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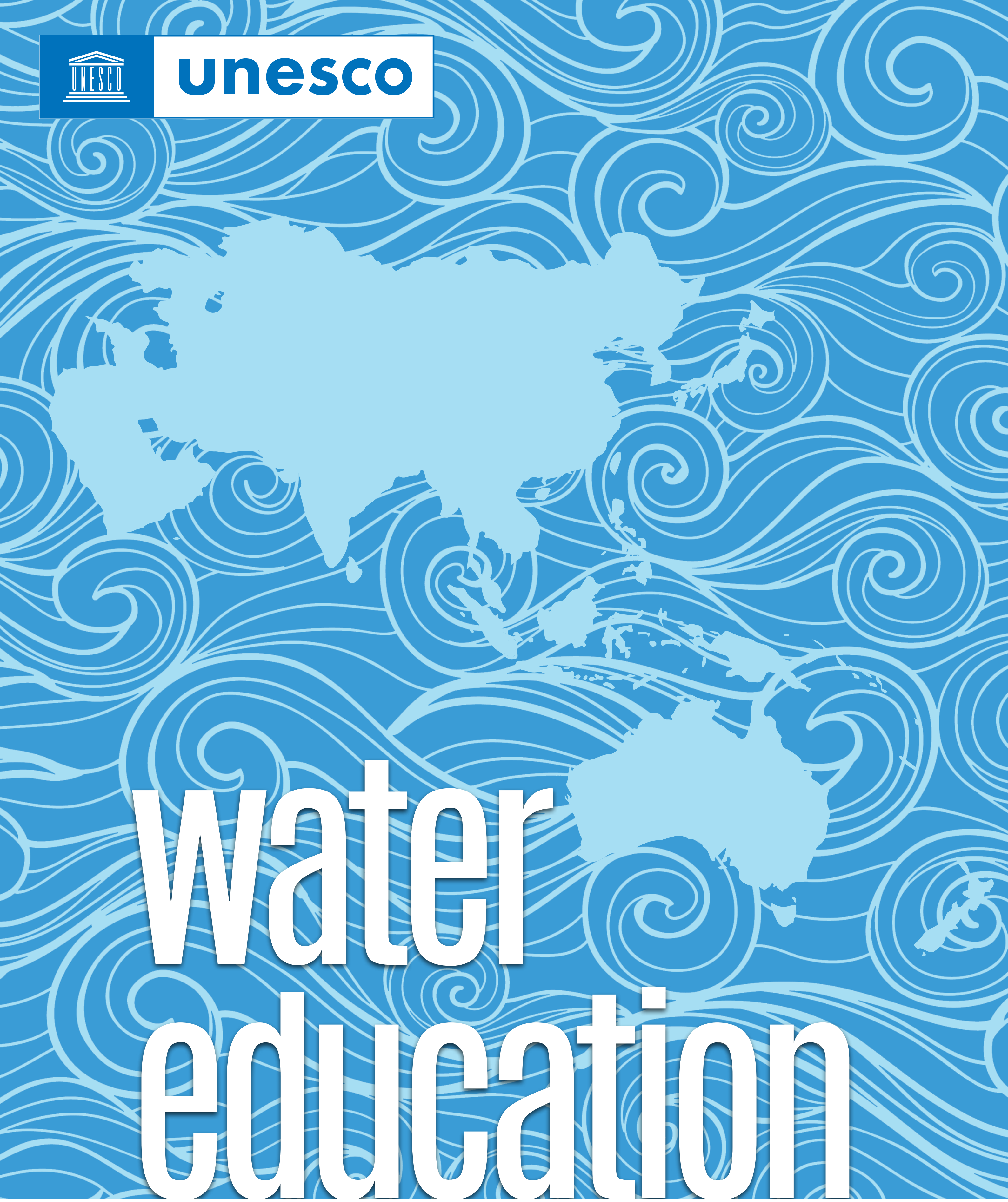

water education

for climate resilience in Asia and the Pacific

A REGIONAL CURRICULUM

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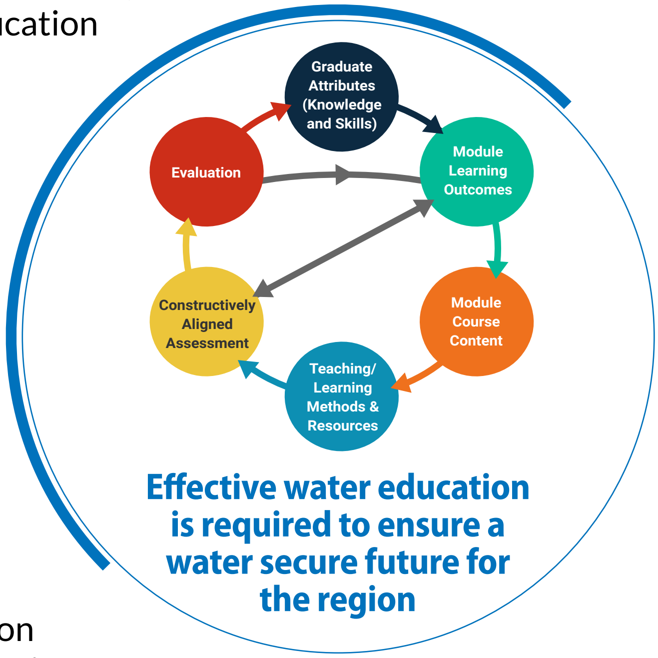
Water education: key to water security

A fundamental element towards attaining water security, water education has been at the heart of UNESCO's Intergovernmental Hydrological Programme since its establishment in 1975.

However, in much of Asia and the Pacific, water security remains elusive. Ensuring a water secure future for the region will require the unlocking of broader appreciation, acceptance and internalization of basic water science principles and concepts among experts and communities alike. For this, broader and more effective water education is required.



For this potential to be fulfilled, reinforced human, financial and technical resources are required to deliver education, training and capacity development across large segments of society. Not only does this require the mobilization of a much larger contingent of trainers, instructors and conveners—it requires the development of new teaching and learning approaches, methodologies and curricula.

This curriculum represents an invitation to tertiary-level educators as well as water managers and decision-makers to redouble efforts towards water security in Asia and the Pacific – and invitation grounded in a process that lies at the heart of UNESCO's mission: the sharing of knowledge, experience and technologies – in this case among scientific, educational and water management communities across the region.

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"Since wars begin in the minds of men and women it is in the minds of men and women that the defences of peace must be constructed"

water education

for climate resilience in Asia and the Pacific

A REGIONAL CURRICULUM

Foreword

Shahbaz Khan
Director and Representative
UNESCO Regional Science Bureau for Asia and the Pacific
Jakarta, Indonesia

Water Education has been at the heart of UNESCO's Intergovernmental Hydrological Programme since its establishment in 1975. The programme's current strategy notes that water education is *key for water security*. As water security remains elusive in much of Asia and the Pacific, this should be understood as a reference to an unfulfilled potential. If Asia and the Pacific is to have a water secure future, it will require the unlocking of broader appreciation, acceptance and internalization of basic water science principles and concepts—for which water education is the key.

To fulfil this potential, reinforced human, financial and technical resources are required to deliver education, training and capacity development across large segments of society. Not only does this require the mobilization of a much larger contingent of trainers, instructors and conveners—it requires the development of new teaching and learning approaches, methodologies and curricula.

The volume you are now reading makes a targeted contribution towards this essential effort. It is the result of a process that lies at the heart of UNESCO's mission: the sharing of knowledge, experience and technologies – in this case among scientific, educational and water management communities across Asia and the Pacific.

This regional curriculum is a result of a multi-year project supported by the Government of Japan through UNESCO Funds-in-Trust under the title "International Hydrological Programme Water Informatics for Sustainability and Enhanced Resilience in Asia and the Pacific", abbreviated as **IHP-WISER in Asia and the Pacific**. This curriculum draws on important developments in ecohydrology, integrated water resources management (IWRM) and sustainability science.

As a key activity under this project, UNESCO undertook an analysis of the current state of tertiary and professional water curricula in Asia and the Pacific. This was done so as to enable UNESCO to identify and address any gaps by devising a targeted curriculum document for water educators drawing on innovative approaches to water security and sustainability advocated by UNESCO and the wider UN system as part of the 2030 Agenda and the Sustainable Development Goals. Water flows through all of the Sustainable Development Goals: without water security, sustainable development is fundamentally compromised – and without water education that addresses the realities of water insecurity in the region, water security will remain elusive.

It is my pleasure herewith to present the resulting curriculum document, not only for its emphasis on delivering targeted innovative content, but also due to its potential to strengthen the science-policy interface for water sustainability in the region. Throughout the development of the curriculum, focus has been placed on ensuring its contribution towards climate change impact resilience in Asia and the Pacific through the linking of science and policy.

I wish all readers and users an enjoyable and enriching experience with this curriculum, and look forward to receiving feedback and suggestions for us to further improve the document.

Contents

Acknowledgements

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The development of this curriculum has been funded by the Government of Japan through the UNESCO-Japan Funds in Trust Programme and administered by the UNESCO Jakarta Office, Regional Science Bureau for Asia and the Pacific.

The author thanks Hans Thulstrup and Bustamam, UNESCO Jakarta Office, for their ongoing support, and participants of a UNESCO Water Education Workshop held in Jakarta on 4–5 September 2019 for their inputs and feedback on a draft curriculum. Thanks are also extended to Ruchi Renavikar for her research assistance in the gap analysis that formed a preliminary phase of this project. Matt Colloff, Australian National University Fenner School of Environment and Society, is acknowledged with thanks for developing the practical unit on which Student Activity 2 in Module 5 is based.

Acronyms

AQF	Australian Qualifications Framework
FAO	Food and Agriculture Organization of the United Nations
IHP	Intergovernmental Hydrology Programme
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated water resource management
SDG	Sustainable Development Goals
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNEP	United Nations Environment Programme
WHO	World Health Organization

Introduction

The development of a regional curriculum for water education in Asia and the Pacific is an important step towards sustainable management of water resources in the region.

With a focus on ecohydrology, integrated water resource management (IWRM) and sustainability science for climate change resilience, this curriculum brings together resources and recommendations from UNESCO programmes and publications to provide tertiary educators with a relevant, robust pedagogical *framework*.

UNESCO is leading the Global Education 2030 Agenda through Sustainable Development Goal 4 (SDG 4) Quality Education to 'ensure inclusive and quality education for all and promote lifelong learning.' The objectives of this curriculum has particular relevance to SDG 4 Target 4.3: *Equal access to affordable technical, vocational and tertiary education* and SDG 4 Target 4.7: *Education for sustainable development and global citizenship*.

UNESCO's Intergovernmental Hydrology Programme (IHP) is aligned with the SDGs, leading research agendas in developing knowledge relating to water and sustainability from a systems perspective. Now in its eighth phase as IHP-VIII 2014–2021, the programme's focus is water security, including the theme of 'water education, key to water security.' In 2017, UNESCO supported the development of a comprehensive, three-volume water management curriculum, titled ´Water management curricula using ecohydrology and integrated water resources management' (Regional Humid Tropical Hydrology and Water Resources Centre for South-east Asia and the Pacific, 2017).

In addition, key recommendations from UNESCO's 7th World Water Forum on Water Education and Capacity Building identified the following opportunities for water education curriculum development at the tertiary level:

a. Integration of water curricula into non-water programmes.
b. The use of information technology to inspire interest and engagement by students.
c. Field work as a key component of the curriculum.

Curriculum approach

The curriculum design is based on a number of modules, aimed at later year undergraduate and graduate students. This approach takes into account the diversity of end-users, both educators and students, and the diversity of landscapes in which they live and work. Given the target student cohorts, foundational knowledge in hydrology such as the hydrological cycle, the water balance and freshwater systems (rivers, lakes, groundwater) is assumed. This content would be covered in first or second year classes. Nevertheless, in Module 3, an optional introductory lecture is suggested with readings to facilitate learning within non-water programmes at later year levels.

This curriculum is not intended to be a degree programme. It is also not designed to be a full semester course, per se, although it is possible to manipulate and extend components in order to meet that latter requirement. Rather, the curriculum is designed so that educators can infill their own courses with one or more modules to complement their own courses.

There is some variability in the modules. The first module is designed as either a self-paced reading module, where the student is solely responsible for their learning and the pace at which they engage with the material; or, alternatively, it can be delivered as a series of tutorials run by the lecturer or tutor. These two options are offered to adapt to student key competencies in English language. The other modules are largely based on the concepts of *students as partners* (Healey et al., 2014), and a *flipped classroom* approach (Sharples et al., 2014) in which learning is student-focused with educators as guides.

Module content is designed to be used as a framework for developing multiple lectures but also to provide the lecturer with core indicative content to be used as 'springboards' for student reading, research and in-class discussion. Additional material is provided for experiential learning opportunities including discussion, practical exercises and field trips.

This report is divided into three sections.

Section 1 provides the global context for the curriculum; identifies the key principles and pedagogy of the curriculum design; lists the planned graduate attributes; and describes the relevant standards that can be applied to those attributes for quality assurance.

Section 2 comprises six learning modules.

1. Understanding the Great Acceleration and the Anthropocene
2. Climate change
3. Ecohydrology and water sustainability
4. Ecohydrology and the water plant nexus
5. Integrated water resource management
6. Water ethics

Each module includes:

- Summary of module content
- Aims and objectives
- Learning outcomes
- Proposed assessment
- Indicative content
- Student-focused learning activities
- Quick student quiz
- References

Section 3 provides supplementary teaching and learning resources, including student evaluation forms to provide feedback to educators; a list of online water games that can be used in practical classes or workshops; and a description of work-integrated learning to help students transition to the workforce.

SECTION 1
CONTEXT AND CURRICULUM DESIGN

Global context for managing water in the twenty-first century

The Industrial Revolution of the late eighteenth and early nineteenth centuries transformed agrarian economies into industrialized, urban economies based on mechanized manufacturing and industry. Rapid technological advances had significant impacts on humans, their living standards and relationship to the environment. Critically, as industrialization spread, human populations increased quickly, bringing greater need for and use of energy, water and food, as well as an increase in contaminants and waste by-products. It is now understood that exponential human population growth from the mid-twentieth century, precipitated by the post-Second World War economic boom, has profoundly influenced socioeconomic trends and precipitated Earth system responses including, but not limited to, climate change. This complex of changes is now referred to as the Great Acceleration within the Anthropocene era.

Water is a component of this factorial complex, with the development of water resources being associated with growing demand for drinking water, primary production, and industrial uses. During this period, an engineering approach has dominated water resources management through the construction of large dams, weirs, locks, and barrages, and water distribution networks for irrigation and urban supply. However, in the last few decades the need for a more holistic approach has been increasingly recognized; to understand the nexus between engineering and the environment. This is required in order to slow down, stop or even reverse the trend of environmental degradation and the loss of ecosystem function on which life on Earth, as we know it, can exist.

Given this context, it is imperative that training for emerging young professionals working in the water sector is not only based on engineering solutions, but also on integrative approaches. An analysis of tertiary courses offered across the Asia-Pacific region indicated that water is still predominantly offered within engineering programmes. This suggests that the study of water as an engineering subject is predicated on the pressures to harvest, impound, divert and distribute water to support not only population growth but also urbanization, food and water security, and energy production.

By contrast, the regional analysis identified few water education courses with integrated approaches to management and sustainability. This raises and confirms concerns for the training of future water professionals. The development of this curriculum attempts to address that imbalance and provide educational resources to support knowledge transfer for climate change resilience, adaptation and capacity building.

Curriculum design

The overarching goal is to provide the framework for a regionally relevant curriculum on ecohydrology, IWRM and sustainability for climate change impact resilience. It is anticipated that the curriculum will be used by educators to supplement or complement their existing curricula, and is not intended as a comprehensive, stand-alone course.

The conceptual framework is illustrated in Figure 1.

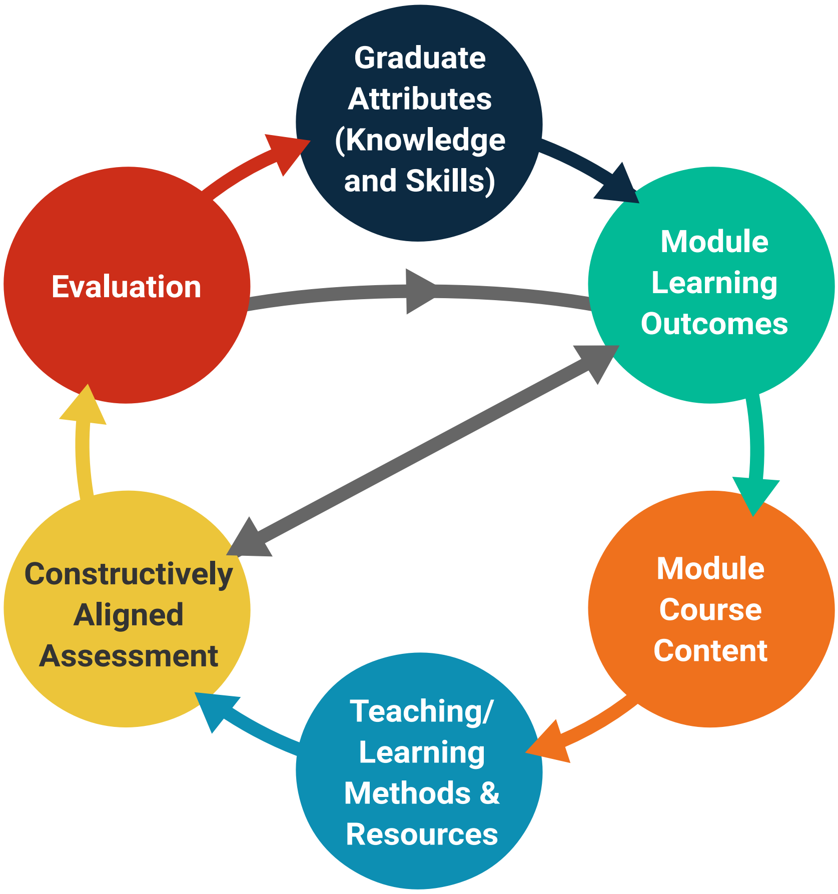

Figure 1 Elements of the curriculum design

A number of key principles underpin the purpose, design, and pedagogical practice of the curriculum as well as its quality:

a. It is *standards-based*. In this curriculum, the Australian Qualifications Framework (AQF) has been referenced, although it is assumed that users will refer to their own national standards as required.
b. It involves *student-centred learning*.
c. It is informed by *current research*.
d. Learning outcomes, teaching/learning activities and assessment are *constructively aligned* (Biggs, 2003). That is, the intended learning outcomes, what teaching and learning activities are undertaken so that the student learns, and how the student is assessed all need to be linked. Development of learning outcomes refers to the Revised Bloom's Taxonomy (Anderson et al., 2001).
e. It provides *skills-building* for future career pathways.

