also must understand pre-conceptions that students of a particular age may have about a topic and have a range of strategies to address these pre-conceptions. We emphasize that these skills are equally pertinent to the high school teacher and the university professor.

As applied to science education reform, PCK follows a constructivist approach that is inquiry-oriented and student-centered. As such, teachers must "…select science content and adapt and design curricula to meet the interests, knowledge, understanding, abilities, and experiences of students" (Park *et al.*, 2011). Under these conditions, teachers with more sophisticated PCK skills may have a greater ability to implement educational reforms and the "deep sustainability" approach to the hydrosocial cycle described in the next section may present challenges for teachers to translate into pedagogy (see also Seow *et al.*, 2019a, 2019b). The question for this paper then becomes whether the waterscapes framework can be helpful in explaining the complex social and physical interactions of the hydrosphere.

Water Resource Management Frameworks and Implications for Pedagogy

Waterscapes, socio-hydrology, and IWRM have some similarities, but also a number of important differences. Wesselink *et al.* (2017) delivered an extensive and thoughtful comparison of the hydrosocial cycle and socio-hydrology and here we hope not to reiterate their very good summary, but rather offer some additional insights.

Linton and Budds (2014) provided a very detailed discussion of the properties of the hydrosocial cycle:

> We employ a relational-dialectical approach to conceptualize the hydrosocial cycle as a socio-natural process by which water and society make and remake each other over space and time....
>
> In the hydrosocial cycle, things like water, society and social power retain their positive identities but are understood to relate internally, whereby they are neither considered as already-existing entities, nor ones that can maintain independent identities following interaction with each other....
>
> This, in practice, implies that we need to think differently about water... One starting point, as suggested above, is to question the meaning of water(s) in any given situation. This will entail asking what different waters, knowledges, and meanings are articulated and how these might internalize vested interests and power structures.... (p. 175)

This clearly non-neoliberalist approach asks us to think in a new way about water, where we have a virtual molecular “watersociety” with internal bonding; the chemistry analogy being a water molecule (H0H). Socio-hydrology and IWRM, on the other hand, lend themselves to a more neoliberalist political interpretation and might be written Society + Hydrology (or as an ion group, H+ and OH-), which are separate, but connected entities (consistent with Chorley’s opening quote). In our experience, working with line agencies and community groups in applied water projects in North America and Southeast Asia, this proposed new way of thinking about water (i.e. “watersociety”) may present conceptual barriers (see also, Garcia, 2008). Similarly, this new way of thinking about water may present PCK challenges for teachers. As such, we suggest a “shallow sustainability” approach in applying the waterscapes (and hydrosocial cycle) concept, as opposed to the “deep sustainability” approach described by Linton and Budds (2014). Shallow sustainability focuses on the means we use to accomplish an end, favoring efficiency and substitution, while deep sustainability addresses the ends themselves through a more holistic approach. Shallow sustainability would address transportation issues by producing more efficient cars and alternative fuels, while a deep sustainability approach would focus on creating a quality of life in which one would work locally and eliminate the necessity for automobile transportation. If we extend this analogy to water, a shallow sustainability approach would pursue the construction of a raingarden to manage pluvial flooding whereas a deep sustainability approach would ask what is water and how do the social needs of all community members shape the oneness with the resource.

Water resource management typically is applied at the watershed scale. The watershed might be thought of as the fundamental hydrologic and geomorphologic unit because the physical boundaries facilitate the determination of water, sediment, and chemical mass balances, which are useful in supporting water resources management decision-making. While this physical boundary approach is helpful in quantifying mass balances, it also tends to focus attention on the local drivers and processes within the watershed and de-emphasizes external forcing factors (the issues of climate change not withstanding). This is underscored by the IWRM principle that management must be addressed and implemented at the lowest appropriate level. In part we might see this as a scale issue, and as noted above, the waterscapes framework can support a dynamic scaling approach. Furthermore, while IWRM retains a certain technical pragmatism that is attractive to on-the-ground application, we believe that waterscapes, with its geographical focus on spatial and temporal relations and human-environment interactions, can serve to fill the conceptual shortcomings of IWRM (cf. Cohen & Davidson, 2011) and provide a deeper appreciation for the complexities of water resource management. We would further contend that the richness of geographical community narratives gives a "face" to the daily negotiations of water accessibility and resiliency that cannot be entirely captured in mathematical abstraction (cf. Vogel *et al.*, 2015).

As sound water management continues to be an important theme globally, education is essential to ensure that the next generations will learn about innovative and sustainable approaches to management. What are the implications of such a shift in relation to geographic and water resources management pedagogy? In addition to the way curricula can be developed and what issues in water resources management and geography can be taught, it will also change the way we think about how the topics are taught. Let us consider case studies from Singapore to explore the implications of waterscapes for pedagogy.

Framing PCK and Waterscapes – the Singapore Curriculum Context

Because of its small catchment area and dense population, water is a matter of national security in Singapore (Tortajada, 2006) and the closed-loop water management approach in this island-state has evolved to become one of the most sophisticated and resilient systems in the world (Irvine *et al.*, 2014; Luan, 2010). Appropriately, water is a focal point in the Singapore geography curriculum, which has a rich modern history that has been traced by Irvine *et al.* (2015a), while Chang (2012) provides a detailed and critical review of geography education at all levels in Singapore.