It is also relevant to the curriculum design that educators are now facing a new generation of students, collectively known as 'Generation Z' - a generation exposed to social media since childhood. They have the capacity for rapid speed and multi-channel processing of information, multi-tasking, and non-linear visual thinking. They also have expectations of immediate feedback and rewards as well as having continuous access to multiple sources of information (Cilliers, 2017; Seemiller and Grace, 2017). It is also useful to note that, for this generation, social interactions have been increasingly virtual rather than face-to-face. All of this has significance for tertiary educators. First, the use of multiple forms of digital technology should be included in the learning environment, where such resources are available. Second, due to reliance on social media through important developmental stages, some students are not accultured, necessarily, to effective inter-personal or inter-group communication. Consequently, although use of 'gaming' and other online tools can be used to enhance learning, experiential educational activities that encourage face-to-face interactions should be a salient component of the curriculum in student-focused activities.

Although students undertaking modules within this curriculum are expected to be enrolled in a diverse range of study programmes, it is assumed that they will be later year Bachelors undergraduate students (or equivalent), or Masters by coursework students. The skills or attributes expected at these levels, as defined in the 2013 Australian Qualifications Framework are provided in Table 1, with students at Diploma level being presented as a point of comparison only. The learning outcomes for this curriculum are informed by these AQF graduate attributes (knowledge and skills). It should be noted that other national standards can be readily aligned with those presented here.

Table 1: AQF graduate attribute descriptors according to qualification level

KNOWLEDGE	Diploma (Level 6)	Bachelor degree (Level 7)	Masters by coursework (Level 9)
	Graduates will have technical and theoretical knowledge and concepts, with depth in some areas within a field of work and learning.	Graduates will have a broad and coherent body of knowledge, with depth in the underlying principles and concepts in one or more disciplines as a basis for independent lifelong learning.	Graduates will have a body of knowledge that includes the understanding of recent developments in a discipline and/or area of professional practice.
			Knowledge of research principles and methods applicable to a field of work and/or learning.

SKILLS

Diploma (Level 6)	Bachelor degree (Level 7)	Masters by coursework (Level 9)
Graduates at this level will have:	Graduates at this level will have:	Graduates at this level will have:
• Cognitive and communication skills to identify, analyse, synthesize and act on information from a range of sources.	• Cognitive skills to review critically, analyse, consolidate and synthesize knowledge.	• Cognitive skills to demonstrate mastery of theoretical knowledge and to reflect critically on theory and professional practice or scholarship.
• Cognitive, technical and communication skills to analyse, plan, design and evaluate approaches to unpredictable problems and/or management requirements.	• Cognitive and technical skills to demonstrate a broad understanding of knowledge with depth in some areas.	• Cognitive, technical and creative skills to investigate, analyse and synthesize complex information, problems, concepts and theories to different bodies of knowledge and practice.
• Specialist technical and creative skills to express ideas and perspectives.	• Cognitive and creative skills to exercise critical thinking and judgement in identifying and solving problems with intellectual independence.	• Cognitive, technical and creative skills to generate and evaluate complex ideas and concepts at an abstract level.
• Communication skills to transfer knowledge and specialized skills to others and to demonstrate understanding of knowledge.	• Communication skills to present a clear, coherent and independent exposition of knowledge and ideas.	• Communication and technical research skills to justify and interpret theoretical propositions, methodologies, conclusions, and professional decisions to specialist and non-specialist audiences.
		• Technical and communication skills to design, evaluate, implement, analyse and theorize about developments that contribute to professional practice or scholarship.

A complementary set of graduate attributes are associated with preparing students for the workplace and optimizing their employability. Work-integrated learning is increasingly recognized as an important component of tertiary education, by which students acquire key competencies in work readiness. These competencies can be acquired through learning experiences that are embedded in the curriculum through research-led or project-focused learning in partnership with government agencies, non-government organizations, businesses and community groups. Benefits should be reciprocal for the tertiary institution/student and the host organization, and be based on well-established partnerships in which mutual trust already exists. Information on work-integrated learning is provided in Section 3, with links to student self-assessment of key competencies.

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SECTION 2
LEARNING MODULES

The curriculum comprises six learning modules providing foundational content to support student-focused learning. The overall structure of the modules is provided below.

Module 1: Introduction to the Anthropocene and the Great Acceleration (self-paced reading module)

- The geologic time scale
- The five mass extinctions
- The Holocene
- The Anthropocene
- The Great Acceleration
- The Anthropocene and water

Module 2: Climate change

Lecture 1: Introduction to climate change

- Climate and climate change defined
- Climate change over (i) geologic time and (ii) the last 150 years
- Evidence for climate change and analytical techniques

Lecture 2: Climate change now and in the future

- Impacts of anthropogenic climate change
- How are human activities and climate change linked?
- Climate change predictions and uncertainties
- Future strategies

Lecture 3: Climate change policy

- International climate change policy
- Regional climate change policy and intervention

Student-focused learning activities

1. Workshop 1: Small group research and discussion looking at evidence for climate change and adaptation across the region
2. Workshop 2: Interrupted debate on the topic ‘Is climate change real?’
3. Excursion to government meteorological offices
4. Comparative policy evaluation

Module 3: Ecohydrology and water sustainability

Optional lecture on introductory hydrology for non-water students

- The hydrological cycle
- The properties of water
- Water quality

Lecture 1: Ecohydrology

- What is ecohydrology

Lecture 2: Water use

- The water resource base and water use
- Water and human use

Lecture 3: Regulated rivers, navigation and floodplains

- River regulation
- River navigation
- Irrigation

Lecture 4: Water quality and human health

- Sanitation and water-related diseases

Lecture 5: Contamination and pollution

- Contamination and pollution
- Antimicrobial use and resistance as an emerging global issue
- Microplastics
- Case study of contamination

Lecture 6: Water and gender

- Water as a gendered issue
- Gender and water management

Lecture 7: Urban water (Part 1)

- Urban hydrology
- Growing cities
- Water supply and demand
- Water security

Lecture 8: Urban water and sustainability (Part 2)

- Hot cities
- Sustainable urban water design

Student-focused learning activities

1. Field trip: Water quality testing
2. Workshop: Conceptual site modelling
3. Field trip to dam site
4. Workshop: Water and human health
5. Field trip: Group data collation and mapping: Measuring an urban heat island
6. Field trip: Urban stormwater management

Module 4: Ecohydrology and water-plant nexus

Lecture 1: The hydrology-ecology nexus

- The hydrology-ecology nexus

Lecture 2: Water and plants

- Water and plants

Lecture 3: Changing landuse and water

- The water balance
- Hydrological responses to a changing landscape: rural
- Hydrological responses to a changing landscape: urban expansion

Lecture 4: Fire and vegetation

- Fire basics
- Hydrological impacts of fire linked to vegetation changes

Lecture 5: Water quality

- Biogeochemical cycles
- Vegetation and water quality
- Plant uptake of water and elements in solution

Student focused learning activities

1. Workshop. Exploring the water-vegetation nexus by developing a conceptual model
2. Workshop: Ecohydrology and concepts of sustainable urban design
3. Field trip: Peri-urbanization
4. Workshop: Biogeochemical cycles and water

Module 5: Integrated Water Resource Management

Lecture 1: IWRM basics

- What is IWRM?
- IWRM as a framework for integration
- Challenges
- IWRM, governance, policies and SDG indicator 6.5.1

Lecture 2: IWRM unlimited

- IWRM in practice – a case study approach

Lecture 3: IWRM and Ridge to Reef (R2R)

- Expanding the concept of IWRM to 'Ridge to Reef'

Lecture 4: The 'how to' of IWRM using the IWRM guidelines (Part 1)

- Revisiting the 'spiral conceptual model'
- Implementation as a four-phase process

Lecture 5: The 'how to' of IWRM using the IWRM guidelines (Part 2)

- Institutional frameworks
- Performance indicators and benchmarking

Student-focused activities

1. Workshop: A critical interrogation of IWRM: what can make it succeed?
2. Workshop: Water-sharing in the Murray-Darling Basin
3. Workshop: Unpacking IWRM in an interrupted case study scenario
4. Workshop: Implementing IWRM
5. Field trip: Visit to a government department, non-government organization or consultancy with responsibilities or interest in IWRM
6. Field trip: Visit to a field-based IWRM project

Module 6: Water ethics

Lecture 1: Water ethics

- Water as an ethical issue
- Water ethics principles
- Challenges to ethical resource management
- Indigenous water knowledge and water rights
- Case studies

Student focused activities

1. Four-way water moot
2. Developing a local water ethics charter

Module 1: Introduction to the Anthropocene and the Great Acceleration

Summary

Geologic time has been constructed by geologists from sequences of sedimentary rocks laid down over millions of years, and divided into distinct periods due to the appearance or disappearance of distinct groups of fossils, or where there has been a significant change in the types of rock present. These geological periods reflect the history of earth according to patterns of change. In some cases, a geological boundary has represented a sudden major extinction of lifeforms, such as the Cretaceous–Tertiary extinction when almost 75 per cent of the Earth's flora and fauna became extinct about 66 million years ago. Currently the Earth is in the Holocene Epoch, which commenced at the end of the last glaciation, or ice age, about 11,650 years ago.

It has been argued that humans have become a geological force imposing changes that will be detected in the geological records of the future. This has been a contentious viewpoint, first presented over a century ago and gaining traction since 2000 when the term 'Anthropocene' was introduced (Cutzen and Stoermer, 2000; Cutzen, 2002). As a concept, it is now widely used and informally accepted in peer-reviewed literature, although the term has no formal status within the geologic time-scale, including its definition and its actual beginning. Some suggest that the Holocene itself encompasses the Anthropocene, whilst others limit it to the rapid changes experienced in the twentieth century.

Since the end of the Second World War in 1945, the world's human population and associated activities have experienced a rapid acceleration known as the 'Great Acceleration'. A significant proportion of the Earth's land surface has been modified for human use or benefit, and the composition of the atmosphere is now measurably different to that even 100 years ago. Many scientists believe that we are now experiencing the sixth great extinction event.

Aims and objectives

The aim of this foundational module is to introduce students to the concept of earth systems change, and how these have been recorded and interpreted over both geologic and recent time. Students will use this information to explore the unique attributes of the Holocene and critically review the literature regarding the use of the term 'Anthropocene'. Through critical analysis and discussion, students will assess the key characteristics of the Great Acceleration.

Learning outcomes

On satisfying the requirements of this module, students will have the knowledge and skills to:

Undergraduate learning outcomes 1–3

1. Define core terms, concepts and theories of the geological time scale up to the present.
2. Integrate information from a range of disciplines to describe past and present Earth system changes.
3. Critically evaluate empirical research on the Anthropocene.

Postgraduate learning outcomes 1–5

4. Apply research skills and specialist knowledge in new contexts.
5. Demonstrate an understanding of the ideological discourses underpinning concepts of the Anthropocene.

Proposed assessment

Assessment task (undergraduate)	Value	Links to learning outcomes
1. Annotated bibliography about 1,200 words Select three readings from the module reference materials (including references and websites). For each, provide a citation, followed by a concise paragraph (400 words) that describes and evaluates the work. This provides the reader with an understanding of the topic, and the relevance and quality of argument/data presented.	To be assigned by lecturer	1–3

Assessment task (postgraduate)	Value	Links to learning outcomes
1. Annotated bibliography about 1,600 words Select four readings from the module reference materials (including references and websites). For each reading, provide a citation, followed by a concise paragraph (400 words) that describes and evaluates the piece of work. This provides the reader with an understanding of the topic, and the relevance and quality of argument/data presented.	To be assigned by lecturer	1, 2, 3, 5
2. Short essay (1,500 words) ***Select one of the following options:*** Topic 1 The Anthropocene has not been formally recognized as a geological period by the International Union of Geological Sciences. Are there features of the Anthropocene that suggests humans have indeed transformed Earth systems to the extent that a new geological period has emerged? Topic 2 What have been the key pressures, responses and impacts of the Great Acceleration at (i) a global scale and (ii) a regional Asia-Pacific scale?	To be assigned by lecturer	1–5

Module indicative content

The reference material in this module guides students to an understanding of the key concepts relevant to water challenges in the twenty-first century. There are two options embedded in the design. The first option is for those students who have key competencies in English language. For those students, this is a self-paced reading module in which the students need to access and read a number of peer-reviewed journal articles and other materials.

For students with limited English language competencies, the module can be presented by the lecturer/tutor as a series of tutorials (ideally two sessions (i) the geologic time scale; mass extinctions; and the Holocene; and (ii) the Anthropocene and Great Acceleration). Using this format, the topics are covered through discussion, led by the lecturer/tutor. Note that the readings on the Anthropocene and the Great Acceleration are based around the seminal works for this topic.

Topic	Content
The geologic time scale	The geologic time scale maps out the natural history of the Earth, dividing time into periods that are characterized by unique biota (for example, the Ordovician period was dominated by graptolites, the Devonian period is often referred to as 'the age of fishes'). **To do**: Life on Earth is dependent on water. Find out where water came from in the early beginnings of Earth's history. Explore the geologic time scale, defining each period and the boundaries separating them, and how long each period lasted. In what geologic period has it been established that life began?
The five mass extinctions	A mass extinction is considered to be an event through geologic time when a majority of species disappeared. **To do**: Go to the following site to find out when the five mass extinctions occurred in the past: https://cosmosmagazine.com/palaeontology/big-five-extinctions
The Holocene	The Holocene is the most recent geologic period that started 11,700 years ago and includes the present day. It is characterized by a number of key features of climate (global warming at the boundary with the earlier Pleistocene period followed by relatively stable temperatures); animals that died out (megafauna at the Pleistocene-Holocene boundary); and by the emergence of human civilizations dependent on the domestication of animals and plants and productive agriculture. Unlike other geologic periods, no unique fauna have been defined for the Holocene, but the period is largely described in terms of human technological development (e.g. Mesolithic, Neolithic and Bronze Ages). In this sense, the Holocene can be viewed as the beginning of a wholly human-influenced geologic period.

The Anthropocene	At the beginning of the twenty-first century, two scientists, including a Nobel laureate, coined the term 'the Anthropocene' to describe the period in which humans have placed an indelible mark on the planet, altering a number of Earth systems. We tend to focus on climate change, but this is just one system that has been affected by human activities. **Read**: (i) Crutzen, P.J. 2002. The geology of mankind. *Nature*. 45:23. https://www.nature.com/articles/415023a?TB_iframe=true&width=921.6&height=4678.2#citeas (ii) Steffen, et al. 2011. The Anthropocene: Conceptual and historical perspectives. *Philosophical Transactions of the Royal Society, A 369:842-867* https://royalsocietypublishing.org/doi/10.1098/rsta.2010.0327 **Access** the Smithsonian National Museum of Natural History website to get an overview of the Anthropocene, which includes some questions to co)nsider about the future: http://humanorigins.si.edu/research/age-humans-evolutionary-perspectives-anthropocene
The Great Acceleration	The Industrial Revolution in the late eighteenth century precipitated a cascading response in human population and economic growth. By the middle of the twentieth century, a tipping point seemed to be reached by which exponential rates of change occurred across multiple aspects of the natural and human world. These changes are now referred to as the Great Acceleration. Understanding the scale and scope of these changes is critical when examining the challenges that face us now and in the foreseeable future. It is now being suggested that due to biodiversity losses induced by human activities, we are now facing the sixth extinction. **Read**: (i) Pages 14–18 of Steffen et al. 2004. Executive summary of *Global Change and the Earth System: A Planet under Pressure*. Verlag-Springer, Berlin Heidelberg New York. Look at and critically interpret the plots on pages 15 and 16. igbp.net/download/18.1b8ae20512db692f2a680007761/1376383137895/IGBP_ExecSummary_eng.pdf

	(ii) Ceballos et al. 2015. Accelerated human-induced species losses: Entering the sixth mass extinction. Science Advances 2015 1(5), 5 June 2015. https://advances.sciencemag.org/content/1/5/e1400253/tab-pdf
The Anthropocene and water	In preparation for future modules, students should look at the following website and video: https://globaia.org/water-anthropocene An emerging key issue since the Great Acceleration relates to water, its uneven distribution globally and water scarcity. Compare maps of global water availability, water stress/scarcity and human population to identify and compare areas where access to available water for human use currently is, and increasingly will be, constrained.

Quick quiz

On completion of this module, the following self-checking quiz can be provided to students using an online platform such as Moodle or Quizlet.

Question	Answer
What is the period of time over which the Holocene period extends?	The Holocene is the current period of geologic time and commenced approximately 11,700 years ago.
What are the key features of the Holocene period?	• Climate warming after the last ice age • Extinction of megafauna • Human development of agriculture
What is the definition of the Anthropocene?	This is a term coined by scientists Crutzen and Stoermer in 2000 to define a new period in the Earth's natural history during which humans have influenced the state and dynamics of Earth systems.
When did the Great Acceleration start and what precipitated it?	It has been argued that the Great Acceleration started with the Industrial Revolution, although some suggest it started in the mid-twentieth century – both relate to rapid changes in population, economic growth and industrialization.
What are the key changes in Earth systems brought about by the Great Acceleration?	• Rising greenhouse gases } Climate change • Rising sea surface temperatures } • Ocean acidification • Deforestation • Loss of biodiversity and the sixth extinction

How is a mass extinction defined, and how is the sixth mass extinction different to those occurring in the geological past?	A mass extinction occurs when at least 60 per cent of extant genera become extinct within a period of no more than a few hundred thousand years. In the geologic past, mass extinctions were thought to result from catastrophic volcanic activity, meteor impacts and climate change. The sixth extinction currently occurring is the result of human activity.
What is a hidden bias in the data for the Great Acceleration?	The changes to Earth systems are not occurring across all areas of the planet, nor at the same pace or intensity.
What are key drivers for water security?	Climate, the spatial distribution of freshwater resources globally, and the pressures exerted by human populations.
How can the data for the Great Acceleration be useful?	• As the basis for intergovernmental agreements. • Identifying approaches for measuring and monitoring change. • Academic research and learning/training.

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Module 2: Climate change

Summary

Over the last 150 years, the Earth's climate has changed to such a degree that is beyond any natural background variability evident in the geologic record. This has been attributed to human activities that contribute to increased greenhouse gas emissions. In a complex feedback process, these increased gaseous emissions have prompted the following responses at a global scale: increasing atmosphere and ocean temperatures, melting and retreating polar and glacial ice, rising sea levels, increasing areas of desertification, and changing weather patterns. This has profound implications for our future. In this module, the current scientific understanding of climate change is outlined. Key questions will be explored such as how climate has changed relative to the geologic past; what are the impacts of climate change; what are some approaches for climate change mitigation, adaptation and resilience?

Aims and objectives

The aim of this module is to introduce students to the science of climate change. By addressing a number of key questions, students will develop critical foundational knowledge relevant to the sustainable management of water resources, to be covered in later modules. The objectives include:

1. To critically review information from a range of sources to characterize climate change drivers, processes, impacts, mitigation and adaptation.
2. To connect theoretical knowledge and practical skills in data analysis so that students can explore and interpret data relating to climate change.

Learning outcomes

On satisfying the requirements of this module, students will have the knowledge and skills to:

Undergraduate learning outcomes 1–3

1. Critically evaluate information from a range of sources on climate change, and climate change impacts and responses.
2. Demonstrate competence in data interpretation and problem-solving.
3. Effectively communicate knowledge and understanding of climate change to both specialist and non-specialist audiences.

Postgraduate learning outcomes 1–5

4. Independently develop, integrate and apply problem-solving.
5. Synthesize information from a diverse range of written and oral sources.

Proposed assessment

Assessment task (undergraduate)	Value	Links to learning outcomes
1. Summary report from flipped classroom activity. (1,000 words)	To be assigned by lecturer	1–3

Assessment task (postgraduate)	Value	Links to learning outcomes
1. Short essay addressing the question: What are the implications of climate change for small island nations in the Pacific? (1,500 words)	To be assigned by lecturer	1, 3, 4, 5

Module indicative content

A critical publication for this module is *The Science of Climate Change: Questions and Answers*, published by the Australian Academy of Science (2015). https://www.science.org.au/files/userfiles/learning/documents/climate-change-r.pdf For the version with full references go to www.science.org.au/climatechange.

Format: Three lectures provide basic content on which student activities develop and expand through a flipped classroom approach.

Topic	Content
Lecture 1: Introduction to climate change	
Defining climate and climate change	The *climate* of a region is the result of interactions between the atmosphere, hydrosphere, cryosphere, lithosphere and biosphere. Climate refers to a statistical description of the weather, including means, extremes and variability of precipitation and temperature, for example. *Climate change* refers to a change in weather patterns, sea surface and land surface temperatures, and glaciated areas over time scales of decades and longer (minimum 30 years). Some climate change is due to natural causes, e.g. vulcanism or solar irradiation, or to human activity and changes in the composition of the atmosphere.

	It is important to understand how climate is controlled. Many factors drive climate but the atmosphere-ocean (A-O) interaction is critical. Dynamics of A-O interaction and geographic location produces profound spatial and temporal variability in rainfall. Introductory climatology texts provide useful information on this interaction (for example, Cornell et al., 2012; Dessler and Texas A&M University, 2015; Emanuel, 2018) Also, refer to: Webster, P. 1994. The role of hydrological processes in ocean-atmosphere interactions. *Reviews of Geophysics*. 32(4): 427-76. It is important that students understand that an imbalance between rates of incoming and outgoing solar radiation (due to changes in atmospheric composition) will result in climate change. Provide a brief description of the atmosphere including its composition. Note that Earth's climate is driven by solar energy. When incoming solar radiation is balanced by outgoing energy, the Earth is in a state of radiative equilibrium. However, if there is a disturbance to either incoming or outgoing radiation, there will be a response of increasing or decreasing temperatures respectively. For detailed information and graphics relating to climate and Earth's energy balance (and disequilibrium), refer to: Australian Academy of Science. 2015. *The Science of Climate Change: Questions and Answers*. Australian Academy of Science, Canberra. pp. 7. https://www.science.org.au/files/userfiles/learning/documents/climate-change-r.pdf Climate and Earth's energy balance https://earthobservatory.nasa.gov/features/EnergyBalance
Climate change (i) over geologic time and (ii) over the last 150 years. *This consolidates knowledge developed in Module 1.*	• Note that climate changes over millions of years have been attributed to plate tectonics and changes in the tilt of the Earth. Refer to Bureau of Meteorology, 2008. • Describe fluctuations in temperature and greenhouse gas (CO2, NH4 and N2O) concentrations across geologic time recorded in ice cores back to 800,000 BP (relevant data plots available in Australian Academy of Sciences, 2015; Jouzel et al., 2007; or Steffen et al., 2004), noting the changes between glacial and interglacial (warmer periods) of ~10,000–30,000 years, with cycles initiated by slight perturbations in the energy system, for example, that were then magnified by feedback responses. • Describe the changes in global air temperatures and CO2 concentration since the Industrial Revolution that have been attributed to anthropogenic activities (relevant data plots available in Australian Academy of Sciences, 2015; or Hartman et al., 2013).

	• Refer back to the importance of maintaining the radiation balance. Note that an increase in atmospheric black carbon (generated through incomplete combustion, particularly associated with diesel fuel use) and its subsequent deposition in the Himalaya, has changed the *albedo* of glacial surfaces, causing increased melting and downstream flood risks in some of Asia's major river systems. At least half the acceleration rate of ice loss in the Himalaya can be attributed to black carbon (see Maurer et al., 2019). Note that this is an example where complex interactions between Earth systems can be mitigated quite easily. Go to Climate Change Coalition's website for graphics and data. https://ccacoalition.org/en/slcps/black-carbon
Evidence for climate change – and analytical techniques used.	• Evidence for climate change in the geologic past (including the Holocene) is found in ice cores, marine and lake sediment cores, speleothems (cave stalagmites and stalactites), tree rings, pollen marine microfossils (e.g. foraminifera) and fossil coral. • Analyses of stable isotope ratios (oxygen-deuterium) in ice provide evidence for past temperatures whilst analysis of bubbles in the ice by gas chromatography provides data for greenhouse gases. Rates of sedimentation, types of pollen (terrestrial) and foraminifera (marine) in sediment cores provide evidence of environmental processes and change. Speleothems can be dated using uranium-thorium ratios and palaeoclimate reconstruction through analysis of oxygen isotopes. Analysis of tree ring width provides evidence of climate variability in the past. • Mapping the spatial distribution of loess soils in the northern hemisphere provides terrestrial evidence for the distribution of past ice sheets.

Topic	Content
Lecture 2: Climate change now and in the future	
Impacts of anthropogenic climate change	Impacts of anthropogenic climate change due to global warming include: • Rising sea levels, ocean acidification, change in frequency and magnitude of extreme climatic events. • Changes in ecosystem composition, function and spatial distribution. • Increased fire risk. • Decreased food and water security. • Human health (e.g. heatwaves, changed distribution of insect vector diseases). • Energy and transport infrastructure.

	Note that there are mega-scale impacts (e.g. global warming), but also regional or local impacts. The changes to Earth systems are not occurring across all areas of the planet, nor at the same pace or intensity. **Refer to:** • Australian Academy of Science. 2015. *The Science of Climate Change: Questions and Answers*. pp. 24–27. Examples used in this publication refer to Australian conditions generally. Impacts that are relevant to countries where this module is being delivered should be provided to students (e.g. heatwave impacts on health in Singapore; change in spatial incidence and insect vectors of dengue in Southeast Asia; incidence and impacts of fires in Indonesia; decreased food security in drought-affected regions of central and western Asia and Pacific Islands; increased risk of glacial lake outburst floods in high altitude Asia). • Intergovernmental Panel on Climate Change (IPCC) reports on impacts (these focus on the United States but are still useful). **Option to watch:** YouTube video Climate Change & Our Health with Al Gore and President Hilda Heine, Marshall Islands: https://www.youtube.com/watch?v=eEUmsfXtaRo Video describes impacts of climate change on low-lying atolls of the Pacific.
How are human activities and climate change linked?	• Note that concentrations of greenhouse gases, specifically CO2, NH4 and N2O, have been relatively stable since the last ice age but started to increase since the Industrial Revolution and have increased exponentially since mid-twentieth century due to fossil fuel combustion, manufacturing industries and deforestation. • Focus on trends in emissions of CO2 over the last 160 years, according to different sources. • Examine both the sources and sinks of CO2, and what this means for global warming and ocean acidification. • The global warming potential (GWP) for CO2 is 1 and for NH4 is 28 (IPCC 5th Assessment Report https://www.ipcc.ch/assessment-report/ar5/). Trends in the emissions of NH4 should also be explored with reference to sources (e.g. wetlands, mangroves, natural gas and petroleum industries, livestock production, rice paddy fields, burning biomass, solid waste (anthropogenic) and the relevance of landuse change e.g. increased rice and livestock production for food security).

	Refer to: • Australian Academy of Science. 2015. The Science of Climate Change: Questions and Answers. pp. 12–15. • United States Environmental Protection Agency website. https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data
Climate change: future predictions and uncertainties	• Climate change predictions are based on modelling such as atmosphere–ocean general circulation models, earth system models, regional climate and global climate models. These do not simply rely on linear relationships derived from past climate data, but are mathematical models integrating 'submodels' for processes occurring in the atmosphere, oceans, land surfaces and biosphere, at a range of scales. For global climate change predictions, the best tools are global climate models (GCM). However, note that bias occurs in GCMs and modified approaches need to be applied to account for this. (See Cannon et al., 2015; Navarro-Racinnes et al., 2015) • Useful information on climate change and its predicted emergence at regional and even local scales has been generated using the signal to noise ratio approach. Explain the terms signal, noise and emergence and use Figures 1 and 2 in https://www.climate-lab-book.ac.uk/2014/signal-noise-emergence/ as the basis for interpretation of potential regional and local climate change impacts in the near future. **Refer to**: • Climate change in Australia website for a concise description of GCMs including a short video and diagrams as supporting material. https://www.climatechangeinaustralia.gov.au/en/climate-campus/modelling-and-projections/climate-models/ • For examples of models used for IPCC reporting: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter09_FINAL.pdf • Uncertainties around climate predictions are a function of data inputs to models, but also the rate of future emissions; the complex feedback mechanisms that modify or amplify disturbances to climate; and random, natural processes such as catastrophic volcanic eruptions. • Despite uncertainties in predictions, scientists are virtually unanimous in their consensus that human-induced climate change is real.

	For information on scientific consensus refer to: • Geological Society of London. 2010. *Climate change: evidence from the geological record. A statement from the Geological Society of London, November 2010*. (see conclusions pp. 6). https://www.geolsoc.org.uk/~/media/shared/documents/policy/Statements/Climate%20Change%20Statement%20final%20%20%20new%20format.pdf?la=en • NASA Global Climate Change website. https://climate.nasa.gov/scientific-consensus/
Future strategies	Describe the three major strategies for addressing future climate change: emissions reduction; sequestration; and adaptation. Strategies involving emissions reduction and sequestration are examples of *mitigation* or control. *Adaptation* strategies are responses to climate change that moderate impacts, cope with its consequences or even take advantage of any benefits that might arise locally. Examples of mitigation and adaptation strategies should be provided. These strategies all require international collaboration and cooperation achieved through formalized agreements. Examples of such instruments should be provided (e.g. IPCC and the Kyoto Protocol, Paris Agreement, (Intended) Nationally Determined Contributions [NDC]). What other regional or national initiatives exist? **Refer to:** IPCC, 2014. 5th Assessment Report: Synthesis Report Topics 3 and 4) and Australian Academy of Science. 2015. *The Science of Climate Change: Questions and Answers*. pp. 30–31.

Topic	Content
Lecture 3: Climate change policy	
International climate change policy	Introduction to the rules, legal principles and international institutions of the climate change regime: • Since the term 'climate change' was first introduced in the late 1970s, policies to address the issue have been quickly drafted. This lecture provides a brief history of international climate change policy focusing on prominent international policies and treaties from the Kyoto and Montreal Protocol to the Paris Agreement and its ratification. • An emphasis on the aims, objectives and strategies employed by the following conventions to combat climate change and the evolution of strategies can be noted and discussed in class.

	• Some significant policies and protocols include the following: i. United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC is a one of three conventions adopted at the Rio Earth Summit in 1992. ii. Montreal Protocol, 1987. iii. Kyoto Protocol, 1997. iv. Paris Agreement which builds upon the UNFCCC, 2015. v. The Intergovernmental Panel on Climate Change (IPCC): The principal assessing body of the United Nations produced a synthesis report of its 5th assessment which is perhaps one of the most comprehensive reports that provides an overview of climate science knowledge and data across the globe. https://www.ipcc.ch/report/ar5/syr/
Regional climate change policy and interventions	• Regional policy approaches, management and adaptation strategies for climate change and global warming in the region where this module is taught, can be noted and discussed in this lecture. • Science-policy interaction for climate change issues can be assessed by identifying the Nationally Determined Contributions (NDCs) of relevant countries and the differentiated responsibilities assigned to developed and developing countries by the Paris Agreement. The NDC registry provides access to all countries' NDCs. • https://www4.unfccc.int/sites/ndcstaging/Pages/Home.aspx • Regional climate change adaptation and policy interventions are highly politicized in their approach and can be taught in conjunction with national water governance principles. • Preliminary introduction to the foundations of regional or national climate change policy are important to understand the local climate discourse and its impacts on the global climate change regime. Example: Recently, India has made significant progress in developing regional climate change policy and implementing action plans at various policy levels through its National Action Plan on Climate Change (NAPCC). https://www.adaptation-undp.org/explore/india This can be used as a case study for a developing country in contrast to the climate change policy interventions and action plans made by a developed country (for example, New Zealand).

Student-focused learning activities

Activity 1: Workshop on evidence for climate change impacts and adaptation practices across the region

Learning objective: To develop an understanding of the evidence for climate change, and how it is challenging nations and communities across the Asia-Pacific region.

Depending on the availability of resources, students can undertake initial research in-class online, or before class using library facilities.

1. To do: 30 minutes – Break class into groups of 4–6 people (depending on class size). Each group will be allocated a country or region. Within each group, members will undertake research to identify the following:
    - Key characteristics of country/region allocated to the group (biophysical, socio-economic, geo-political).
    - The key threats and challenges imposed by climate change, and the implications for national government and local communities.
2. Five minutes per group – Report findings to the class noting sources of information (try to resist the use of Wikipedia).
3. 20 minutes whole class discussion – What strategies can individual nations implement to address climate change at regional, national and community scales? What are the commonalities or specificities across the Asia-Pacific region in the challenges to implementing these strategies?

Activity 2: Interrupted debate on 'climate change – is it real?'

Learning objective: To critically evaluate the arguments for and against the existence of human-induced climate change.

To do: Prior to class, students are to undertake independent and small group-based research on the current evidence for human-induced climate change, and also, explore the literature (blogs, newspaper articles and other grey literature) that challenges this concept. They need to bring their source material to class.

The class should be divided into paired groups comprising four students each. Within each group, one side will present specific types of evidence FOR anthropogenic climate change, from various geographic locations. The other side will then refute those arguments and take the position of climate sceptics. Allow these small group debates to continue for 20 minutes and then, without warning, tell the students to change their position to argue from the opposite perspective. This changeover is the 'interruption'. Participants must argue their position with diligence, regardless of their own personal opinion.

At the end of the debates, a vote should be taken from the class as to whether they agree, disagree or abstain from the consensus opinion that human-induced climate change is a fact.

Activity 3: Excursion to government meteorological offices

Learning objective: To understand the processes by which climate is monitored at national and local scales, and used for forecasting weather, tracking extreme climate events and climate change projections.

A visit to government offices responsible for climate data allows students to see the extent of national climate networks, the role of meteorologists in data collection, collation, quality control and interpretation, and the tools used for predictions, modelling, and data archiving. This can be complemented with a field site visit to a meteorological station.

Activity 4: Comparative policy evaluation (1 hour)

Learning objective: To contrast and draw inferences from different approaches to climate change policy employed by two countries (developing versus developed country for best contrast) to address climate change.

To do: Prior to class, students are required to read the relevant prescribed course material and journal articles to undertake a comparative analysis between the climate change policy and action plans of two different countries.

1. The class will be divided into three groups. Group 1 will present the case of country A and Group 2 will present the case of country B, while Group 3 will represent an assessing body which will draw inferences and identify the differences between the political approaches and action plans of each country to address climate change. If the class size is large, then these three-way groupings can be replicated as many times as required, and final discussions to be held within the group clusters rather than whole-of-class.
2. Group 1 and 2 will be given 20 minutes each to present their case and Group 3 will be given 10–12 minutes to provide their feedback.
3. Group 3 will act as a panel and can provide recommendations and suggestions to Group 1 and 2 on their policy interventions.
4. The remaining 10 minutes can be utilized to address questions and class discussion on the drawbacks and advantages of regional climate change policies of both countries.

Example:

Prescribed reading for this activity:

1. Sathaye et al. 2006. Climate change, sustainable development and India: Global and national concerns. http://www.ssvk.org/climate_change_sustainable_development.pdf.
2. Gurran and Hamin. 2009. Climate change policy adaptation and mitigation in Australia and USA. https://www.sciencedirect.com/science/article/pii/S0197397508000659

Quick quiz

Question	Answer
How does climate change in the Anthropocene differ from climate shifts in the geologic past?	In the past, periods of warming and cooling could be attributed to natural processes such as a change in the tilt of the Earth on its axis or plate tectonics. Current climate change is due to human activities that have changed the balance between incoming and outgoing radiation, and in the composition of the atmosphere.
Name the factors that influence uncertainties in future climate predictions.	• Data inputs • Rate of future emissions • Positive and negative feedback mechanisms • Catastrophic volcanic eruptions
What is meant by 'signal', 'noise' and 'time of emergence' in relation to climate change? What does the 'signal to noise ratio' tell us about climate change in a specific region?	When climate change is occurring with a change of temperature this is denoted as a 'signal' in the data. However, this signal can be hidden by the natural variability in climate, called the 'noise' The point at which the signal can be identified in the presence of the noise is referred to as the 'time of emergence'. The signal to noise ratio can be used to show which regions have the largest signal relative to the degree of natural climate variability, and hence where the greatest impacts of climate change will be expressed.
What human activities are recognized as the salient causal agents for climate change?	• Fossil fuel combustion • Deforestation • Manufacturing
Three gases are associated with climate change. What are they and what are their global warming potential (GWP) values for a 100-year time horizon?	• Carbon dioxide (CO2) GWP = 1 • Methane (NH4) GWP = 28 • Nitrous oxide (N2O) GWP = 26
What are the three key strategies for addressing future climate change?	• Emissions reduction • Carbon sequestration • Adaptation

Name the fundamental institutional instruments that have informed and supported international cooperation in climate change action?	• IPCC • UN Framework Convention on Climate Change • Montreal Protocol • Kyoto Protocol • Paris Agreement
What is meant by (Intended) Nationally Determined Contributions?	These are the *intended* targets in reducing greenhouse gas emissions through the efforts of each country according to their domestic capabilities and circumstances. Some countries have also included an 'adaptation component'. Emission reductions are intended to be based around the key concepts of equity, sustainable development and the eradication of poverty. NDCs are not legally binding.
Are NDCs legally binding?	No. But each party is legally bound to have their progress monitored and assessed by a technical review panel, and to take actions to improve their outcomes.
What is the expected outcome of the (I) NDCs?	INDCs are expected to deliver significant reductions in, and slow down the growth of, greenhouse gas emissions, but will not be adequate in reversing the increasing trend of global emissions by 2025 and 2030.
What is the COP?	COP is the Conference of the Parties, a formal meeting of the UN Framework Convention on Climate Change Parties, held annually since 1995. A key responsibility of COP is to assess progress in dealing with climate change at global and national scales.

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Module 3: Ecohydrology and water sustainability

Summary

In this module the pressures of human population growth and climate change on water resources are explored. Adaptation measures have been adopted to not only cope with limited resources, but are also used as strategies for future sustainability.