Adapted from Roberts (2013), the 2014 syllabus (and retained through the 2021 revised syllabus), Geographical Inquiry, has been used as a key guide for pedagogy in the 2014 and 2021 school geography syllabus in Singapore. A related signature pedagogy in the geography curriculum is the required

Geographical Investigation (GI) at each grade level. The GIs typically are fieldwork-based and require the students to plan their research, gather and analyze data, and construct their geographical interpretations, as well as evaluate and communicate their findings. The intent of the GI is to reinforce classroom learning through fieldwork by giving the students an appreciation for real-world applications of geographical knowledge and skills.

Teacher preparation in Singapore currently follows two primary paths - a Bachelor of Arts or Science in Education, or the Postgraduate Diploma in Education (PGDE). All student teacher preparation in Singapore is done at the National Institute of Education (NIE), Nanyang Technological University. The four-year BA program, in the case of geography, requires students to complete both a full complement of physical and human geography courses (culminating in a required overseas field experience for their final year project) and pedagogy. Students enrolled in the 16-month PGDE program already have obtained an undergraduate degree, and apart from a small amount of content upgrade, focus entirely on pedagogy classes. Fieldwork for both the BA and the PGDE programs is an essential element of geographic education and prepares students to implement the GIs of the geography curriculum.

We now turn to a series of case studies to illustrate how waterscapes can clarify content within a curriculum in a way that supports PCK. For this, we focus on examples from the geography curriculum in Singapore. Examples could be equally drawn from geography curriculum throughout the world.

Waterscapes as a new pedagogical framework for Water Resource Education

Case study – the hydrosocial cycle and water management in Singapore

The senior author is a hydrologist who focuses on urban hydrology and was skeptical of the need to include the explicit designation of "social" as part of the discussion on the hydrologic cycle. It seemed to him that there would be no value-added in the modified term since human interactions and impacts are an integral component in all his research. However, because Singapore's geography curriculum has an in-depth focus on water issues, as do the BA and PGDE programs at NIE, we decided in some way to explore the need for specifically designating the "social" part of the hydrologic cycle. To address this question, we projected a diagram of the hydrologic cycle that included representations of a city, waterbodies (Lake Washington and Puget Sound, U.S.A.), farmland, and forest (i.e., differing land uses, including human activity) at the start of four different NIE classes. The students simply were instructed to "Describe What is Going on in this Diagram." No other explanation was provided, and the students were given five minutes to complete the task. The characteristics of the four classes are summarized in Table 1. The classes represent a range of levels and experience in geography but were selected by convenience as they were being taught by various of the co-authors. The total sample size across all classes was 43.

Table 1
Classes participating in the hydro-social cycle Description Experiment

Class	Academic Level	Class Size	Comments
AAG10A, *Elements of Physical Geography*	Year 1, BA program	9	A mix of students having geography as a primary or secondary focus
AAG40D, *Geographical Methods and Fieldwork*	Year 4, BA program	13	All students having a primary focus in geography and conducting their final year project
QCG52C, *Teaching Outside the Classroom*	PGDE program	8	Not all students had a Geography bachelor's degree
MAS944, *Global Cities*	Masters in Humanities Education	13	All were graduate students but only 2 were teaching Geography

A simple word cloud was constructed based on the narratives that each student provided and is shown in Figure 2. A few trends could be identified from this exercise and are apparent in the word cloud. First, in general, the students provided excellent process-oriented narratives and clearly described water movement through the hydrologic cycle. However, only 7 of 43 students (16%) made any meaningful statements regarding human interaction with the hydrologic cycle, with an additional 4 students referring to Puget Sound or Lake Washington by name. The PGDE class provided the least detail in the description of the hydrologic cycle and had the second lowest percentage (12%) of participants noting a human influence. Perhaps this result is related to the lack of a geographic background (not all PGDE students have a Geography degree). They may be only starting to transition from expert student to novice teacher, without the more extensive content-pedagogy connections of the BA program. Interestingly, the MA class had the highest percentage (38%) of participants noting a human influence, but only 2 in the class were geography teachers. Since the MA class represented older students than the PGDE class, this result may reflect the importance of what Morine-Dershimer and Kent (1999) call personal pedagogical knowledge, or the knowledge obtained through personal, practical experience.

Figure 2
Word Cloud

Note: Word cloud constructed from Singapore student descriptions of the hydrologic cycle diagram.

There is no doubt that we might have conducted a more rigorous and extensive evaluation, for example, using concept mapping. However, let us accept for now that there seems to be some evidence, at least in the context of the Singapore education system, that the majority of students do not explicitly identify the interaction between society and the hydrosphere. The question then becomes, how might the concept of waterscapes and hydrosocial cycle be implemented? Here, we turn to another case study in Singapore, Water Sensitive Urban Design.

Water Sensitive Urban Design and raingardens to illustrate the connections between the hydrosocial cycle and PCK

Water Sensitive Urban Design (WSUD) has been aggressively pursued in Singapore as a means of minimizing localized flooding, but maximizing the release of runoff to drinking water reservoirs and improving runoff quality (e.g., Irvine *et al*., 2014; Lim & Lu, 2016). The objective of WSUD is to mimic a site's pre-development hydrology utilizing design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source. WSUD is de-centralized and works with nature to reduce flooding and improve runoff quality. WSUD technologies include raingardens, cleansing biotopes, green roofs, grassed swales, pervious pavement, constructed and floating wetlands, rain barrels, and conservation of trees.

WSUD is of particular relevance to the Singapore Secondary 1 and junior college geography curricula, with their focus on approaches to managing urban flooding. Indeed, the Public Utilities Board (PUB, Singapore's water agency) has implemented a raingarden program with schools, while the Housing Development Board (HDB, the statutory board responsible for Singapore's public housing) has now included WSUD in all new HDB estate designs (Loc *et al*., 2020).