In the industrial age, water resources were managed with a technical or engineering perspective, with water being impounded, harvested and distributed to meet human needs. Issues surrounding water quality have also tended to focus on interventions at the source, or through institutional instruments. In many different settings, this approach has led to 'over-engineered' landscapes and waterways, which ultimately impacts on ecosystems. Over the last few decades, a broader, more holistic approach for water resources management has developed to address environmental degradation caused by multiple pressures, including but not limited to, climate variability and change, human population growth, increasing water abstractions and poor water quality.

Ecohydrology is one aspect of the changing face of water science and management in developed and developing countries. It is the integration and application of multiple disciplinary knowledge from physical and social sciences. A holistic approach can improve public health and livelihoods; and achieve greater protection of the environment.

By developing an understanding of ecohydrology, students can appreciate the role of water in sustaining life due to its ability to act as a transport medium, a solvent and a coolant, and in its role in many biogeochemical reactions. Building a robust knowledge base in ecohydrology, in tandem with an understanding of how landscapes have been highly modified by engineering approaches to water management, is increasingly relevant to environmental management today.

Over the last 160 years, in response to the Industrial Revolution and associated economic growth, people have moved towards cities and towns to derive benefits from employment and better services. Improvements in living conditions, health and diet have been correlated with longevity and, ultimately, population growth. Drinking water is essential for survival, but water is also required for cooking, bathing, sanitation, food production and industry. Therefore, as populations have grown, there has been an increasing need to harness, extract and impound water to meet demand. These adaptation measures can have significant negative impacts on, and compromise the function of, ecosystems and environmental services, on which human populations are ultimately dependent. Human activities have also compromised water quality by contamination and pollution of water sources from agriculture, industry, or poor sanitation. In some areas, particularly highly populated towns and cities, the quantity of water may be adequate, but water suitable for use is not available.

Superimposed on the increasing human need for water are the impacts of climate change on the world's supply, demand and quality of water resources. Climate change models predict an increase in magnitude and frequency of extreme climate events, such as tropical cyclones, drought and floods. Mean annual river flows are expected to increase in certain regions such as the high latitudes and some tropical areas, but to decrease in arid and semi-arid regions around the globe such as Australia, and parts of the United States, Mediterranean Europe and Africa.

These hydrological changes will place increased pressures on the need to supply enough good quality water, and to protect populations and infrastructure from climate-related damage.

Aims and objectives

The core purpose of this module is to build an understanding of the vulnerability of water resources to population growth and climate change through both an engineering and ecohydrological lens. Within this context, students are encouraged to question what are the inherent challenges to pursuing the goal of sustainable water management?

Learning outcomes

On satisfying the requirements of this module, students will have the knowledge and skills to:

Undergraduate learning outcomes 1–3

1. Summarize the specific contexts that influence water availability, supply and demand in a rapidly changing world.
2. Identify principles of good practice in water sustainability.
3. Develop skills in water assessment and monitoring.

Postgraduate learning outcomes 1–5

4. Evaluate the complexity of adaptation strategies for water sustainability.
5. Assess the impacts of changing climate and landscape on water resources and their management.

Proposed assessment

Assessment task (undergraduate)	Value	Links to learning outcomes
Poster on a topic relating to water and sustainability supported by case study examples.	To be assigned by lecturer	1–3

Assessment task (postgraduate)	Value	Links to learning outcomes
Research paper on an aspect of either (i) operational flexibility in dams and river regulation in a changing climate; (ii) gender and water; or (iii) the challenges of managing municipal water equitably in cities with unplanned informal settlement expansion.	To be assigned by lecturer	1-5

Module indicative content

Format: Three lectures/seminars to provide basic content for student activities to develop and expand knowledge using a flipped classroom approach.

This curriculum is expected to fit in with existing water curricula and students are assumed to be familiar with basic concepts such as the hydrological cycle and the partitioning of water along discrete but also interconnected pathways; and the hydrology of freshwater systems (rivers, lakes and groundwater). If not, an introductory lecture to explain these concepts to students with a non-water background is outlined below.

Topic	Content
Optional introduction to hydrology and water quality for students in non-water programmes.	**Part 1** To study water in the context of climate change and population growth, it is essential that students understand core concepts of hydrology. An introductory lecture should be given to those students in non-water programmes of study, covering the following topics: • The hydrological cycle and its component processes (precipitation, interception, throughfall, evapotranspiration, surface runoff and streamflow, infiltration, groundwater recharge, flow and discharge). **Refer to**: Davies, T. 2008. *Fundamentals of Hydrology*. Routledge. This is a simple, very readable introductory text suitable for students across all disciplines. • The properties of water (molecular structure and its role in water adhesion, cohesion, capillary flow, surface tension, and water as a universal solvent); occurrence in three states at ambient temperatures; water density versus temperature; and the ecological consequences for aquatic biota. • Measuring flow. Describe the simple relationship of velocity multiplied by cross-sectional area as the basis for estimating stream discharge, and how this can be measured automatically by data loggers at gauging stations. Provide images of different types of gauges used locally or regionally. • The hydrograph. Note that a time series of flow will generate a hydrograph and provide a simple labelled diagram . Explain how a hydrographs can be used to interpret a river's responses to rainfall under different storm and catchment conditions (it is useful to consider the factors that control the shape of the hydrograph – rainfall duration, intensity and volume; proportion of catchment in which rainfall has occurred; catchment shape and topography; soil type; vegetation type and cover; proportion of catchment that is impervious to water–e.g. urban and landuse). • How does the slope of the hydrograph provide information on stream response time, but also the relative contributions of quick and slow flow, and recovery to pre-event flow conditions? • Provide a graphical time series of streamflow to explain the importance of interrogating data for quality. Is the data run long enough? Are the data accurate? Are the data independent? Is there a temporal trend? Are the data homogeneous?

	Part 2 All students should understand key biological and chemical attributes used to determine the quality of water, and by extension, the health of a freshwater system. Key indicators should be described with reference to the recommended values to meet specific international or national water quality guidelines (for example for drinking water, or for the protection of aquatic ecosystems). These indicators include pH, electrical conductivity, water colour, turbidity, suspended sediments, dissolved oxygen, biological oxygen demand, chemical oxygen demand, chlorophyll a, total phosphorus, total nitrogen, and faecal coliforms. See Student Activity 1 for a laboratory or field-based exercise in water quality testing.

Lecture 1: Ecohydrology

Topic	Content
What is ecohydrology?	The subdiscipline of ecohydrology studies the interactions between the biosphere and hydrosphere. Nuttle's (2002) definition can be used as an introduction: *'[ecohydrology] is the subdiscipline shared by the ecological and hydrological sciences that is concerned with the effects of hydrological processes on the distribution, structure and function of ecosystems, and on the effects of the biotic processes on the elements of the water cycle.'* This subdiscipline has emerged out of, and countered, the 'single problem-single factor-single solution paradigm' of the past, and has evolved in tandem with on-ground management practices such as IWRM (see Module 5). As an area of research, practice and education, it underpins sustainable water management. **Refer to additional resources below and Module 4: Ecohydrology: the water-plant nexus.** UNESCO. 2007. Ecohydrology: an interdisciplinary approach for the sustainable management of water resources. 14 pp. https://unesdoc.unesco.org/ark:/48223/pf0000152987. Useful graphic showing the relationship between ecohydrology and IWRM; and links to other resources/publications.

UNESCO. 2016. Ecohydrology as an integrative science from molecular to basin scale: historical evolution, advancements and implementation activities. IHP VIII Programme. 22 pp. https://unesdoc.unesco.org/ark:/48223/pf0000245512. Provides useful graphics and lists key demonstration sites around the globe.

Video: UNESCO's water programmes: 50 years, 50 movies on water. https://www.youtube.com/playlist?list=PLWuYED1WVJIOoTU02RZALTxUCucY-Q3YT.

Zalewski, 2002. for a useful summary of ecohydrology as a sub-discipline, with supporting graphics. https://doi.org/10.1080/02626660209492986

The applications of ecohydrology can be understood when posing a series of questions:

- How do hydrological processes affect biodiversity (at basin, catchment and local scales)?
- What are the hydrologic controls on biotic and abiotic processes (for example, in acid sulphate soil environments; urban stormwater systems; and sewerage treatment plants)?
- How does climate variability and climate change affect a catchment's water balance and hence its environmental services?
- How are the ecosystems of small streams affected by changes in groundwater storages?
- What managed flow regimes optimize in-stream habitability?
- What factors control the distribution of aquatic species in different reaches of a river (regulated and natural)?
- What are the risks of upstream development on estuarine and coastal waters?

Provide answers to these questions via a case study approach, or more simply via graphical representations that identify the salient linkages between hydrology and ecology.

Refer to: Zalewski and McClain (1998) This publication is dated, but it provides a useful set of examples to demonstrate the broad range of ecohydrological applications.

http://unesdoc.unesco.org/images/0011/001146/114659Eo.pdf

To locate more recent case studies, the international, peer-reviewed journal *Ecohydrology* is a rich resource.

Note that the International Hydrological Programme's (IHP VIII) *Strategic Plan for 2014–2021* refers specifically to ecohydrology as a key theme relevant to global and regional water security. This plan scrutinises the urgency in protecting water resources from further harm, by using an ecohydrological approach to build resilience in river basins against the combined stressors of climate change and anthropogenic activities. Key objectives are the integration of hydro-technical and ecohydrological approaches to water management and use of ecosystem properties as a management tool.

Refer to: Donoso et al. 2012. International Hydrological Programme Eighth Phase: Water security: responses to local regional and global challenges. *Strategic Plan IHP-VIII 2014–2021*. UNESCO.

(https://forskning.ruc.dk/en/publications/international-hydrological-programme-ihp-eighth-phase-water-secur)

A useful demonstration site is the Putrajaya Lake and wetlands in Malaysia. Supporting documentation can be found at the following websites:

i. Integrated catchment management of Putrajaya Lake. http://ecohydrology-ihp.org/demosites/print/124
ii. Putrajaya Lake management and operational system. http://plwmos.ppj.gov.my/v_intro_lake_wetland.asp
iii. Putrajaya ecohydrology management of lake and wetland in an urban ecosystem. This website includes a video of the wetlands, their values and uses from an ecohydrological perspective. http://www.riversnetwork.org/rbo/index.php/river-blogs/central-africa/item/3562-putrajaya-eco-hydrology-management-of-lake-and-wetland-in-an-urban-ecosystem

Lecture 2: Water use

Topic	Content
The water resource base and water use	Earth is referred to as the 'Blue Planet' (from iconic 1960s imagery taken from space) where life is sustained by the presence of water. There is a finite volume of freshwater present. • Show the relative volumes of seawater, freshwater locked up in polar and glacial ice and groundwater, and freshwater in rivers and lakes. • As well as understanding the *stocks* of freshwater, we need to understand the *circulation* of water through the *hydrological cycle*. • We also need to understand the terms for sustainably managing water resources: renewable, non-renewable, actual (varies according to supply and demand), internal, external and exploitable. **Refer to**: updated country data for total renewable freshwater supply by country (FAO, 2013). http://worldwater.org/wp-content/uploads/2013/07/ww8-table1.pdf • The spatial distribution of freshwater (provide plots of mean annual runoff and stream discharge) shows that water availability is heterogeneous around the globe. • Areas of water scarcity and water stress are also unevenly distributed globally. This has implications for human populations in a world of increasing population and climate pressures. **Refer to**: Oki and Kanae. 2006. Global hydrological cycles and world water resources. *Science*. 313: 10681072.
Water and human use	If Module 1 has not been delivered, watch the following video on water and the Anthropocene to demonstrate human impacts on global water supply: https://globaia.org/water-anthropocene • Description of different uses of water – drinking, domestic, agriculture (primary production), industry, environment, hydropower production. Explain the difference between consumptive and non-consumptive uses. • Examine the relative proportions of available water used by each of the above, at global and national scales. It is also interesting to look at local differences within a country according to climate type, e.g. semi-arid versus humid or tropical, or, between rural and urban. • Note that agriculture is a major user of water (provide pie charts to show this for different countries across the region, and globally) and explain the links between water use, human population and food production. • Explore drinking water as an essential resource, using World Health Organization (WHO) guidelines for daily needs. **Refer to**: The Pacific Institute's databases on water supply, withdrawals, access to improved drinking water, areas irrigated in each country, and national water footprint for each sector and country. https://www.worldwater.org/water-data/

Lecture 3: Regulated rivers, navigation and floodplains

Topic	Content
River regulation	Increasing human needs for water has generated an imperative to supply water as required regardless of climatic conditions. This has led to the regulation of rivers where water is stored in reservoirs behind dams and released as required for downstream users, or to mitigate effects of flooding. This has profound impacts on the river's flow regime in terms of flow volumes, seasonality, frequency, duration and magnitude of floods, and periods of low flow. Many of the major rivers of the world are now regulated. By contrast, an unregulated river has natural flow regime. The construction of dams can be seen as an adaptation to increased human populations and the need for a reliable supply of water for a range of uses. The building of dams is a legitimate solution to meeting water demands by multiple and often competing users. However, dams change flow regimes and impact ecosystems both upstream and downstream. • Describe the multiple purposes of dams (and the need for minimum headspace in multi-use dams), the topographic, hydrological and geological requirements for siting, and the types of dams. • Examine the process of 'running the river' through the three modes of dam operations – storage, supply and spill – and use streamflow hydrographs downstream of a dam to illustrate when these modes are in operation. Show hydrographs of streamflow in a river system pre- and post-dam construction. • Consider the impacts of dams on local climate; seismic activity; fish movement and genetic flow of species along a stream network; sedimentation upstream and both stream aggradation and sediment depletion downstream of a dam; and thermal pollution. Also look at the impacts of dams in the areas flooded by the reservoir including displaced populations, loss of productive land, and loss of culturally important sites. Case studies of these impacts should be used to emphasize critical linkages between hydrology and both terrestrial and coastal/marine ecosystems.
River navigation	• In-land river navigation and transport is another significant use of freshwater resources. This topic can be introduced through a case study of river navigation and its impacts on river systems. In addition, the impacts of climate change on river navigation can also be discussed.

	Useful case studies include: • The world's largest inland water transport network can be found in China. Funded by the World Bank in 2015, the Jiangxi Shihutang Navigation and Hydropower Complex project was constructed to improve water navigation and provide hydroelectricity (World Bank, 2015). However, the impacts of this project on the network of river systems went unreported. • Another example is India's ambitious River Inter-link project, aspiring to link several Indian rivers by a network of engineered canals and reservoirs to reduce drought frequency in north-west India and to improve in-land water navigation (World Bank, 2017). • The Mekong River Commission is one of the few transboundary governing bodies that plays a key role in developing the use of Mekong river basin for transport and communication to promote regional cooperation.
Irrigation	The diversion of water from rivers through irrigation networks is also an adaptation to the increased need for food security. 'Making the desert bloom' concept increases the area of arable land by expanding irrigated agriculture in otherwise marginal landscapes. Archaeological evidence demonstrates the use of irrigation over past millennia across Asia. Expansion in the latter part of the twentieth century, in tandem with dam construction, is a feature of the Great Acceleration. • Describe irrigation types and water efficiencies including application and distribution network efficiencies. • Highlight water used by irrigators according to crop type; and, economic return per unit of water used according to crop type. • Identify ecohydrological impacts including waterlogging, salinization, changed surface-groundwater interaction, reduced water quality of return flows to rivers, entrainment of fish in irrigation distribution networks, and invasion of pests. • Also note the less understood aspects of irrigation benefits to biota where habitat is available in otherwise hostile agricultural environments (e.g. the use of irrigation canals by reptiles and amphibians for refuge). Consider the impacts of converting open channels to closed pipelines for increased water efficiencies at the cost of biota which have already adapted to these highly modified landscapes. Note that, separately and in combination, dams and irrigation diversions disconnect a river system from climate and have profound impacts on ecosystems. Use examples of both inland and coastal rivers where this can be clearly demonstrated for a river system within Asia and the Pacific. **Refer to**: Rivers Network web site to access maps, basin and catchment scale information, and videos relevant to the country of interest. https://www.riversnetwork.org/rbo/index.php

Lecture 4: Water quality and human health

Topic	Content
Sanitation and water-related diseases	Access to safe drinking water and sanitation is a basic human right, recognized by the UN General Assembly in July 2010, making it binding under international law. However, over 11 per cent of the world's population do not have access to adequate water supplies and about 25 per cent lack adequate sanitation. This has enormous ramifications for human health. • Explain water quality standards for human water uses, and how they are applied to manage water sources, ensure treatment is sufficient, and to meet compliance. Reference both the WHO international water quality guidelines and national guidelines relevant to student country or location of delivery of this curriculum. • Begin by telling the story of John Snow's discovery that contaminated drinking water was causing a cholera outbreak in London in 1854. This led to the understanding of the oral-faecal route of contamination and diarrhoeal diseases. Watch: An animation of the 1854 cholera outbreak in London based on records of incidence. https://www.youtube.com/watch?v=5JbtHiFXbU0 • Briefly outline the different classifications of waterborne diseases, including faecal-oral diseases; water-washed eye and skin diseases; ingested or penetrating worm diseases; and water-related insect vector diseases (note that a student activity undertakes more detailed studies). • Consider water resources development (dams and irrigation systems) and the economic focus on water, food and energy security gains. These developments are also associated with increases in insect vector diseases – explain why, and what management is required. • Examine annual global data on the incidence of water-related diseases and note where hotspots occur. • Look at Millennium Development Goal 7 which included a target to halve the number of people who did not have access to clean drinking water by 2015. Note that the target was achieved globally, BUT disaggregating the data shows that 8 out of 10 people without improved drinking water sources are rural; and the least developed countries did not meet the target. The goal for improved sanitation was not met. Note the proportion of the global population who have a mobile phone compared to those with improved sanitation. Also, query what is meant by 'improved'. Use this information to argue for the need to interrogate global data.

	• Explore the SDGs for water and sanitation. What are they and are they achievable? What are the challenges in achieving these goals in terms of continuing dam construction and irrigation expansion; climate change; and diversity in national capacity? • Conclude by identifying responsibilities for protecting human health through sustainable water management by government authorities (multi-tiered); water utilities and providers; industry (polluter pays); non-government organizations and aid agencies; and communities.

Lecture 5: Contamination and pollution

Topic	Content
Contamination and pollution	• Define the difference between contamination and pollution, and use examples of diminished water quality due to (i) pathogens, (ii) eutrophication, (iii) sediment transport and high turbidity, (iv) industrial and agricultural effluent containing complex compounds (forward reference to antimicrobials that will be covered in detail later in the lecture, but also refer to other anthropogenic pollutants associated with industry and agriculture such as polychlorinated biphenyls [PCBs], persistent organic pollutants, volatile organic compounds and hydrocarbons), and (v) heavy metals. • Note the difference between point and diffuse sources of contamination and how this informs management. • Refer to guiding principles for minimizing or managing water quality to protect human and environmental health. These could include prevent pollution rather than treat symptoms of pollution; apply the precautionary and polluter-pays principles; set realistic standards and regulations; establish mechanisms for cross-sectoral integration; develop participatory engagement by all relevant stakeholders; develop portals for open access to data/information; and support transboundary cooperation on water pollution control.
Antimicrobial use and resistance as an emerging global issue	Raise the issue of antimicrobial use and associated challenges for future human health and the environment due to antimicrobial and antifungal resistance. • Note the broadscale use of antimicrobials in humans, and their release, largely unmetabolized, via sewage effluent into rivers. Use relevant literature to identify agriculture as the principal source of antimicrobials (for disease management, prophylaxis–particularly in intensive farming–and growth promotion). Note that water is a major pathway and matrix for antimicrobials.

	• Developing countries are particularly vulnerable to the impacts of antimicrobial resistance due to poor wastewater management, inefficient treatment facilities and the proximity of communities to effluent discharge points near hospitals, abattoirs, open sewers, and the use of human and animal wastes as fertilisers in market gardens. • See references such as WHO, 2014; Review on Antimicrobial Resistance, 2014; and Sharma et al., 2018. • Access the WHO site for reference material and access to global databases to show current and projected incidence of antimicrobial resistance by country. https://www.who.int/antimicrobial-resistance/en/
Microplastics	• Global production of plastics has increased since the mid-twentieth century and is now around 400 million tonnes/annum. It is predicted to double by 2025 and triple by 2050 (FAO, 2017 in WHO, 2019). Refer to Figure 1.1 in WHO (p. 5, 2019) to show the exponential increase in plastics. Plastics degrade into microparticles as small as 0.004 μm (invisible to the naked eye) with the largest being around 5 mm in diameter. • Identify and show images of the two types of microplastics: » Primary microplastics – manufactured microbeads used in cosmetics, toothpaste, detergents and some medicines. » Secondary microplastics – derived from degradation of larger plastic debris. • Note the major types of microplastics as thermoplastics (PE, PP, PET, PS, PVC, PC and PA) and thermoset plastics (PUR, epoxy resins and polyesters). Define these two groups according to their uses. Note the use of PE, PVC, PUR, PP and PA in water distribution networks. • Microplastics have a wide range of sources, including plastic containers, bags and synthetic clothes, and they are delivered to the environment via water runoff/discharge and wind from sites of accidental spill, littering, landfill and industrial effluent. • Note that most research has focused on the marine environment, but microplastics are equally important in terrestrial environments. **Refer to** Dris et al. (2015) for a useful schematic of source and transport pathways of microplastics in an inland urban setting through a river system and to the ocean. This publication includes useful data for the study undertaken in the Seine River, Paris. • Microplastics contaminate waterways and marine waters and it is thought that they pose significant risks to ecosystems. They absorb and adsorb to other pollutants in the environment so a wide range of persistent organic pollutants can be associated with microplastics.

	• Microplastics are ingested by marine and freshwater aquatic biota, including 90 per cent of seabirds around the world. Microplastic ingestion may lead to digestive obstruction and a false sense of having eaten enough, so that reduced food intake can lead to malnutrition. Of increasing concern is that 90 per cent of bottled water has been found to contain high concentrations of these materials (WHO, 2019). • Note that little is known about the potential impacts on human health. Larger ingested particles will be excreted, but health implication of ingestion or inhalation of smaller microplastic particles is currently unknown and needs further research. • **View** National Geographic video: 'Are microplastics in our water becoming a macroproblem?' https://www.youtube.com/watch?v=ZHCgA-n5wRw • **Refer to**: Microplastics in Drinking Water publication (WHO, 2019) https://www.who.int/water_sanitation_health/publications/microplastics-in-drinking-water/en/. This publication includes useful data, graphics and background information on occurrence of microplastics, potential human health risks, treatment technologies and current knowledge gaps. • **Refer to** Eriksen et al., 2017 to consider some solutions to managing microplastics in freshwater and coastal environments.
Case study of contamination	Rather than cover all aspects of water quality, use a case study approach to highlight the cascading effects of contamination or pollution that affects a whole nation, region or community. Case studies include: • Arsenic contamination of groundwater in Bangladesh. • Lead contamination of domestic water supply in Flint, United States. • Mercury contamination from artisanal small-scale gold mining in Indonesia. • Acidic discharge from acid sulphate soils in the Mekong, Viet Nam. • Sediment transport from logging in Australia. • Ok Tedi Mine downstream impacts on communities in the Fly River, Papua New Guinea. • Poor drinking water quality during prolonged drought in Australia and Pakistan. • Urban runoff in China. • Diarrhoeal diseases after tropical cyclone-induced flooding in Fiji. These case studies could also be used for student research in an assessable activity.

Lecture 6: Water and gender

Topic	Content
Water as a gendered issue	Note that water is a gendered issue due to the responsibilities that women have for collecting water for drinking, cooking and bathing in many countries. The time spent collecting water can compromise a woman's ability to participate in other activities including decision-making in water management, and also compromises girls' access to education. Clean water is essential for women's hygiene during menstruation, pregnancy, child-bearing and child rearing. Sanitation also affects women and children where open defaecation occurs, and safety is an issue; and where unimproved sanitation compromises the health of women and children. Facilitating women's involvement in decision-making in water management is integral to their empowerment. What are the key points around access to clean, safe water and improved sanitation being a gendered issue? i. Impacts on productivity ii. Poor health iii. Risk of violence iv. Barrier to education A number of facts that are relevant to water and gender include the following: • 8 out of 10 households globally rely on water collected by women and girls. This amounts to hundreds of millions of hours spent daily around the world in the collection of water. Improving drinking water services will have a strong gender impact. (WHO and UNICEF, 2017) • One million deaths of women and babies each year are associated with unsanitary births. Infections account for 26 per cent of neonatal deaths and 11 per cent of maternal deaths. (WHO and UNICEF, 2019). • Although women represent almost 50 per cent of agricultural labour in developing countries, their agricultural productivity is around 20–30 per cent lower than male farmers. (FAO, 2017) • Note that women are particularly vulnerable during natural disasters such as drought and floods. Reduced mobility due to pregnancy, responsibilities for babies and children, or age, poses higher risks during floods, for example. In regions where increased risks of natural disasters are associated with climate change, this translates to cascading impacts for women in terms of greater vulnerability.

	Refer to: UN Women. 2018. Pacific Gender and Climate Change Toolkit Modules 2.2 and 2.4. https://www.unwomen.org/-/media/headquarters/attachments/sections/library/publications/2015/toolkit%20booklet%20pages.pdf?la=en&vs=4359 • An excellent self-contained module on water and gender can be found at http://www.thewaterchannel.tv/gender/content/chapter1/1_1.html
Gender and water management	Use the following videos to consider water and gender and its relevance to water management: Gender and Water Alliance http://www.thewaterchannel.tv/media-gallery/5939-gender-and-water-alliance Open 'Video Las Lolas' and start at 50 seconds: http://www.watergovernance.org/programmes/knowledge-management-strategy-on-democratic-economic-governance-deg-km/gender-equality-and-womens-leadership/ Additional useful resources: • International Fund for Agricultural Development (2012): Gender and Water – Securing water for improved rural livelihoods • UNICEF: Gender and water, sanitation and hygiene (WASH) • UNESCO World Water Assessment Programme: Overview of resources on gender-sensitive data related to water • UN-Water: Gender, Water and Sanitation – A Policy Brief • UN Women: Women and the Sustainable Development Goals • WaterAid: Water and Women

Lecture 7: Urban water (Part 1)

Topic	Content
Urban hydrology	Engineering students will understand the principles of urban hydrology and the hydraulics of both open channel flow and pipe flow. In this lecture, the key concepts of urban water hydrology will be covered as the basis for understanding the need for and urgency of sustainable management of urban water systems. The lecture should be aimed at both science and non-science, non-water students. • View the UNESCO video 'Water in cities' as an introduction: https://www.youtube.com/watch?v=ImzNmJT3_OA&list=PLWuYED1WVJIPVor5RZ6GfS_RuVyVSK-4-&index=33&t=0s

	• Relative to rural land, urban landscapes are dominated by impervious surfaces, higher surface roughness, and a constructed drainage system (and sewerage). Images to show the contrast should be shown. How is water partitioned differently as an area changes from rural to urban? How is this reflected in the water balance of an increasingly urbanized catchment? • Urban streams respond to rainfall quicker and have higher discharge and peak flows than prior to development. Compare hydrographs for a catchment pre- and post-urbanization. What is controlling the gradient of the rising and receding limbs? How might the shape of the hydrograph vary according to climate? What role might urban greenspace play in attenuating the peaks of an urban hydrograph? • The difference in stream discharge after urbanization can be predicted by the proportion of catchment converted to impervious surfaces, and the proportion of catchment serviced by stormwater drainage and sewerage. • Changed hydrological responses increase flood risk. Use a city example that has increasing flood risks as it has developed, For example, Jakarta, Indonesia; and Brisbane, Australia. What compounds these risks (floodplain encroachment)? • Describe urban water disaster management (structural and non-structural) including, but not limited to: hydrological monitoring; flood control structures; modelling/mapping areas at risk of flooding of specific recurrence intervals; flood warning systems; regulation and zoning of flood-prone areas; and application of hydro-informatics using digital information (for the latter, see Price and Vojinovic, 2008) . • Examine the roles that detention ponds, control structures and retention basins play in reducing urban flood risks (by modifying flow velocities and volumes, and flood response times).
Growing cities	• Provide some historical context in the changing role of cities pre- and post the Industrial Revolution. • Describe the growth of cities, particularly in the twentieth century, the key drivers of this trend, and how the development of peri-urban areas in developed and developing countries differ. Include reference to informal settlements, as well as other rapid changes that can affect urban water management such as changing landuse or building density and loss of greenspace. • Note the development of mega-cities. Consider the increasing urban populations in coastal environments and the vulnerability of these cities to climate change-induced sea level rise. • Managing urban water requires extensive infrastructure to provide for multiple water uses, sanitation, stormwater runoff, and urban ecosystems. As cities grow, so do the demands for all of these services.

	Use maps and plotted data from Our World in Date website to show variability globally. https://ourworldindata.org/urbanization The time scale on the x-axis of plots can be varied to show the exponential growth occurring across the Great Acceleration. Graphs can also have data for specific countries added.
Water supply and demand	• Urban water supply can be drawn from: i. Rivers and surface reservoirs (often within designated water supply catchments with landuse limitations to protect water quality, e.g. Melbourne, Australia; New York, United States). ii. Groundwater bore fields – these can be the sole source of water e.g. Honiara, Solomon Islands; American Samoa; Kiribati; Hyderabad, India; Chonquing, China; Karachi, Pakistan. iii. Recycled water from treated sewage effluent (e.g. NEWater Singapore; groundwater replenishment with recycled water, California, United States). Refer to: Irvine et al. (2014) regarding the Four National Taps strategy in Singapore. iv. Desalinization (Malta; Kitakyushu, Japan; Durban, South Africa; Barcelona, Spain). v. Sourced from location outside urban agglomeration, e.g. Hong Kong, Singapore; Ahmadabad, India; Tel Aviv, Israel. Refer to MacDonald et al. (2014). • Provide schematic diagram to show the infrastructure of a representative city, including primary water sources; water treatment plants distribution networks, stormwater and sewerage system including sewage and/or effluent treatment plants. • Consider the vulnerabilities across such a system in terms of losses, the rate of obsolescence, risks of contamination, flood risks, and impacts of increasing demand/reduced supply due to population growth and climate variability and change.
Water security	Water security is a function of the balance between supply and demand. • Supply will vary depending on rainfall and the type and extent of development in catchment areas, which will affect water quality and the levels of treatment required for use. • Demand may vary seasonally, with higher demand in hotter and drier periods. As populations grow in urban areas, demand is also out-pacing supply. Water stress and scarcity are increasingly important issues for urban water utilities. • Two basic approaches to provide adequate water security have historically included: (i) increase supply by building larger storages, exploiting groundwater, or using alternative sources such as desalinization and recycled water. Refer to case studies where each of these have been employed. (ii) reduce demand through water conservation measures, including water restrictions, improved water use efficiency and pricing. What are the limitations of each of these approaches?

Lecture 8: Urban water and sustainability (Part 2)

Topic	Content
Hot cities	• Well-planned cities have included extensive areas of vegetated public space. Vegetation provides a number of ecosystem services (e.g. habitat) and both public health and social benefits (shade and cooling, natural 'scape' that improves well-being and reduces anti-social behaviour). • Increased urban populations drive planning towards higher density housing, urban infill of greenspace, and, in developing countries, urban sprawl as slums and informal settlements. • Integrated approaches using green building codes and optimizing greenspace are critical for climate change resilience. **View video** on this approach in Manilla, Philippines: Preserving landscapes and open spaces seen as key to 'green cities' . https://www.youtube.com/watch?v=1LQR_2GYabg • As cities grow, and the percentage area of impervious surfaces increases, urban climates become increasingly hostile. This is due to increased temperatures and lower humidity as a function of: (i) transfer of sensible heat from buildings and sealed ground surfaces into the surrounding air; (ii) a reduction in vegetation; and (iii) transfer of water through sealed drainage networks. • The development of urban heat islands has been well documented since the 1980s. Look at examples of heat islands and their development in tandem with population growth and urban intensification. **View student-produced video**: Urban Heat Island Effect: What neighbourhoods are vulnerable? Case study. https://www.youtube.com/watch?v=TNklpWkUulo • What are the longer-term health implications of climate change in cities where heat island effects occur? What are the possible solutions?
Sustainable urban water design	Sustainable urban water design is the planning, design and development of a city that addresses issues of water sustainability as well as protection of the environment. Different approaches include water-sensitive urban design, 'sponge cities', integrated water resources management (IWRM) and ecologically sustainable development (ESD). In addition, there is an emerging lifecycle framework for the production, transport and installation of urban infrastructure, including (but not limited to) water supply, stormwater and sewerage systems. This approach takes into account the relative environmental burdens associated with the use, density and/or dimensions of different building materials. Lifecycle assessments can be used to determine the environmental suitability of urban infrastructure – with improved outcomes for urban sustainability. See Gabarrell et al. (2015). All of these approaches have an ecohydrological basis.

- The principle objectives of sustainable urban design are water conservation, wastewater minimization and stormwater management. Each of these objectives work towards integrated management for the conservation of water as well as protection of aquatic ecosystems.
  i. Water conservation: reducing demand and increasing water use efficiencies, rainwater harvesting, stormwater harvesting (to use for greenspace irrigation).
  ii. Wastewater minimization: reuse of greywater and/or treatment to allow for discharge.
  iii. Stormwater management: managing stormwater quality (e.g. urban wetlands, gross pollutant traps), sewer infiltration, inflow reduction.

- Note that sustainable urban design can be undertaken at plot, precinct, and regional scales with integration into the built form.
- Examples of integrated urban design should be shown to illustrate the opportunities for embedding sustainable practices in city planning: constructed wetlands, bio-retention basins, naturalising engineered urban waterways and drains, improved stormwater treatment technologies, increased greenspace and replacement of impervious surfaces, increased urban trees and green roofs.

View videos:

- Water-sensitive urban design (Ireland): https://www.youtube.com/watch?v=b_DTnOzYTR4
- Transforming a city: urban water innovation (Kunshan, China): https://www.youtube.com/watch?v=oSrNdhwTW_U
- Preventing stormwater runoff (United States): https://www.youtube.com/watch?v=N9HUoMnvsRw

Quick quiz

Question	Answer
What is the principle concept that informs the study of ecohydrology?	That the integration of hydrological and ecological knowledge can be applied to the sustainable management of freshwater resources at a catchment or basin scale, in order to deliver outcomes with environmental, economic, social and cultural benefits.

List the key uses of water and, globally, what is the major user of water.	• Uses of water include drinking, domestic, industry, primary production (agriculture), energy production (hydropower), water-dependent ecosystems and recreation. • The major user of water globally is agriculture.
What is meant by the term 'river regulation'	The operation of engineering works on river systems including dams and weirs and their control on the flow regime of a river in terms of flow volumes, seasonality, and the magnitude, duration and frequency of floods and low flow conditions.
What are the downstream impacts of dams?	• Changed flow regime • Reduced sediment load and transport • Stream aggradation • Thermal pollution • Reduced biodiversity and gene flow in aquatic species
Why is the disconnection of a river from its floodplain due to river regulation important?	• Interruption to periodic deposition of flood-derived nutrient-rich sediment reduces the fertility and productivity of floodplain soils. • Critical ecological signals for plant growth and reproduction in flood-dependent species are reduced or lost.
Name two salient factors that have changed the spatial distribution of insect vector waterborne diseases.	• The construction of dams and irrigation networks • Climate change
How is water contamination different to water pollution?	Water can be contaminated in the presence of a substance where it should not occur, or is at concentrations above background levels. Water is polluted when contamination results in adverse biological effects to resident communities.
Provide examples of point source and diffuse sources of pollution.	Point source pollution – sewage treatments plants; factories and power plants; mining; road and building construction sites; feedlots and abattoirs. Diffuse source pollution – agricultural and urban runoff; forestry operations.

How is water a gender issue?	It is disproportionally harder for women and girls to lead healthy, productive lives if there is inadequate access to safe drinking water and improved sanitation in the home, at work and at school.
What are the salient controls on stream responses to rainfall in an urban setting?	• The proportion of the catchment that has impervious surfaces. • The proportion of the catchment that is serviced by stormwater drainage and sewerage.
Describe the two basic approaches in ensuring urban water security.	• Increasing supply by enlarging storage (dams), developing or increasing groundwater abstraction, or developing alternative sources such as desalinization or reused water. • Reducing demand through pricing, improving water efficiencies, and applying restrictions to water use.
Name the three objectives of sustainable urban water design.	• Water conservation, wastewater minimization and stormwater management.
How can the concepts of ecohydrology be applied to sustainable urban water management?	• The integration of more greenspace, constructed wetlands, bio-retention ponds, naturalizing engineered stormwater and drainage channels, replacement of impervious surfaces, and improved stormwater and sewage treatment technologies all include ecohydrological methods.

Student-focused learning activities

Activity 1: Water quality testing in the field

Learning objective: To use field equipment for testing water pH, electrical conductivity (EC), dissolved oxygen (DO), temperature and turbidity; and interpret the results.

Required: Handheld turbidimeter and multi-meters for testing pH, EC, DO and temperature, sample bottles, deionised water, wash bottles for rinsing; Kim wipes for wiping probes and turbidimeter glassware.

To do: Provide students with worksheets that describe the site to be visited, upstream landuses, geology and stream characteristics (i.e. natural flow regime/regulated; natural channel / engineered; perennial/ephemeral; largely rural/urban), as well as downstream water uses.

Handouts should include the relevant national or international guidelines for the parameters to be measured according to different water uses (e.g. drinking, domestic/primary production, aquatic ecosystems). Relationships between temperature and DO should be explained.

Demonstrate the use of the equipment, the protocols for sampling water, and how to minimize cross contamination between samples. If only one set of water quality equipment is available, select a pair of students to sample water and test it for the relevant parameters. Where multiple kits are available, divide class into groups and ask students to take multiple readings along the stream reach.

The site selected should allow multiple comparative measurements to be taken at different points downstream to consider what factors are controlling water quality. Factors could include water inflows from tributaries, stormwater inlets, spring discharges into the stream, or point sources of pollution along the reach.