PUB, in partnership with NIE, AECOM, and Green Earth Consultants, collaboratively constructed a demonstration raingarden at NIE, details of which are discussed by Chang *et al*. (2018). The raingarden is instrumented with an Internet of Things (IoT) meteorological station (Figure 3a) and provides numerous learning opportunities including determination of simple water budgets, measuring infiltration rates (Figure 3b), and understanding how raingardens (as an example of WSUD) can be both a water management technology and make a city more liveable through enhancing greenspace. Urban liveability is a theme in the lower secondary geography curriculum.

Frequently, however, our NIE team is asked by teachers what they can do with a raingarden. The opportunities are boundless with respect to water management, liveability, and even climate change, but it requires us to help teachers bridge from established PUB policies and programs to the geography curriculum. How might waterscapes and the hydrosocial cycle help with this? To begin, fieldwork explicitly supports Geographic Investigations (GIs) as a signature pedagogy in Singapore schools. Infiltration measurement (Figure 3b) is an example of a specific GI undertaken at the Junior College level. The IoT meteorological station (Figure 3a) supports the Singapore Upper Secondary Geography 21st century competency goal of developing confident learners who can communicate effectively through the use of ICT (including big data).

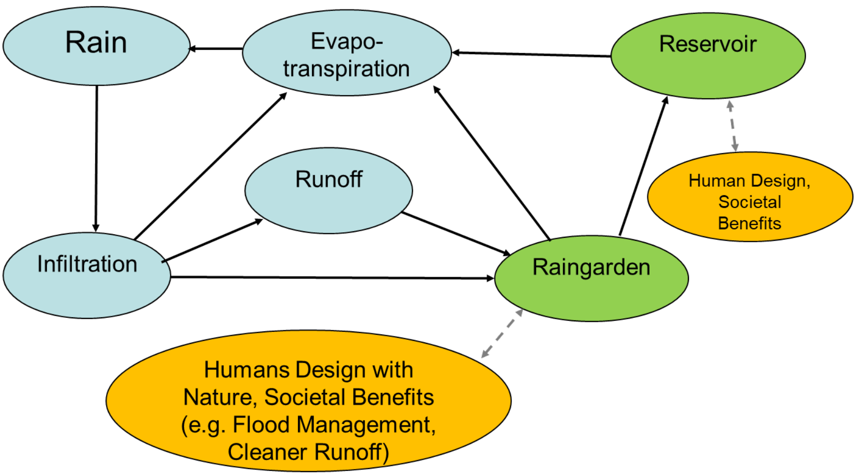
As such, several geography classes at NIE use the meteorological data in assignments. Selected final year project research has focused on sampling and evaluating the efficacy of the raingarden in improving runoff water quality (nutrients and total suspended solids). Water quality assessment is a Lower Secondary GI. These various topics and experiences are linked throughout the undergraduate program by content and pedagogy lecture material on pluvial water management, WSUD, and urban liveability.

Figure 3
A Demonstration Raingarden at NIE

3a. (above) NIE raingarden with IoT meteorological station in the foreground.
3b. (below) NIE students conducting infiltration experiments in the NIE raingarden. (Photo by authors)

As noted above, the hydrosocial cycle includes the human element explicitly as part of the hydrologic cycle. Teachers and student teachers in Singapore are well versed in the operation of the hydrologic cycle (Figure 2), but the standard hydrologic cycle might be modified, as in Figure 4, to represent the hydrosocial cycle for the raingarden. This type of hydrosocial cycle modification could be done for any WSUD, or water management structure, such as a reservoir. We acknowledge that our WSUD interpretation of the hydrosocial cycle is decidedly a “shallow sustainability” approach. It does not consider water and society as one, but as being separate and intimately linked.

Figure 4
Modified Hydrologic Cycle



Note. Components of the traditional hydrologic cycle (blue ovals) with some type of water resource management structure (e.g., raingarden or reservoir, green ovals), and the social interaction with the hydrologic cycle (tan ovals).

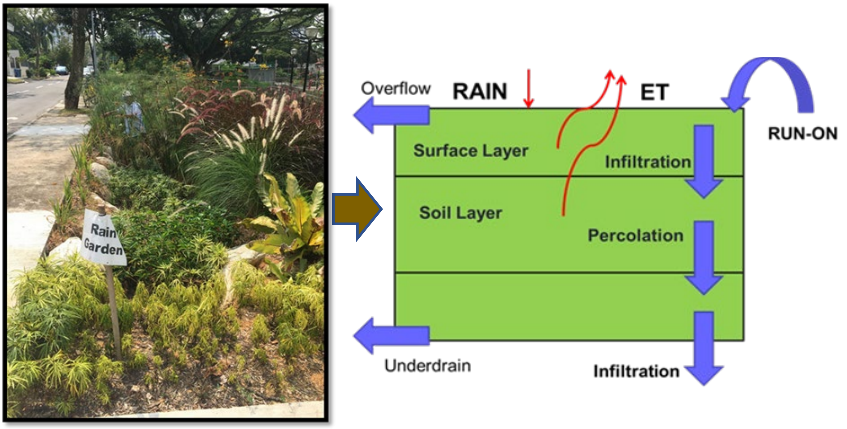
Components of the content, fieldwork, and lecture material noted above were incorporated into a Year 3 ecohydrology and catchment management course. It culminated in an assignment that applied PCSWMM, a deterministic, mathematical model, to deepen the understanding of WSUD benefits and connections to localized flood and water quality management. The first two individual assignments in the class (measuring infiltration rates in the raingarden and estimating evapotranspiration rates from the raingarden using the IoT data) provided input to the final assignment that applied PCSWMM to explore different design and runoff scenarios. PCSWMM, which is based on the U.S. EPA SWMM model, is a dynamic, deterministic water quantity and quality model that has been applied extensively around the world (e.g. Ho *et al*., 2015; Huber *et al*., 2005; Shrestha *et al*., 2014), As such, application of PCSWMM within a class assignment provided the students with an authentic learning experience. Model theory and hands on training were provided in the class. The assignment explored different development scenarios:

1) What would the runoff from the NIE raingarden catchment area look like prior to construction of the raingarden, when it was only a grassed area?
2) What would the runoff from the NIE raingarden catchment area look like after the construction of the raingarden?
3) What would the runoff from the NIE raingarden area look like if the raingarden was turned into a parking lot?

This assignment provided the students with experience in visualizing how a mathematical model represents the physical landscape to explore design options (Figure 5), which is most important as it links familiar visual perceptions with the technical aspects of mathematical modelling. In this way we hope to promote a multidisciplinary bridge akin to the classic human-environment investigations in the traditional geography curriculum.

Figure 5

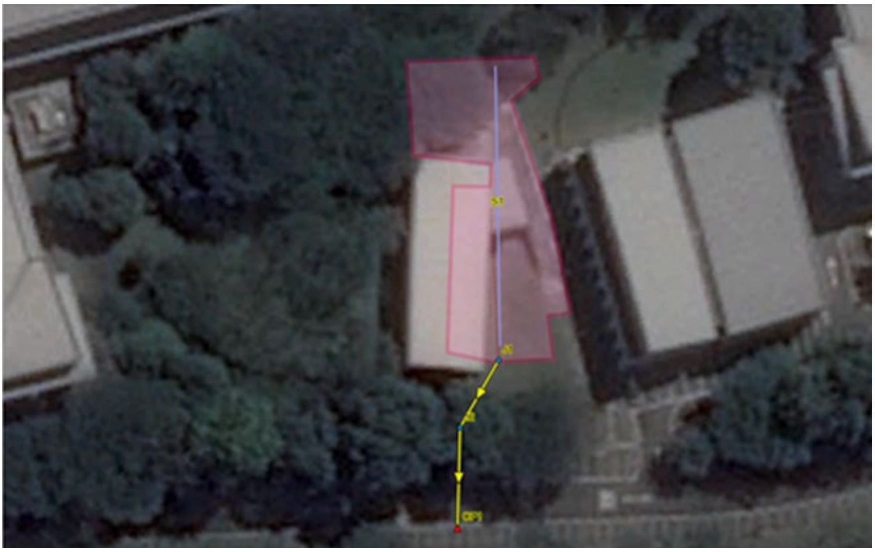
Faber Park Raingarden and it's Substrates



Note. Faber Park Raingarden, Singapore (left) as it appears visually at street level (photo by authors) and how the raingarden substrates (three layers in this example) and associated hydrologic processes are represented schematically in the PCSWMM model (right).

PCSWMM model results for a 40 mm rain event having a peak intensity of 66 mm/hr, as measured at the IoT meteorological station on March 26, 2018, are shown in Figures 6 and 7. To conclude this section, we have connected mathematical modelling with water resources management using the hydrosocial cycle as a theoretical underpinning (Figure 4). If we consider the waterscapes framework in this case study, we see that the general closed loop management and green infrastructure philosophy presented by PUB is implemented at a local scale (NIE campus). This process included flow of capital, policy, and even socio-political relations from outside of the NIE campus. Let us examine a final, larger scale example of waterscape theory in the next section to underscore some of the ideas initiated in this section.

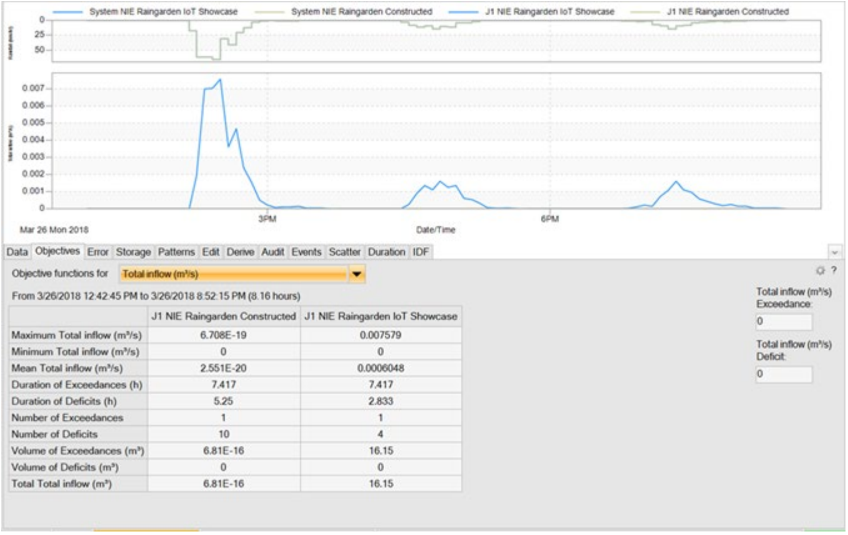
Figure 6
PCSWMM Model



Note: Plan view of raingarden and catchment area (pink polygon) with underdrain (yellow line) leading to a larger surface drain as represented in PCSWMM.