Other questions may include:

- Is there a trend in water quality downstream?
- Are there any 'hotspots' that would be worthy of further investigation?

If it is an engineered stream sealed with concrete, then the higher pH should be explained.

Where a number of measurements are possible, rotate the students who use the equipment to maximize their experiential learning across the class.

Activity 2: Conceptual site modelling

A conceptual site model is a written or pictorial representation of an environmental system and the biological, physical and chemical processes that determine the transport of contaminants.

In this activity, students will work in small groups to interpret a satellite image of a catchment area where mining is occurring, with downstream impacts on water quality. Students will develop an understanding of the sources, pathways and risks associated with the mobilization and transport of contaminants through a catchment. Lecturer/tutor should select a catchment with a stream that is impacted by mining activities. Satellite imagery must be available that shows the extent of the mining, its connectivity to the stream, and both surrounding and down catchment vegetation, landuse, towns and other infrastructure that students will be able to identify.

Learning objectives:

- To interpret satellite imagery of a catchment experiencing extensive mining development and to identify different landuses, the pathway of a stream/river and its connectivity between landuse(s) and water quality degradation.
- To consider sources of potential/actual contamination of waterways, and the pathways that contaminants may take.
- To identify potential downstream risks.
- To develop a hypothetical monitoring network to assess water quality, and the risks to downstream water users.

Students need to be made aware of the different purposes of water quality monitoring: establishing baseline conditions; identifying cause and effect (e.g. logging, mining, agricultural activities, natural hazards); quantifying changes in water quality over time; or ensuring compliance with guidelines to manage health risks or environmental needs.

To do:

1. Go to Google Earth and find the allocated site (provide latitude and longitude coordinates). Look at the developments in the area and consider the main landuses.
2. Looking at the hardcopy Google Earth image provided, try to develop an inventory for the area. Include:
    - Different landuses (try to identify what these might be: mining, palm oil plantations, food crops, port facilities, ore stockpiling, quarrying)
    - Rivers and streams
    - Towns, villages and settlements (peri-urban settlements?)
    - Built infrastructure (e.g. roads, bridges, ports)
    - Industrial sites
    - Locations where native animal species habitat is likely
3. By looking at the satellite image and reviewing the landuse inventory, students should discuss what are the potential contaminants that could enter the stream and what pathways they might take. This discussion supports the creation of a conceptual site model by filling in the table provided (see Section 3). Emphasize the need to consider the different sources of risk to water quality, potential contaminants, pathways that the contaminants take (for surface runoff on catchment slopes, or roads; groundwater; streamflow etc) and who/what will be impacted.
4. Once the table has been in-filled, use this information to explore questions such as:
    - How might water quality vary downstream during wet and dry seasons?
    - Are there any environmental or public health 'hotspots'?
    - Who/what will be at highest risk?
5. Students should now be ready to answer where and when should sampling of water occur in this area? What parameters of water quality should be measured?

Activity 3: Field trip to a dam

Learning objective: To make field observations, and to observe and describe the purpose, function and impacts of large dams.

Pre-trip preparation

- Handouts for students in digital or hardcopy: geological and topographic (or digital elevation model) maps of dam site showing location of dam, area of reservoir, and drainage network. If possible, also have a map of landuse upstream and downstream of dam.
- Be familiar with the type of dam, its construction, and purpose. Also be familiar with the uses of water: domestic water supply, irrigation supply, hydropower; flood mitigation, recreation, the environment, industry etc. Any potential competing needs of different users should be known. This information will be shared with the students either orally or as a handout.

- Have available an annual or multi-year hydrograph of (a) streamflow below the dam and (b) dam capacity, as a student handout.
- Organize for an engineer or water manager responsible for, or familiar with, dam operations to be available to give a short talk to the students. Ideally, a catchment manager should also be available to give another perspective on the dam and the need to manage the upstream catchment to optimize water quality.

Field trip

- Two options are available for this trip depending on whether it is to be assessable. Either (i) students observe, and listen to information being provided, or (ii) also take notes on a handout which is then submitted. If the latter, then the content of the students' answers should include descriptions based on observations and information provided; inferences; and interpretation of hydrograph data.
- As students travel to the dam, they should be noting the key landscape attributes and, if possible, stop by the river to observe the flow regime, and whether there is evidence of erosion or aggradation.
- At dam site, talks by engineer/managers or, if not available the lecturer, should provide all relevant information on the dam, its uses, any issues or points of interest, and the impacts both upstream and downstream. Establish whether any management strategies have been put in place to assist fish passage, provide environmental flows downstream or to otherwise protect ecosystems both up and downstream of the dam. Note in some cases there may be impacts on communities displaced by reservoirs upstream of the dam and this should be discussed and noted.
- Students should note what mode of operation is currently underway at the dam. If the dam is in supply mode, or storage mode with environmental releases, have information available as to whether water is being taken from the surface or subsurface. Students should consider what implications this has for water quality downstream (for example, will water quality vary due to DO concentrations or temperature?). This may need explanation to describe temperature and redox stratification of the reservoir.

Activity 4: Workshop on water and human health

Learning objective: To develop an understanding of water-related diseases, incidence and water management approaches to control incidence.

To do: (30 minutes) Break into groups of 4–6 people (the actual number will depend on class size). Each group will be allocated a water-related disease (waterborne or water-related insect vector) from this list: malaria, cholera, leptospirosis, dengue, diarrhoea, hepatitis, polio, schistosomiasis, typhoid, Japanese encephalitis, yellow fever, filariasis.

Within each group, students will undertake research to identify the following:

- Description of the disease, its signs and symptoms.
    - » Epidemiology (WHO website https://www.who.int/health-topics). You can also find out about the incidence of the disease for a selected country through the WHO

website https://www.who.int/gho/en/. A live map is available at: https://outbreaks.globalincidentmap.com/. However, you should also look at other sites for information on the disease.
    » Treatment.
- Report findings to class (five minutes per group).
- Discuss strategies that could be used to manage water resources to control the incidence of the disease. To protect public health, do you need to prioritize or target particular groups of people and if so, who? How can you justify that prioritization? (20 minutes)
- Report findings to class (five minutes each group plus question time).

Activity 5: Field data collection and analysis of heat island effects

Learning objective: To collect, collate and analyse data from an urban area to establish the extent and magnitude of a heat island effect in an urban setting.

Heat island effects can be easily generated from existing data and the use of geographic information systems (GIS). This exercise provides students with the lived experience of changing urban temperatures, encouraging them to observe, infer and reflect on the climate variability in their town/city.

Required: Multiple GPS and wet-dry thermometers, one set per group.

Logistics: Students should have own transport and have communication access to stay in touch with the lecturer/tutors throughout the exercise.

To do: Students should be divided into groups of 4-6 people.

An area within a city or town should be selected, and both hardcopy and digital maps provided. Groups are assigned a number of sites to monitor from 4 p.m. to 11 p.m. The selection of sites by the lecturer should allow for the creation of a map that contours temperature and humidity values. Areas to target should include medium to high density buildings and greenspaces (such as parks and ovals). Monitoring greenspaces should be limited to their perimeters for safety reasons, particularly after dark.

Measurement of temperature and humidity should be taken ideally every half hour, which is possible if a group is assigned just one site to monitor. However, where groups have been allocated 2–4 sites, hourly measurements are more realistic and achievable. In this case, the measurement sites need to be located close enough to minimize the time difference in measuring. Maximum time taken for each rotation across all sites needs to be no longer than one hour. This allows for a minimum of seven measurements per site between 4–11 p.m.

Data from each group should be sent to lecturer/tutors who collates all information and shares the full dataset to all students. Contoured maps of temperature and humidity can be constructed by each group for 4 p.m., 8 p.m. and 11 p.m. This can be undertaken manually, or using a software platform (for example, Surfer) or GIS. Individually, each student should answer the following questions:

- What broad landscape features were associated with the highest temperatures in (i) late afternoon; (ii) evening; and (iii) middle of the night?
- What broad landscape features were associated with the lowest temperatures in (i) late afternoon; (ii) evening; and (iii) middle of the night?
- How does humidity change spatially and temporally over the period of monitoring?
- What activities might exacerbate the heat island effect?
- What are the most likely controls on heat generation in urban areas and what mitigation strategies could be put in place accordingly?

Activity 6: Field trip to observe urban stormwater management

Learning objective: To make field observations in order to develop an understanding of how integrated infrastructure is used to manage urban surface runoff.

Field trip sites should include stormwater channels, retention ponds and detention basins, gross pollutant traps and constructed urban wetlands. Notes should be made of the presence of any debris and rubbish, sites of pollution, and structural integrity of engineered channels/culverts/control structures etc.

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Module 4: Ecohydrology and water-plant nexus

Summary

Ecohydrology can also help build a better understanding of the linkages between the flows and storage of water across the landscape, and the structure and function of plants. For water managers, understanding this relationship builds capacity in developing strategies that improve catchment condition, influence flow regimes, affect micro-climate, increases water quality and maintains ecosystem services.

In this module, some basic principles of hydrology and botany are applied in two aspects of ecohydrology: (i) the partitioning of water along different pathways in the hydrological cycle and the interactions between water and plants; and (ii) the uptake of water and solutes by plants. Case studies will be used to illustrate examples of these processes. These interactions can have profound implications for human health and well-being, livelihoods and ecosystem condition, with increasing urban populations and climate change (particularly increased incidence and magnitude of climate extremes).

Aims and objectives

The aim of this module is to develop a knowledge of water-plant interactions and to examine the ways in which catchment hydrology and water quality can be enhanced by managing vegetation.

Learning outcomes

On satisfying the requirements of this module, students will have the knowledge and skills to:

Undergraduate learning outcomes 1–3

1. Understand the interactions between water and vegetation and its relevance to sustainability.
2. Predict how the water balance will respond to changes in catchment conditions due to the interaction of water and vegetation systems.
3. Demonstrate familiarity with a range of water resource management strategies in both rural and urban settings.
4. Integrate information from meteorology, hydrology and ecology to interpret stream or groundwater responses to vegetation change.

Postgraduate learning outcomes 1–5

5. Appreciate the relationship between raw data and their interpretation, and how a limited knowledge influences water management and decision-making.
6. Consider and use a range of methods for addressing water resource management from an ecohydrological perspective.

Proposed assessment

Assessment task (undergraduate)	Value	Linked learning outcomes
Reflective journal with commentary on each of the topics covered in the lectures and student-focused activities.	To be assigned by lecturer	1–3

Assessment task (postgraduate)	Value	Linked learning outcomes
Portfolio covering each of the topics of this module, with case studies from across the region to use as supporting material.	To be assigned by lecturer	1–5

Module indicative content

Lecture 1: The hydrology-ecology nexus

Topic	Content
The hydrology-ecology nexus	Key interactions occur between water and the biosphere as water is partitioned into different pathways of the hydrological cycle. Briefly describe these interactions, supported by a diagram of the hydrological cycle, as a foundation for later lectures on specific aspects of ecohydrology. The nexus between water and the biospheres can be noted in the following points: • The hydrological cycle – plant interactions. Most of the processes of the hydrological cycle, once precipitation has fallen, can be linked to plants in the way that they intercept, use and transpire water. Students will undertake a workshop to unpack this relationship. Plants also take up solutes that can then accumulate in leaves/tissue. This has implications for water quality and its potential applications in bioremediation in catchments. • The hydrological cycle – sediment and solute transport via the pathways of runoff and streamflow – and the implications that this may have for ecosystems downstream including in-stream aquatic biota. • The hydrological cycle – storage (dams, lakes and wetlands) where impoundment of sediment and biogeochemical processes driven by redox, temperature, and nutrient availability can have implications for in-storage and downstream water quality and geomorphic processes. • The hydrological cycle and groundwater-dependent ecosystems. • The modified hydrological cycle in urban environments and the duality of engineered and nature-based solutions for stormwater, wastewater, sanitation and flood management.

	• Upstream and downstream impacts of dams. • Note the ecosystem services provided by surface waterbodies for habitat, and by groundwater for groundwater-dependent ecosystems. A significant intergovernmental policy effort that addresses the ecology-hydrology nexus is the Ramsar Convention of Wetlands. This convention provides a framework for management of Ramsar-designated wetland conservation sites all over the world. Conventions, such as the Ramsar, provide a direct link to the management of ecological ecosystems that impact the global hydrological cycle, the climate regime and migration of bird and animal species.

Lecture 2: Water and plants

It is recommended that this lecture be co-taught with a specialist in plant ecology. It is assumed that all students will now have a knowledge of the hydrological cycle and its component processes. In this lecture, the controlling factors and processes of water uptake, movement and use of water in plants are described.

Topic	Content
Water and plants	• The roles of water in sustaining plant life (from whole plant to molecular scales). • Consider the spatial distribution of rainfall and vegetation type for a particular country or region where there is a wide range in mean annual rainfall. Show graphical data for rainfall versus above ground biomass or primary productivity. Ask students to provide their interpretations of the relationship. Note that there are multiple publications on this topic. See Hu et al. (2007) as one example. • Soil moisture and hydraulic lift (or hydraulic redistribution) Refer to Amenu and Kumar (2018) for some useful diagrams. • Plant water potential and the movement of water in the soil-plant-atmosphere continuum. • Solar radiation, the energy balance and evaporation. • Evapotranspiration (evaporation from wet surfaces plus transpiration through stomata). Include reference to factors that control evapotranspiration rates: wind speed and turbulence, air vapour pressure and ambient temperature. Examine data that shows daily and seasonal changes in temperature, radiation fluxes, leaf water potential and leaf-to atmosphere vapour pressure to highlight the relationships. • The hydraulic architecture of plants (the relationship between leaf area, sapwood area, hydraulic conductance and conductivity of sapwood and xylem).

	• Trees are an important pathway for water in a catchment. Look at comparative data for water use by different tree species, and by tree age, and seasonality. • What are the main sources of water for plants and how do we know where water is coming from in a plant (e.g. recent precipitation held in storage in upper soil profile, streamflow, water delivered via throughflow from up-slope, or deeper groundwater and capillary fringe). Technique: Isotopic analyses.

Lecture 3: Changing landuse and water

Topic	Content
The water balance	Revision on the water balance is useful in this lecture, prior to examining the impacts of landuse change and climate on catchment vegetation. • Describe the water balance and its components, giving examples of the global water balance, and regionally relevant water balances at national and basin scales. Why is information on a catchment's water balance useful? • Provide examples of water balances for both an inland and coastal river catchment at the estuary. **For an inland river system** $P = \quad ET + SR + R \pm \Delta S$ where P = precipitation (rainfall) ET = actual evapotranspiration SR = surface runoff Dis = groundwater discharge R = recharge to groundwater ΔS = change in storage (i.e. soil moisture) **For an estuary** $P + Q_R + Q_{T(IN)} + SR + Dis = ET + Q_{T(OUT)} + R \pm \Delta S$ where Q_R = river discharge Q_T = tidal flows

Hydrological responses to changing rural landscapes	Landuse changes have occurred extensively throughout the Anthropocene, particularly deforestation and the planting of annual crops, as well as the incursion of urban areas into rural landscapes. These changes are reflected in responses in streamflow and groundwater storage. • At a catchment scale, the volume of mean annual evapotranspiration is determined by the interaction between supply (total rainfall) and atmospheric demand (potential evapotranspiration). Plants play a dominant role in this interaction. Evapotranspiration is generally higher for forested than for non-forested catchments because trees having deeper root systems and higher leaf area indices. This means that forested areas are using more water than grasslands. • Since trees use more water than grasslands, a change from forest to cropping or perennial pasture will be associated with decreased streamflow and decreased recharge. Show data plots from Zhang et al. (1999). • This relationship between plant water use and streamflow is important in forested catchments undergoing logging. In a mature forest, streamflow and plant water use will be in equilibrium. With clear felling, bare soils will increase runoff, streamflow and groundwater recharge. On replanting, juvenile trees have a higher rate of water use than mature trees so there is a short-term decrease in streamflow and groundwater recharge, then over the period of tree maturation there is a trend towards equilibrium. Use the 'Kuzcera curve' to illustrate this trend for Australian Mountain Ash but noting this relationship will vary according to species and tree density. **Refer to**: Vertessy et al. (1998) Fig 10, p. 8. **Also see** Brown et al. (2005). • In a forested water supply catchment, the forest age can be a compelling factor in defining catchment yield (i.e. water discharging from the catchment via streamflow). This is due to changes in the partitioning of water along the various pathways of evapotranspiration, interception and runoff as tree leaf area indices, depth of root structures and plant vigour evolve over time. **Refer to** Vertessy et al. (1998) for plots of proportions of water partitioned into these pathways versus stand age. This has implications for managing the supply of water for a given set of climate conditions, but changing vegetation water use. • Development of dense, monoculture plantation forests will impact groundwater recharge and water table depth, with the responses varying seasonally and across the tree rotation through planting, thinning and felling phases. Impacts include reduced streamflow and water security for other users. **Refer to**: Benyon et al. (2005)

	• Groundwater use by deep-rooting trees can maintain naturally low water tables, preventing the mobilization of salts within the soil from reaching surface soils and causing salinization. Clearing trees can induce salinization with associated land and water degradation. Extensive studies have been undertaken in Australia on this topic due to the accumulation of salts within the soil profile, and their mobilization upwards to the root zone and ground surface in response to land clearing. **Refer to**: Eberbach (2003). • Finally note that altered flow regimes in regulated rivers can disconnect the river and floodplain with critical ecological impacts on flood-dependent ecosystems including forests, bird, fish, mammal and amphibian species that rely on periodic inundation for vegetation growth or as triggers for reproduction. Use examples relevant to local regions. These relationships between plant water use and hydrology has significance for reforestation projects, conversion of forested land to agriculture and the availability of water for other uses.
Hydrological responses to changing urban landscapes	In this part of the lecture, information about landscape change and the linkages between plants and hydrology is limited to urban expansion into rural areas (peri-urbanization). Reference should be made back to Lectures 7–8 on urban water in Module 3. Describe the process of landscape change as rural areas are converted to peri-urban areas. This can include spatially fragmented locations in developed countries with low population density, and spatially concentrated areas in developing countries, including informal settlements. Note that in developed countries, the process is outward looking from cities for lifestyle benefits within commuting distance but, in developing countries, it is inward looking for urban employment and services. The vegetation and hydrological changes will vary accordingly: • Developed countries: some increases in tree cover (as patches), groundwater abstraction, small farm dams and roading. These changes will affect streamflow due to over-abstraction, interception of water by dams, and impacts on groundwater dependent ecosystems. • Developing countries: broadscale loss of vegetation, increase in areas of impervious surfaces changing the rainfall-runoff relationship, poor water quality due to sanitation issues, and water scarcity. **Refer to**: Low Choy et al. 2008 (Chapter 2); Woltjer, 2014; Narain and Singh, 2019.

	Ask students to work in pairs to modify the water balance for an inland catchment where the following changes occur: a. Conversion of native forest to agriculture (i.e. land clearing for palm oil plantation or for annual cropping). b. Conversion of pasture to plantation forestry (for wood production). c. Conversion of dryland pasture to irrigated rice.