Figure 7

PCSWMM Results



	J1 NIE Raingarden Constructed	J1 NIE Raingarden IoT Showcase
Maximum Total inflow (m^3/s)	6.708E-19	0.007579
Minimum Total inflow (m^3/s)	0	0
Mean Total inflow (m^3/s)	2.551E-20	0.0006048
Duration of Exceedances (h)	7.417	7.417
Duration of Deficits (h)	5.25	2.833
Number of Exceedances	1	1
Number of Deficits	10	4
Volume of Exceedances (m^3)	6.81E-16	16.15
Volume of Deficits (m^3)	0	0
Total Total inflow (m^3)	6.81E-16	16.15

Note: PCSWMM results for storm event of March 26, 2018. Rainfall hyetograph from IoT station used as model input is shown in the top graph. Runoff from the area before the raingarden was constructed is shown as the blue line. Runoff leaving the raingarden, after raingarden construction, is shown in the tan line and essentially is not visible compared to the pre-raingarden construction scenario due to raingarden storage.

Loss of Wetlands, Phnom Penh, Cambodia

In this section we more fully connect the umbrella waterscape concept, including the hydrosocial cycle, within a larger and international spatial scale. This wetland example explicitly underscores the 21st century competency focus in the Singapore geography curriculum with respect to data acquisition and interpretation. The 21st century competencies of being a concerned citizen who appreciates the interdependency and fragility of the local and global environment and who has a sense of responsibility toward the Earth and its ecosystem also are addressed. This case study has been regularly featured in the AAG40B, Geographies of Sustainability class at NIE.

Phnom Penh, Cambodia does not have a traditional wastewater treatment plant to treat municipal waste. Instead, it relies on a system of naturally-occurring wetlands located in peri-urban regions. A combination of sampling and modelling conducted in the largest of Phnom Penh's wetlands, Boeng Cheung Ek, over the past decade has shown that it effectively treats wastewater quality (Irvine *et al*., 2006; Sovann *et al*., 2015; Visoth *et al*., 2010). Boeng Cheung Ek, which traditionally ranges in size from 1,300 ha in the dry season to 2,000 ha in the rainy season, provides a source of food and livelihood for the peri-urban community living on its shores (Ro *et al*., 2020; Figure 8).

Figure 8
Wetland Farmers

Note: Wetland farmers offload water spinach for local markets, with their wetland "fields" in the background and the encroaching city in the far background (photo by author, circa 2007)

After emerging from the tragic Khmer Rouge period during which the city was nearly entirely abandoned, development of Phnom Penh has flourished, with the population increasing from 999,800 in 1998 to 1.731 million in 2015. As the city has developed, it has begun to fill in the wetlands that provide wastewater treatment and flood protection services (Loc *et al*., 2020; Ro *et al*., 2020). The in-filling of Boeng Kak (a smaller wetland in north Phnom Penh) has been highly contested due to the displacement of marginalized communities and the apparent increase of localized flooding from a reduction in storage capacity (e.g., Schneider, 2011). Boeng Cheung Ek appears to be following the course of Boeng Kak. A recently completed 2-lane motorway has longitudinally dissected the wetland and water spinach production areas closest to Phnom Penh are rapidly being displaced by modern housing. Through their modelling efforts Irvine *et al*.

(2015b) were able to show that the motorway construction would negatively impact the wastewater treatment capacity of the wetland, but that it would still function. Further plans for infilling, however, make the future of the wetland uncertain and the question is, development for whom? The large, modern homes certainly are not for the young girl in Figure 9. In many ways, then, this issue underscores the waterscape emphasis on flows of capital (especially foreign investment) from outside of the watershed. It also emphasizes the dynamic nature of the rural-urban continuum and how socio-political relations and policy can impact local community.

Figure 9
Young Girl Displaced

Note: A young girl from a water spinach farming family examines the infilling sand that recently had displaced her family's house (photo by author, circa 2011).

Most certainly the situation in Phnom Penh illustrates well Swyngedouw's (2009) observation that "…interventions in the organization of the hydrologic cycle are always political in nature and therefore contested and contestable." But it is important in this contestation to consider the entire picture, from water quality to housing; from urban to peri-urban, and how mathematical models might be used to help make informed management decisions. The waterscapes lens encourages this type of inclusive investigative approach.

Conclusion

The key elements of a waterscape, that it extends beyond the physical boundaries of a watershed to consider the external flows of capital, political relations, and policy that interact with the physical watershed, together with the hydrosocial cycle, can be useful in focusing discussions on human-environment relationships. Certainly, Richard Chorley's observation that the study of water provides a logical link between an understanding of physical and social environments is pertinent to the concept of waterscapes. We have illustrated how PCK within the geography curriculum of Singapore might utilize the concept of waterscapes and the hydrosocial cycle to facilitate an understanding of complex water resource management dynamics. Waterscapes is a concept that is well-suited to teaching and learning about water because it is integrative, offers multiple perspectives, and meets the needs of a robust curriculum on sustainable management of water. Seow *et al*. (2019a) have argued that fieldwork is a type of signature pedagogy for learning geography because it met all the components of a signature pedagogy: (1) the concrete, operational teaching and learning practices employed by teachers; (2) the deep structural understandings they have about knowledge in their subjects; and (3) the professional values, beliefs, and attitudes they have about their craft. Collectively, these dimensions shape the discipline's habits of the "mind" (subject matter) and habits of the "heart" (values) such that when teachers use waterscapes as an organizational concept in class and in the field, they are teaching in a way that is distinctively geographical, considering the human-environment lens (e.g., in the last case study, development for whom?). This human-environment relationship is more easily overlooked in the technically oriented IWRM framework.

Although some may argue that the hydrosocial cycle, in and of itself, should be the framework focus, we believe the overarching idea of waterscapes provides both a broader investigative scope and a more appealing recognition touchstone. We also believe the approach of socio-hydrology, at this point, in trying to mathematically model societal responses deterministically, will be difficult. However, while the waterscapes concept is attractive, certainly in its geographic focus and the possible flexibility in facilitating development of PCK using our proposed "shallow sustainability" approach, it does not seem to have had a particular impact on the broader water resources community. Possibly, the waterscapes concept has not gained traction because frequently a qualitative case study approach has been used in association with a variety of social theories. The case studies are chosen to support the contentions of the researchers and without quantification are not reproducible and can reflect an overt bias towards the "human" side of the argument. In this sense it is analogous to the critical question "this is political ecology but where's the ecology?" (e.g., Walker, 2005). We have shown that mathematical modelling of the physical system and detailed physical and social data collection and analysis can be incorporated into the waterscapes approach which may be more appealing to hydrologic scientists and engineers, while at the same time addressing social concerns. Botkin and Keller (1998) noted that "When we confuse what we would like to believe with what we have the evidence to believe, we have a weak basis for making critical environmental decisions." We believe the evidence should include quantification, which is consistent with the 21st century education competencies, but also must be informed and enhanced through the geographic tradition of rich local narratives. As such, we suggest a possible way forward is to take an approach similar to climate change studies. Detailed mathematical modelling is conducted to characterize the physical system, but a more qualitative scenario or ensemble case study approach might be taken to become familiar with societal needs and thereby inform the modelling via an interactive, spiraling investigative approach.

References

Anderson, A., Karar, E., & Farolfi, S. (2008). Synthesis: IWRM lessons for implementation. *Water SA*, 34(6), 665-669.

Bakker, K. (2010). The limits of 'neoliberal natures': Debating green neoliberalism. *Progress in human geography*, 34(6), 715-735.

Bednarz, R. S. (2006). Environmental research and education in US geography. *Journal of Geography in Higher Education*, 30(2), 237-250.

Biswas, A. K. (2008). Integrated water resources management: is it working?. *International Journal of Water Resources Development*, 24(1), 5-22.

Borchardt, D., Bogardi, J. J., & Ibisch, R. B. (Eds.). (2016). *Integrated water resources management: Concept, research and implementation*. New York, USA: Springer.

Bourget, P. G. (2006). Integrated water resources management curriculum in the United States: results of a recent survey. *Journal of Contemporary Water Research & Education*, 135(1), 107-114.

Botkin, D. B., & Keller, E. A. (1998). *Environmental science: earth as a living planet* (No. Ed. 2). John Wiley & Sons Ltd.

Castree, N. (2002). False antitheses? Marxism, nature and actor - networks. *Antipode*, 34(1), 111-146.

Castree, N. (2010). Neoliberalism and the biophysical environment 1: What 'neoliberalism'is, and what difference nature makes to it. *Geography Compass*, 4(12), 1725-1733.

Carlsen, W. (1999). Domains of teacher knowledge. In *Examining pedagogical content knowledge* (pp. 133-144). Springer, Dordrecht.

Chang, C.H. (2012). A critical discourse of Singapore's school geography for the twenty-first century. *Literacy Information and Computer Education Journal*, 3(3), 717-729.

Chang, C. H., Irvine, K., Wu, B. S., & Seow, T. (2018). Reflecting on field-based and technology-enabled learning in geography. In *Learning geography beyond the traditional classroom* (pp. 201-212). Springer, Singapore.

Charnay, B. (2011). A System Method for the Assessment of Integrated Water Resources Management (IWRM) in Mountain Watershed Areas: The Case of the “Giffre” Watershed (France). *Environmental management*, 48(1), 189-197.

Chorley, R. J. & Kates, R.W. (1971). Introduction. In R. J. Chorley (Ed.). *Introduction to physical hydrology* (pp. 1-7). United Kingdom: Methuen and Co. Ltd.

Church, M. (2010). The trajectory of geomorphology. *Progress in Physical Geography*, 34(3), 265-286.

Cohen, A., & Davidson, S. (2011). The watershed approach: Challenges, antecedents, and the transition from technical tool to governance unit. *Water alternatives*, 4(1), 1.

DeLyser, D., & Sui, D. (2014). Crossing the qualitative-quantitative chasm III: Enduring methods, open geography, participatory research, and the fourth paradigm. *Progress in Human Geography*, 38(2), 294-307.

Di Baldassarre, G., Viglione, A., Carr, G., Kuil, L., Yan, K., Brandimarte, L., & Blöschl, G. (2015). Debates - Perspectives on socio-hydrology: Capturing feedbacks between physical and social processes. *Water Resources Research*, 51(6), 4770-4781.

Garcia, L. E. (2008). Integrated water resources management: A ‘small’ step for conceptualists, a giant step for practitioners. *International Journal of Water Resources Development*, 24(1), 23-36.

Gess-Newsome, J. (1999). Pedagogical content knowledge: An introduction and orientation. In J. Gess-Newsome & N.G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 3-17). Dordrecht: Springer.

Giordano, M., & Shah, T. (2014). From IWRM back to integrated water resources management. *International Journal of Water Resources Development*, 30(3), 364-376.