Lecture 4: Fire and vegetation

Topic	Content
Fire basics	The incidence of fire is expected to increase with climate change. Fire within catchments will impact vegetation with cascading implications for catchment hydrology. This is an example where ecohydrology is a critical component of integrated strategic planning. • Note that the heat, smoke (particulates), ash deposition, and volatiles released to the atmosphere during fire all have ecological and hydrological impacts. • Heat generation will be a function of what is being burnt, and the fuel load (i.e. the availability of dry biomass). Fuel can comprise grass, leaves, trees, fallen branches and logs, and mosses. Variation in the type of fuel defines the heterogeneity of fuel load, heat combustion and fire intensity across a catchment. • Heat generation will also be a function of wind, how dry the fuel is, and atmospheric humidity. There is a wide range of energy release under different conditions leading to the concepts of cool and very hot fires (1,000–20,000 kW m-1). • Cool fires burn low vegetation but high intensity hot fires can burn whole trees to the height of the forest canopy. • Dry fuel burns more readily so fires will be more prevalent during dry seasons and drought. **Watch a video of fire**. Note its characteristics and classify whether cool or hot.
Hydrological impacts of fires linked to vegetation changes	• Removal of understorey and leaf scorching in low to medium intensity fires leads to reduction in transpiration and interception due to loss of leaf area, increase in surface runoff and sediment/nutrient transport, reduced water quality in streams and an increase in infiltration to soil moisture.

	• Loss of canopy cover as well as understorey in hot to very hot fires leads to major reductions in interception and evapotranspiration, combined with increased runoff and groundwater recharge. Loss of natural vegetation filters such as wetlands, bogs, fens and meadows can increase the mobilization of a wide range of naturally occurring or anthropogenically-derived elements and compounds including nutrients and heavy metals. • **Refer to: Abraham et al., 2017** • Streamflow responses to rainfall after fires are quicker, 'flashy' and water quality is poor. High runoff responses are controlled not only be vegetation changes but also soil changes resulting in hydrophobicity. Increased flood risks and channel migration can be associated with large-scale, high intensity fires. • Impacts on catchment hydrology will depend on severity of fire, proportion of catchment burnt, whether dominant plant species are fire-sensitive or fire-resistant, and the density of post-fire regrowth (which are a function of fire intensity, vegetation species composition and climate). • Note the Kuczera curve can also be applied to hydrological responses to fire. • There will ultimately be impacts on aquatic ecosystems due to changes in flow and water quality – what might these impacts be? **Refer to**: Owens et al. (2013) and Lane et al. (2006).
	Watch video on wildfire: There is an abundance of videos available online that show wildfires. Select one and use as the basis for discussion on vegetation changes and associated hydrological responses.

Lecture 5: Water quality

Topic	Content
Bio-geochemical cycles	It is important for all students to understand: (i) the concepts and processes of biogeochemical cycles; (ii) the relevance of key cycles to water quality, ecosystem composition and function; and (iii) how human activities have changed these cycles, and what the consequences of such changes are for aquatic ecosystems. The concept of biogeochemical cycling and the hydrology-ecology nexus should be examined with reference to different freshwater environments. This should provide the foundations for student-led research and practical exercises (see activities). Each of the key biogeochemical cycles (carbon, nitrogen, phosphorus and sulphur cycles) that are critically important for ecosystems locally and globally should be briefly explained using flow diagrams.

	Pose this question for reflection: How have humans altered these cycles and what are the consequences of such changes? This can be linked to Student Activity 4: The carbon cycle.
Vegetation and water quality	• Overland and in-stream sediment transport: The interception of precipitation and surface runoff by vegetation can reduce sediment transport and turbidity of streamflow. • Turbid water reduces light penetration in the water column and can smother or bury aquatic biota and plants, with associated impacts on water, dissolved oxygen and temperature with many outcomes for river health. • In-stream transport by clay adsorption of nutrients and metals: Clay particles transported in suspension in a stream can adsorb nutrients and heavy metals via cation exchange (explain these processes). • The transport of nutrients can lead to eutrophication of the water body and proliferation of algal blooms which can have catastrophic impacts downstream. **View this video** on the production of harmful algal blooms through eutrophication. https://www.youtube.com/watch?v=bBcaFoR1ZUs • Adsorption of metals can also have downstream consequences due to the exposure by aquatic biota and humans to toxic concentrations of these elements (e.g. copper, cadmium, mercury, aluminium, lead and zinc). • Metal transport in streams can occur via adsorption to clays and as solutes in dissolved form. Metal contamination of surface waters can be associated with mining, industry, and irrigated agriculture, but also from natural sources such as acid sulphate soils, volcanic landscapes, and undisturbed ore bodies rich in these elements. Understanding the sources of contaminants (point or diffuse), modes of transport (natural or anthropogenic), and toxicity are important first steps in developing appropriate management strategies.
Plant uptake of water and elements in solution	Plants take up not only water, but also elements and compounds in solution. Provide a quick review of the pathways and processes from Lectures 1–2 in this module. Note the evidence that elements can accumulate within plants. **Refer to**: • Biogeochemical exploration techniques using the analysis of plant material enriched with elements of high economic value to estimate the location and extent of ore deposits (Bluemel et al. 2013; Collerson et al. 2015; Wolff et al. 2018).

	• Research on bioaccumulation of elements in aquatic or riparian plants of contaminated rivers or wetlands. Phytoremediation uses plants strategically to manage contaminated waters (Rai, 2008; Bonanno, 2012). Ask students how this capacity of phyto-accumulation can provide environmental benefits in freshwater environments (both rural and urban). **View this video** to see integration of engineering and phytoremediation in Pakistan to treat highly contaminated water. 'Treating water with the help of nature'. https://www.youtube.com/watch?v=R_--kALBjJE

Quick quiz

Question	Answer
Name three pathways for water partitioning in which plants play a critical role.	• Evapotranspiration • Interception • Infiltration
Write the water balances for (i) an inland river and (ii) an estuary.	(i) $P = ET + SR + R \pm \Delta S$ (ii) $P + Q_R + Q_{T(IN)} + SR + Dis = ET + Q_{T(OUT)} + R \pm \Delta S$
What is meant by 'the hydraulic architecture' of a plant?	This term refers to the fluid transport dynamics in a plant and includes the uptake of water by roots, its transport through the plant via the xylem, and its transpiration via stomata.
How can deep rooting plants improve land condition?	In areas suffering from salinization, deep rooting vegetation such as trees can lower the water table, preventing salts contained within the regolith (soil) from reaching the surface via capillary action.
Which landuse type uses more water, and what does this mean from a hydrological perspective when grassland is replaced by plantation forest?	Trees use the most water, particularly during juvenile growth. Afforestation of previous grassland will reduce streamflow in a catchment, the magnitude of the effect being controlled by proportion of catchment affected, tree species, density and growth stage.

How does river regulation affect water-dependent ecosystems on adjacent floodplains?	Changes in flow regimes due to river regulation can reduce the frequency of flooding with consequences for water-dependent forests and biota such as birds whose reproductive cycles are reliant on flood events as triggers.
What changes occur to previously rural areas during urban expansion in developing countries?	• Loss of vegetation. • Increase in areas of impervious surfaces resulting in higher runoff, rapid stream responses and higher peak flows. • Reduced water quality due to waste disposal, and unimproved sanitation.
What are the hydrological responses when fire destroys a large proportion of a forested catchment?	• Decreased interception by vegetation. • Where hydrophobicity of soils has been generated, infiltration of rainfall will decrease in the short term. • Increased runoff. • Increased streamflow. • Quicker response times to rainfall. • Higher peak flows.
How does increased turbidity of water impact water quality?	• Decreases light penetration. • Smothers in-stream biota including impacts on fish gill function. • Degrades spawning beds. • Causes deposition downstream. • Reduces food supplies for in-stream biota.
How can plants improve water quality?	• Trapping of sediment. • Uptake of contaminants in solution (e.g. heavy metals, organic compounds).

Student-focused learning activities

Activity 1: Exploring the water-plant nexus workshop

Learning objective: To consolidate knowledge of the hydrological cycle and to construct a conceptual model based on a sound understanding of the water-plant nexus.

To do:

Have students work in pairs to draw the hydrological cycle on large sheets of paper with each component linked to an aspect of water-plant interactions. This should include the following:

- Incoming precipitation *intercepted* by vegetation.

- *Throughfall* of raindrops from top of canopy to ground surface and associated changes in raindrop size/velocity, and concentrated pathways along branches/stems.
- *Evapotranspiration* (evaporation [E] from wet surfaces and transpiration [T] through stomata; and the cooling affects associated with evapotranspiration [ET]).
- *Infiltration* and its variation according to precipitation factors and vegetation density and type.
- *Runoff* and the role that vegetation plays in controlling runoff velocity, sediment trapping, and by extension at a larger scale flood and erosion control.
- *Deep percolation and groundwater recharge* and the role of trees and deep rooting species in providing preferential pathways for recharge and also for plant uptake of water.
- **Streamflow** and the role of riparian vegetation in stabilizing banks; and flood mitigation; in-stream vegetation and impacts on flow dynamics.

Extend students by asking them to also include the relevant properties of water that can be a factor in each pathway.

Ask students to convert this diagram into a conceptual model that demonstrates how climate change resilience can be addressed by managing the vegetation-water relationship within a specific setting. The following settings can be allocated to each group:

- Expanding plantation forestry in a catchment to support industry needs.
- Improving social amenity and thermal qualities of a city's central business district.
- Improving water quality of an urban engineered storm channel that was previously a natural stream.
- Reducing salt loads in a river where saline groundwater discharge occurs in a surface-groundwater connected system.
- Protecting a stream from high turbidity originating from agricultural runoff.
- Planning for optimal ecosystem services of a new urban development.

Activity 2: Ecohydrology and concepts of sustainable urban design

In 2019, the President of Indonesia, Joko Widodo, announced that the nation's capital would be moved from Jakarta to eastern Kalimantan.

Learning objective: To investigate existing pressures on Indonesia's capital, and to produce a set of logistically feasible ecohydrological strategies for new urban design.

To do:

Step 1 (30–45 minutes): In small groups, students should undertake background research on this decision. What are the key drivers underpinning this proposed move? What is the timeframe over which the new city development is expected? What is the water resource base for eastern Kalimantan? What are some of the pressures and vulnerabilities that apply to ensuring a secure water supply at this new location?

Step 2 (30–45 minutes): Groups should develop a basic design plan for the new city from a water security perspective. What are the priorities for securing supply that will be resilient to both climate change and population growth? Identify any constraints.

Step 3 (30 minutes): All class discussion to summarize the design elements that integrate ecohydrological and sustainability principles. What is the consensus about the challenges and opportunities offered by this plan to relocate the capital city?

Activity 3: Peri-urbanization field trip

Learning objective: Depending on local conditions, students will identify the sources and quality of drinking water in a peri-urban setting; the competing needs for water and how (or if) these are addressed; and the challenges for building resilience under conditions of rapid and fragmented expansion.

Logistics: Pre-arrangements should be made for water managers, community members and any non-government organizations responsible for water-related support activities to speak with students at a number of stops.

To do:

Travel from urban through peri-urban to rural zones for students to observe changes in building density and structure, roading, services and type, density and use of vegetation. Stop at a number of peri-urban locations to describe the availability, access to, uses, and quality of water.

Students should take notes that can be reflective on their observations, or constructed around handouts for use as short assessments. At each site, it is recommended that a different stakeholder be available to speak to the group. Gendered issues can be referenced in developing country settings. Students should note water vulnerabilities for inhabitants, sustainability of current water resources, and any adaptation/resilience measures that could be developed to address those vulnerabilities.

Activity 4: Carbon cycle and water

The carbon cycle and the changes wrought on it by anthropogenic activities are the focus of current climate change concerns. Prior to the Anthropocene, the global carbon cycle was in equilibrium with the uptake of carbon dioxide being balanced by its release into the atmosphere.

However, over the last 160 years, the mechanisms for carbon dioxide uptake are insufficient to offset emissions. This imbalance can be attributed to the parallel anthropogenic activities of burning of fossil fuels and incremental loss of forest. The process of carbon sequestration is an important corollary to this issue. It refers to the process by which atmospheric carbon dioxide is captured and stored in a stable form, and this can occur in plants through photosynthesis, and in soils through carbon fixation. It can also occur through a raft of biologically-mediated processes in aquatic ecosystems.

Learning objective: To critically review a journal paper in a collaborative process in order to communicate a complex scientific issue to a broad audience, and to use this communication to infer salient points of argument.

To do:

Students should have read the following paper, prior to this activity:

Govind, A. and Kumari, J. 2014. Understanding the terrestrial carbon cycle: an ecological perspective. *International Journal of Ecology*. 2014. 18 pp. https://doi.org/10.1155/2014/712537

Divide the class into eight groups. Each group is to read and summarize one section only of the paper (**45 minutes**), as follows:

- Introduction
- Complexity of the terrestrial carbon cycle
- Monitoring carbon cycling in terrestrial systems
- Need for modelling carbon cycling in terrestrial systems
- Hydrological controls on terrestrial carbon and nitrogen dynamics
- Hydrological controls on photosynthesis and respiration
- Towards a better understanding of carbon cycling in terrestrial systems
- Addressing the feedback effects in the soil-plant-atmosphere continuum

Each group should report back to the class (**five minutes per group**), summarizing the key points of their section. These can be written up on the board, or paper pinned up on a wall or screen.

All-class discussion (**30 minutes**): From the information that is now available to the whole class, what are the salient points regarding the carbon cycle from an *ecohydrological* viewpoint? How can this knowledge be used to build climate change resilience and at what scale(s)?

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Module 5: Integrated water resources management

Summary

Catchments and the river systems that drain them are complex and highly variable. A river's flow regime is a function of climate, the underlying geology and consequent topography, the vegetation and landuse that occurs within its boundaries, and the interconnections that play out between the physical and human environments.

Across human history, there has been a balance between humans and catchments until the Anthropocene and particularly the Great Acceleration. As catchments were increasingly developed, management of resources became a growing imperative but such attempts tended to be narrowly focused, incremental and reactive. The idea of an integrated approach to catchment management began in the 1930s but it was not until the emergence of a general dissatisfaction of the existing simplistic, disjointed and 'siloed' practices, that such an approach started to develop in the 1990s (Ewing et al. 1997).

Recognizing its value for sustainable water management into the future, nations agreed to adopt integrated water resources management (IWRM) in Agenda 21 at the 1992 Earth Summit. This new approach involved managing land and water that accounted for ecological, social and economic values in decision-making. IWRM is included in Sustainable Development Goal 6, with Indicator 6.5.1 monitoring implementation at the country scale.

IWRM is now practised around the world today. However, the skills required to undertake IWRM in collaboration with policymakers are not clearly articulated by either educators or managers. In this module, IWRM is defined and the key features of IWRM are explored.

Critically, this module can assist students to develop skills relevant to IWRM. However, it should be noted that this model for water management requires the collaborative efforts of water managers, hydrologists, ecologists, engineers, geomorphologists, policymakers, agricultural scientists, farmers and community members. It also needs the commitment and will of politicians. Thus, no single professional will have all the skills required to implement or manage a catchment using IWRM. Nevertheless, understanding what and who is required, how to participate in inter- and multidisciplinary teams, and how to engage with and listen to stakeholders are all essential skills for students who are planning future professions in IWRM.

A wealth of information on IWRM has already been developed by UNESCO including IHP's report on IWRM implementation (2008) and the IWRM guidelines at river basin level (2008). These resources have been used in developing this module. The module also uses case studies in lectures, workshops and field trips, drawn from the Global Partnership in Water IWRM Toolbox and UNESCO's IWRM guidelines at river basin level.

Aims and objectives

The aim of this module is to identify the salient features and requirements of IWRM, and to develop practical skills applicable to IWRM planning and implementation.

Learning outcomes

On satisfying the requirements of this module, students will have the knowledge and skills to:

Undergraduate learning outcomes 1–3

1. Understand the complex interplay between people, climate, land, water and economic development in water resource management.
2. Explain how the changing balance in water availability, demand and values of water informs institutional arrangements, policy and management.
3. Demonstrate familiarity with a range of water resource management strategies in both rural and urban settings.
4. Integrate information from a range of disciplines into a comprehensive picture of IWRM applications.

Postgraduate learning outcomes 1–5

5. Appreciate the relationship between raw data and the interpretation(s) that stem from it, and how a lack of knowledge or uncertain knowledge influences resource management decision-making.
6. Consider and use a range of methods for tackling water resource management problems.

Proposed assessment

Assessment task (undergraduate)	Value	Linked learning outcomes
Report (**2,000 words**) Define the concept of 'readiness' to successfully implement IWRM at a national scale. What indicators could be applied to establish a country's state of 'readiness'? Use this information as the basis for assessing a country of your choice in the region, comparing your assessment with the achievements of that country against SDG 6, Indicator 6.5.1.	To be assigned by lecturer	1–3

Assessment task (postgraduate)	Value	Linked learning outcomes
Report (**4,000 words**) IWRM and climate change resilience. In your country, identify (i) the key water management issues (current and future); (ii) the challenges to successful implementation of IWRM; and (iii) strategies to optimize the success of IWRM to build climate change resilience.	To be assigned by lecturer	1–5

Module indicative content

Lecture 1: IWRM basics

Topic	Content
What is IWRM?	IWRM is commonly defined as: "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." Global Water Partnership, 2000 Although this definition captures the intent of IWRM, it should be critically interpreted. Read and draw attention to some of the reservations expressed by Biswas (2008; 2019). This introduction can form the basis for later in-class discussion. In the past, a top-down and supply-driven approach to water governance has led to unsustainable practices with high economic, social and environmental costs. Conceptually, IWRM comprises adaptive, sustainable approaches to water governance that are based around collaborative planning and decision-making across multiple sectors and scales. At its core, IWRM upholds the four 'Dublin Principles' presented at the International Conference on Water and the Environment (ICWE, 1992) that emphasize the key role that water plays in sustaining life; the need to manage water through participatory processes; water as an economic good; and the important role that women play in managing this resource. In keeping with these principles, IWRM has three key objectives: (i) equitable allocation of water; (ii) water efficiencies; and (iii) environmental sustainability including protection of the surface and groundwater resource base. It is a planning and implementation tool that provides for intergenerational water equity and access, and environmental sustainability. In any given IWRM project, the three objectives can be framed as questions: • Will access to water, or benefits from its use, be negatively impacted for other users? • Will the most efficient use of water be achieved? • What are the impacts on the environment of this action/plan? It is important to note that IWRM can be practised at a range of scales, from small-scale community activities within a sub-catchment; and at catchment and basin scales.