Grindsted, T. S. (2013). From the human-environment theme towards sustainability - Danish geography and education for sustainable development. *European Journal of Geography*, 4(3), 6-20.

Heffron, S. & Downs, R. (2012). *Geography for life: The National Geography Standards, Second Edition,* Washington, D.C.: National Council for Geographic Education.

Hirsch, P., & Lloyd, K. (2005). Real and virtual experiential learning on the Mekong: Field schools, e-sims and cultural challenge. *Journal of Geography in Higher Education*, 29(3), 321-337.

Huber, W. C., Rossman, L. A., & Dickinson, R. E. (2005). EPA storm water management model, SWMM5. In V. P. Singh & D. K. Frevert (Eds.), *Watershed models* (pp. 339-361). Boca Raton: CRC Press.

Irvine, K. N., Murphy, T., Sampson, M., Dany, V., Vermette, S. J., & Tang, T. (2006). An overview of water quality issues in Cambodia. In W. James, K. N. Irvine, E. A. McBean, & R. E. Pitt (Eds.), *Effective modeling of urban water systems, monograph 14,* (pp. 17-52). Guelph: Computational Hydraulics International.

Irvine, K. N., Chan, L., Chea, P., Chea, S., Neung, S., Ngin, P., Sok, K., & Yen, S. (2010). Integrated water resources management– Opportunities and challenges for Cambodia. In K. Irvine, T. Murphy, V. Vanchan, and S. Vermette (Eds.), *Water resources and development in Southeast Asia*, (pp. 108-136). Boston: Pearson.

Irvine, K. N., Chang, C. H., & Das, D. (2016). Waterscapes Asia: Concepts and practices. *Journal of Geography, Environment and Earth Science International*, 5(3), 9.

Irvine, K. N., Chua, L., & Eikass, H. S. (2014). The four national taps of Singapore: A holistic approach to water resources management from drainage to drinking water. *Journal of Water Management Modeling*, C375, 11.

Irvine, K. N., Seow, T., Leong, K. W. & Cheong, D. S. I. (2015a). How high's the water, Mama? A reflection on water resource education in Singapore. *HSSE Online*, 4(2), 128-162.

Irvine, K. N., Sovann, C., Suthipong, S., Kok, S., & Chea, E. (2015b). Application of PCSWMM to assess wastewater treatment and urban flooding scenarios in Phnom Penh, Cambodia: A tool to support eco-city planning. *Journal of Water Management Modeling*, 23 http://dx.doi.org/10.14796/JWMM.C389

Jewitt, G. (2002). Can integrated water resources management sustain the provision of ecosystem goods and services? *Physics and Chemistry of the Earth, Parts A/B/C*, 27(11-22), 887-895.

Jonker, L. (2005). IWRM: What should we teach? A report on curriculum development at the University of the Western Cape, South Africa. *Physics and Chemistry of the Earth, Parts A/B/C*, 30(11-16), 881-885.

Lim, H. S., & Lu, X. X. (2016). Sustainable urban stormwater management in the tropics: An evaluation of Singapore's ABC waters program. *Journal of Hydrology*, 538, 842-862.

Linton, J. (2014). Modern water and its discontents: A history of hydrosocial renewal. *Wiley Interdisciplinary Reviews: Water*, 1(1), 111-120.

Linton, J., & J. Budds. (2014). The hydrosocial cycle: Defining and mobilizing a relational-dialectical approach to water. *Geoforum*, 57, 170-180.

Loc, H. H., Babel, M. S., Weesakul, S., Irvine, K. N., & Duyen, P. M. (2015). Exploratory assessment of SUDS feasibility in Nhieu Loc-Thi Nghe Basin, Ho Chi Minh City, Vietnam. *British Journal of Environment and Climate Change*, 5(2), 91-103.

Loc, H. H., Irvine, K. N., Suwanarit, A., Vallikul, P., Likitswat, F., Sahavacharin, A., Sovann, C., & Le, S. H. (2020). Mainstreaming ecosystem services into public policies and planning: Current practices, bridges and barriers in Southeast Asia. In V. Mauerhofer, D. Rupio, & L. Tarquinio (Eds.), *Sustainability and law: General and specific aspects,* (pp. 631-665). Springer Nature, Switzerland AG, Cham.

Loucks, D. P. (2015). Debates - Perspectives on socio-hydrology: Simulating hydrologic-human interactions. *Water Resources Research*, 51(6), 4789-4794.

Luan, I. O. B. (2010). Singapore water management policies and practices. *International Journal of Water Resources Development*, 26(1), 65-80.

Medema, W., McIntosh, B., & Jeffrey, P. (2008). From premise to practice: a critical assessment of integrated water resources management and adaptive management approaches in the water sector. *Ecology and Society*, 13(2), 29.

Mekong River Commission (2016). IWRM-based Basin Development Strategy 2016-2020. MRC: Vientiane.

Morine-Dershimer, G., & Kent, T. (1999). The complex nature and sources of teachers' pedagogical knowledge. In J. Gess-Newsome and N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 21-50). Dordrecht: Springer.

Park, S., Jang, J. Y., Chen, Y. C., & Jung, J. (2011). Is pedagogical content knowledge (PCK) necessary for reformed science teaching? Evidence from an empirical study. *Research in Science Education*, 41(2), 245-260.

Pattison, W. D. (1990). The four traditions of geography. *Journal of Geography*, 89(5), 202-206.

Perreault, T., Wraight, S., & Perreault, M. (2012). Environmental injustice in the Onondaga lake waterscape, New York State (USA). *Water Alternatives*, 5(2), 485-506.

Powell, N., & Larsen, R. K. (2013). Integrated water resource management: A platform for higher education institutions to meet complex sustainability challenges. *Environmental Education Research*, 19(4), 458-476.

Ro, C., Sovann, C., Bun, D., Yim, C., Bun, T., Yim, S., & Irvine, K. N. (2020). The economic value of peri-urban wetland ecosystem services in Phnom Penh, Cambodia. In *IOP Conference Series: Earth and Environmental Science*, 561(1), 012013, 1-8. IOP Publishing.

Roberts, M. (2013). *Geography through enquiry*. Sheffield: Geographical Association.

Schneider, H. (2011). Development at the expense of the environment and the poor: The conflict for Boeng Kak lake in Phnom Penh, Cambodia. *Pacific News*, 36, 4-10.

Seow, T., Chang, J., & Irvine, K. N. (2019a). Field-Based Inquiry as a Signature Pedagogy for Geography in Singapore. *Journal of Geography*, 118(6), 227-237.

Seow, T., Irvine, K. N., Beevi, I., & Premathillake, T. (2019b). Field-based enquiry in geography: the influence of Singapore teachers' subject identities on their practice. *International Research in Geographical and Environmental Education*, 28: 1-15.

Shah, A., & Treby, E. (2006). Using a community based project to link teaching and research: The Bourne Stream partnership. *Journal of Geography in Higher Education*, 30(1), 33-48.

Shrestha, A., Chaosakul, T. A., Priyankara, D. P., Chuyen, L. H., Myat, S. S., Syne, N. K., Irvine, K. N., Koottatep, T., & Babel, M. S. (2014). Application of PCSWMM to explore possible climate change impacts on surface flooding in a Peri-urban area of Pathumthani, Thailand. *Journal of Water Management Modeling*, C37, 7

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15(2), 4-14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, 57(1), 1-23.

Sivapalan, M., Konar, M., Srinivasan, V., Chhatre, A., Wutich, A., Scott, C. A., Westcoat, J. L., & Rodríguez-Iturbe, I. (2014). Socio-hydrology: Use-inspired water sustainability science for the Anthropocene. *Earth's Future*, 2(4), 225-230.

Sovann, C., Irvine, K. N., Suthipong, S., Kok, S., & Chea, E. (2015). Dynamic modeling to assess natural wetlands treatment of wastewater in Phnom Penh, Cambodia: towards an eco-city planning tool. *British Journal of Environment and Climate Change*, 5(2), 105-115.

Swyngedouw, E. (1999). Modernity and hybridity: Nature, regeneracionismo, and the production of the Spanish waterscape, 1890–1930. *Annals of the Association of American Geographers*, 89(3), 443-465.

Swyngedouw, E. (2009). The political economy and political ecology of the hydro-social cycle. *Journal of Contemporary Water Research & Education*, 142(1), 56-60.

Tortajada, C. (2006). Water management in Singapore. *Water Resources Development*, 22(2), 227-240.

Troy, T.J., Konar, M., Srinivasan, V., & Thompson, S. (2015). Moving sociohydrology forward: A synthesis across studies. *Hydrology and Earth System Sciences*, 19(8), 3667-3679.

Turner, B. L. (2002). Contested identities: Human-environment geography and disciplinary implications in a restructuring academy. *Annals of the Association of American Geographers*, 92(1), 52-74.

Visoth, T., Yim, M., Vathna, S., Irvine, K. N., & Koottatep, T. (2010). Efficiency of Phnom Penh's natural wetlands in treating wastewater discharges. *Asian Journal of Water, Environment and Pollution*, 7(3), 39-48.

Vogel, R. M., Lall, U., Cai, X., Rajagopalan, B., Weiskel, P. K., Hooper, R. P., & Matalas, N. C. (2015). Hydrology: The interdisciplinary science of water. *Water Resources Research*, 51(6), 4409-4430.

Walker, P. A. (2005). Political ecology: Where is the ecology? *Progress in Human Geography*, 29(1), 73-82.

Wesselink, A., Kooy, M., & Warner, J. (2017). Socio-hydrology and hydrosocial analysis: Toward dialogues across disciplines. *Wiley Interdisciplinary Reviews: Water*, 4(2), e1196.

Yang, Z., Long, Y., & Douay, N. (2015). Opportunities and limitations of big data applications to human and economic geography: The state of the art. *Progress in Geography*, 34(4), 410-417.

Zimmerer, K. S. (2010). Retrospective on nature-society geography: Tracing trajectories (1911–2010) and reflecting on translations. *Annals of the Association of American Geographers*, 100(5), 1076-1094.

Dr. Kim N. Irvine is an Associate Professor at the Faculty of Architecture and Planning, Thammasat University, Rangsit Centre, Patum Thani, Bangkok, Thailand.

Dr. Chew-Hung Chang is the Dean of Academic and Strategic Development for the Institute and an Associate Professor at the Humanities and Social Studies Education Academic Group at the National Institute of Education, Nanyang Technological Univeristy, Singapore.

Dr. Tricia Seow is a Senior Lecturer at the Humanities and Social Studies Education Academic Group at the National Institute of Education, Nanyang Technological Univeristy, Singapore.

Dr. Diganta Das is an Associate Professor at the Humanities and Social Studies Education Academic Group at the National Institute of Education, Nanyang Technological Univeristy, Singapore

Dr. Ho Huu Loc is an Assistant Professor of Water Engineering and Management at the School of Engineering and Technology at the Asian Institute of Technology, Thailand.