	Note that IWRM is an iterative, evolutionary and adaptive process, that has been described as a 'spiral' (UNESCO, 2008a, page 9);). Use that diagram to define this process. It is adaptive in that aligned management strategies, planning and policy development can be developed/modified over time in response to changes occurring within a catchment, for example, due to climate change. IWRM approaches have been articulated by the International Water Association and United Nations Environment Programme (UNEP, 2002) as follows: • Fully integrate water and environmental management. • Adopt a systems approach to problem structuring and intervention planning. • Involve participatory processes for all stakeholders. • Are sensitive to social dimensions of local water issues. • Involve capacity building. • Incorporate full-cost pricing, complemented by target subsidies. • Supported by central government. • Make use of best existing technologies and practices. • Have access to sustained financing. • Emphasize equitable water resource allocation. • Recognize the economic good of water. • Build and strengthen the role of women in managing water.
IWRM as a framework for integration	Operationally, IWRM translates to multi- and interdisciplinary teams with a diverse set of stakeholders working collaboratively to design and implement equitable, efficient, and sustainable solutions to water and development issues at a basin or catchment scale. It tends to be project/problem-focused/needs-driven, involves on-ground actions; and also informs and responds to policy development. Using this approach: • Responsibilities, accountabilities and capacities are identified and matched. • Strategies and action plans are developed and implemented in community/government partnerships. • Allocation of resources is determined on a basin/catchment basis. • Monitoring, evaluation and reporting all support decision-making at a whole-of-basin/catchment scale. What are some tools that facilitate the building of knowledge? • Information technology (spatial databases). • Modelling (including numerical, conceptual, Decision Support Systems (DSS), agent-based). • Integrated *assessment* (social, economic, biophysical).

	What is required to make IWRM work? • A systems perspective. • National (or broader) investment framework based on resource economics. • A cyclical planning approach, using rolling renewal of programmes, allowing dynamic responses to change. • Contracts to establish appropriate cost-sharing, co-financing and co-management arrangements. • A legislative framework to: (i) strengthen and formalize the process for coordination and management of resource management investments; and (ii) provide a mechanism of last resort for minimizing risks affecting expected outcomes.
Challenges	Key challenges to IWRM will vary according to location but could include any of the following: • A lack of political will and commitment. • Legislative and regulatory frameworks that are poorly defined (i.e. constrained by either broad ambiguity or a very narrow prescriptive focus) and are not enforceable. • Limited resourcing including economic support. • Poorly developed basin or catchment plans. • Vested interest of a specific and dominant stakeholder. • Lack of engagement and buy-in by stakeholders, and/or a resistance to data and knowledge sharing. • Limited knowledge of the basin/catchment. • Limited or non-existent monitoring. Can these challenges be linked to a country's 'readiness' for IWRM – and how could such readiness be articulated? This open-ended question should be discussed in-class without providing too much detail so that students can 'unpack' the concept.
IWRM, governance, policies and SDG Indicator 6.5.1	Appropriate water governance and IWRM policies have the capacity to address many inter-related and complex issues in IWRM. The Global Water Partnership has developed a working paper aimed at water educators and professionals that calls for significant changes in science-policy interactions and governance (Rogers and Hall, 2003). This paper can be used as an introductory guide to IWRM governance. Explore the recent shift from IWRM to a 'nexus approach' in freshwater resource management (Benson et al. 2015). For a clear definition of the 'nexus approach' refer to that provided by the Global Water Partnership: https://www.gwp.org/en/GWP-Mediterranean/WE-ACT/Programmes-per-theme/Water-Food-Energy-Nexus/the-nexus-approach-an-introduction/

Examples:

- Sponge cities in China aim to combat climate change impacts while building resilient cities through IWRM (Chan et al. 2018).
- Room for Rivers project in the Netherlands employs IWRM and adaptation to flood risk strategy through multilevel water governance, demonstrating a shift from regulation to resilience (Riike et al. 2012).

Progress towards SDG 6 and the implementation of IWRM (Indicator 6.5.1) can be accessed via https://www.unwater.org/publications/progress-on-integrated-water-resources-management-651/.

- Current data (2017) shows a high degree of variability in IWRM implementation for Asia and the Pacific, including some countries for which no data exists. These data can be viewed at the interactive website http://iwrmdataportal.unepdhi.org/.
- The country database in this website provides country indicator performances with an SDG score against (i) enabling environment; (ii) institution and participation; (iii) management instruments; and (iv) financing. This could be used for an online class quiz using Socrative.

Case studies: A review of IWRM policies in a particular country or region will allow for analysis of national IWRM policies and outcomes.

- For example, a case study on IWRM policies in countries with extreme spatial and temporal variation (such as India or China) will enable students to apply SDG 6 indicators to the IWRM policies.
- A recent study on India's national water policy by Biswas et al. (2018) addresses India's IWRM policy development, implementation and river basin management regimes, while showcasing the IWRM framework and the future of IWRM in India. https://doi.org/10.1080/07900627.2019.1576509

Can the achievements of different countries across the region be linked back to the concept of 'readiness'? Present this question as open-ended only as the concept of 'readiness' will be explored in the undergraduate assessment task.

Lecture 2: IWRM unlimited

Topic	Content
IWRM in practice – a case study approach	IWRM can address a range of disparate issues and challenges including, but not limited to: • Competing water needs for supply (e.g. irrigation versus domestic use versus environmental needs). • Catastrophic natural hazards such as floods, tropical cyclones, earthquakes and tsunamis. All events impact access to safe drinking water, sanitation, food security, incidence of waterborne disease and infrastructure damage. • Slow disasters such as drought, water contamination and pollution (e.g. heavy metal and industrial pollution). • Water scarcity in arid and semi-arid environments (including alpine areas). • Reduced water access due to development, population pressures and climate change. • Equity and social justice in water management. • Rehabilitation of people displaced by dam construction. Select two contrasting IWRM case studies, and for each ask the students: what is the biophysical and socioeconomic setting? Who are the key stakeholders? What is the water issue? What planning and actions were undertaken? What were the outcomes? What are some unique characteristics of each case study? Multiple case study examples can be found at the Global Water Partnership IWRM Toolbox website for Asia. https://www.gwp.org/en/learn/KNOWLEDGE_RESOURCES/Case_Studies/Asia/ Note that case studies of the Pacific region are limited to Australia. Use case studies that are both small scale and basin scale in preparation for the following lectures and activities.

Lecture 3: IWRM Ridge to Reef (R2R)

Topic	Content
Expanding the concept of IWRM to 'Ridge to Reef'	The connectivity between terrestrial and coastal/marine systems is being increasingly acknowledged in the development and/or expansion of agriculture, aquaculture, industry and cities in catchments whose rivers flow out to sea.

In island environments and small island developing nations, many, if not all, rivers and streams will flow into the ocean. Land-based activities become not only the responsibility of land and water managers but also coastal managers. Integrated coastal management has been recognized since the Earth Summit in 1992 and noted in Agenda 21, although the focus was on the coastal zone.

View this video: The importance of IWRM https://www.youtube.com/watch?v=VnP-NPR3OiE

Use the Great Barrier Reef in Australia as an example of connectivity between terrestrial processes and coastal responses. Summarize the threats (climate change, sediment and contaminants including nutrients from runoff generated from coastal catchments in Queensland) and their impacts on the reef (sediments smother corals and seagrass meadows; reduces light penetration; nutrients generate algal blooms which promote population increases in the pest species Crown of Thorns starfish).

Ridge to Reef programmes are rolling out across the Pacific including Cook Islands, Fiji, Micronesia, Kiribati, Marshall Islands, Nauru, Niue, Papua New Guinea, Palau, Solomon Islands, Tonga, Tuvalu, Vanuatu, and Samoa with the support of the Global Environment Facility, United Nations Development Programme, FAO, UNEP and the Pacific Community (SPC). The programme concepts will have increasing relevance to other island nations and communities across the region to manage water resources for climate change adaptation and resilience.

Refer to: Pacific R2R website: https://www.pacific-r2r.org/

Note that IWRM and Ridge to Reef are evolutionary processes of water resources management. They can best be illustrated using the Nadi River catchment (IWRM) and Ba River catchment (R2R) in Fiji. Both catchments are located in the drier, rain shadow-affected Western Division, on the island of Viti Levu.

- Nadi River is renowned for flooding with impacts on the township of Nadi, and has been the subject of extensive IWRM-based studies supported by monitoring, assessment and flood control works. The focus is protecting the town from floods.
- The Ba River catchment has a lower population than Nadi but high food production values and a sugar refinery in its lower tidal reaches. It is now the subject of a R2R study due to impacts of land-based activities on coastal systems, the catchment's high vulnerability to drought and flooding, damage from tropical cyclones, and impacts of sea level rise on mangrove forests and coastal fringes.

	Refer to the following project documentation for Fiji R2R project: *Implementing a Ridge to Reef approach to Preserve Ecosystem Services, Sequester Carbon, Improve Climate Resilience and Sustain Livelihoods in Fiji.* https://open.undp.org/projects/00083111.

Lecture 4: The 'how to' of IWRM using the IWRM guidelines Part 1

Topic	Content
	In this lecture students are provided with an outline of how IWRM can be planned and implemented. The lecture relies on information from UNESCO's publications on IWRM guidelines at river basin level (2008) and the Global Water Partnership's IWRM Toolkit. The lecture should be supported by a number of student-focused learning workshops.
Revisiting the 'spiral' conceptual model	Sustainable water resources management integrates social, economic and environmental needs for water within a catchment. This requires time, iterations of process, and adaptation to change. The conceptual model of a spiral for IWRM captures these processes, with each 'turn' of the spiral representing one iteration of, for example, developing sustainable water management practices or building a more integrated and aligned institutional framework for governance. **Show** the spiral model and draw onto it an example of an iterative process from a basin where IWRM is being practised in the region (e.g. Murray-Darling Basin). Question how is this spiral model different to water resources basin planning over extended time, where IWRM is NOT being practiced. **Compare and contrast** two basins where this might apply (e.g. Murray-Darling Basin and transboundary Nile River Basin)
Implementation is a four-phase process	Implementation of IWRM is a four-phase process including: i. Recognizing and identifying key issues and needs of the catchment. ii. Conceptualizing what needs to be assessed and planned out. iii. Coordinating and planning in detail in collaboration with identified stakeholders. iv. Implementation, monitoring and evaluation. **Refer to**: IWRM Guidelines at River Basin Level Part 2-1 (UNESCO, 2008b, pp. 17–49) to get subheadings for each phase and use examples as provided in this text or from knowledge/experience. This should be undertaken as a Q&A session in-class, where subheadings are provided, and students are asked to in-fill detail.

	For example, to identify issues and needs, ask the class, 'Is IWRM needed (or does it need to be adapted to recent change)? What are the issues? What do stakeholders need? What knowledge needs to be gathered? From whom?' Suitable case study basins can be selected from the guidelines or from the Global Water Partnership's IWRM Toolkit. Note that understanding these steps will form the basis for student-focused class activities linked to this lecture. Collectively this will build students' readiness for working in an IWRM setting. **If necessary, going through the four phases may need to be extended into a second lecture period, following the same Q&A process**. Teasing out the details step by step should not be rushed.

Lecture 5: The 'how to' of IWRM using the IWRM guidelines Part 2

Topic	Content
Institutional frameworks	A sound understanding of governance structures is a critical component of IWRM planning and implementation. Policies and legislation across different tiers of government will underpin IWRM. These instruments can define rules for water sharing, responsibilities and accountability at local, provincial, national and international scales. Alignment of and coordination between different government departments in-country, and between governments for transboundary basins, is critical for data sharing and effective knowledge networks. Government plays a key role in funding and support of IWRM projects In turn, IWRM should acknowledge national planning and priorities and provide a platform for building institutional capacity. Refer to the case study Brantas River Basin (UNESCO, 2008b, pp. 61–72 with specific reference to Fig 5.1.2 p. 65).
Performance indicators and benchmarking	Regular assessment and evaluation of the status of planning and management in IWRM is an inherent component of the process. This can be an internal process, or comprise reporting to external interests such as government, non-government organizations and the public through an annual or biennial report, for example.

The report should include information about the structure, stakeholders, knowledge networks, and process as well as progress against a number of indicators. Indicators can measure the condition of the catchment, monitoring regime and developments, progress of IWRM implementation and planning, outcomes of capacity building and any challenges that have arisen, as well as any significant shifts or changes that require adaptation of the original planning. If peer review is included in performance evaluation, what form should it take, and what components of the IWRM should be the focus? How broad or narrow should the review be?

Use a case study to explore the types of performance indicators that can be applied, e.g. biophysical, social, cultural, economic and environmental indicators.

- Case studies can be found in the UNESCO IWRM guidelines and the Global Water Partnership IWRM Toolbox site for Asia. https://www.gwp.org/en/learn/KNOWLEDGE_RESOURCES/Case_Studies/Asia/
- Benchmarking and performance measures can rely on GIS, modelling and visualization tools using quantitative or semi-qualitative values.
- Draw attention to the uniqueness of each IWRM project, important issues, interests/needs of the stakeholders, funding availability and policy/legislative requirements. This uniqueness will also be reflected in the types and number of indicators.
- The cascading effects of climate change compel water management to be addressed at international, national and regional levels. An example of transboundary water governance that addresses climate change through IWRM is the Mekong River Basin. Developed by the Mekong River Commission, the Mekong Climate Change Adaptation Strategy and Action Plan outlines seven strategic priorities and actions to address climate change and improve basin resilience across Viet Nam, Lao People's Democratic Republic, Cambodia and Thailand (Mekong River Commission, 2018). This can be used as a case study example to apply the "how' of IWRM Lectures 4 and 5 in transboundary contexts and assess sustainability of the IWRM plan.

http://www.mrcmekong.org/assets/Publications/MASAP-book-28-Aug18.pdf

Quick quiz

Question	Answer
What is IWRM?	IWRM is a framework to manage water resources sustainably by which managers and decision-makers can develop strategies and employ a range of instruments, using an integrated and collaborative approach.
What are the three pillars of IWRM?	Ecological sustainability, economic efficiency and social equity.
What aspects of IWRM are conceptualized in the 'spiral' model?	In contrast to past linear models of water resources management, IWRM involves iterative, evolving and adaptive processes by which decision-making and planning can take place.
Name the salient requirements for IWRM to be successful.	• Political will • Well-defined legislative and regulatory frameworks • Adequate resourcing • Comprehensive knowledge of the catchment • Sound design and development of catchment plans at appropriate spatial scales • Stakeholder engagement and participation • Ongoing monitoring and assessment
What is the difference between IWRM and R2R	R2R has extended the application of IWRM to include management and monitoring of coastal zone land and water.
List a range of tools that can be employed in IWRM.	• Modelling • Decision support systems • GIS mapping • Participatory processes in planning, management and decision making • Quantitative and qualitative assessments (biophysical, social/cultural and economic)

Implementation of IWRM involves four phases. List these in correct sequence.	1. Identify key issues and needs that must be addressed. 2. Conceptualize planning and assessment process. 3. Coordinate and plan the project in collaboration with stakeholders. 4. Implementation, monitoring and evaluation.
How can performance and progress be evaluated and measured?	Through regular and transparent monitoring, assessment and reporting.

Student-focused learning activities

Workshop 1: A critical interrogation of IWRM: what can make it succeed?

Learning objective: To critique IWRM as a concept and to investigate key elements for success in its implementation. This is linked to Lecture 1 (Module 5). Key competencies in English is required.

Materials to be available *prior to workshop*:

Biswas, A. K. 2004. Integrated water resources management: a reassessment. *Water International* 29(2): 248-256.

Muller, M. 2009. IWRM – is it working? 12th *International Rivers Symposium*, Brisbane, September 2009.

Cashman, A. 2017. Why isn't IWRM working in the Caribbean? *Water Policy*. 19(4): 587-600.

To do:

Break class into groups of 6 people (depending on class size). Students should already have read the three readings for this workshop. Within each group, students should undertake the following:

Discussion time: 30 minutes

1. Identify the inherent questions (these may be explicitly or implicitly expressed by the authors) and the salient points of argument presented in each publication.
2. Discuss these arguments as a group, and develop a set of points that capture the potential challenges and weaknesses of IWRM.
3. Discuss within groups what can be done to address or mitigate these challenges and weaknesses.
4. Each group to report back to class (**5 minutes per group**). Can any overarching principles for success be identified? If so, list these on the whiteboard/blackboard/screen.

Discussion time 10-15 minutes plus 5 minutes per group for reporting back

5. Now discuss the concept of 'readiness'. Consider this to be a step beyond adaptive capacity but rather the degree of preparedness for adaptation and implementation of IWRM. How can this be linked to the success of IWRM at local, basin or national scales?

Note for convenor/tutor: Readiness could include the need for political leadership, institutional organization, adaptive decision-making, stakeholder engagement and public support, availability of useable science, funding structures and support.

Workshop 2: Water sharing in the Murray-Darling Basin

This workshop is intended to help students explore decision-making about shared water use and allocations to different sectors (agriculture, industry, environment, domestic and town water supply), where there are legitimate but competing water uses.

Learning objective: To gain an understanding of how interacting systems of knowledge, values and rules are used in decision-making, where trade-offs have to be made between competing interests.

The management of the Murray-Darling Basin in Australia is generally considered to be a success story in IWRM (although this has been recently challenged, and planning is currently undergoing adaptive change).

Note: This workshop can be used as a template for another basin in other countries of the Asia-Pacific region, for which catchment information is readily available online.

Prior preparation: This activity requires students to have internet access during the workshop. An alternative is for students to be allocated to groups and catchments prior to class, so that they can bring the results of their research as the basis for discussion.

Because the online information is in English, key competencies in this language are required. An alternative approach is to select a different river basin with online or readily available information in the appropriate language used by students in the class, and to modify the workshop accordingly.

The lecturer/tutor needs to be familiar with the catchments of the Murray-Darling Basin, and to have a realistic volume of water to allocate to each catchment (use the annual mean stream flows provided to help with this estimation). Refer to the Murray-Darling Basin Authority website for all relevant information (https://www.mdba.gov.au/discover-basin/catchments).

Use the following river catchments and mean annual streamflows:

Condamine-Balonne	1,305 GL
Border Rivers	130 GL
Gwydir	336 GL
Namoi	696 GL

Macquarie-Castelreagh	1,175 GL
Lachlan	834 GL
Murrumbidgee	4,000 GL
Ovens	1,775 GL
Goulburn-Broken	3,000 GL
Lodden-Avoca	285 GL
Wimmera	206 GL

To do:

Divide the class into groups of 6–8 (depending on class size). Each group will be allocated a catchment within the basin and a volume of water that must be shared between different users.

Within each group, members will nominate themselves as decision-makers representing different agencies and water user groups (e.g. irrigators, Murray-Darling Basin Authority who have developed the basin plan of management, or the state water agency). The task is to have a discussion and make decisions about how to allocate that water, and to define values, rules and knowledge that inform decision-making.

Research and discussion: 30 minutes

Students should collect as much information as possible about the catchment, including details of major wetlands and rivers, irrigated agriculture (type of crops and their water use), tourism and other industries, communities and major towns, as well as any information on how water is currently used and allocated within that catchment. The Murray-Darling Basin Authority website can provide much of this information, at basin and catchment scales (www.mdba.gov.au).

Report back to the class for 5 minutes about the findings from this research. Key findings can also be written up on large paper/screens.

Research and discussion: 30 minutes

In this decision-making part of the workshop, it is important for each group member representing a specific sector, agency or interest group to negotiate their own rules for how water is allocated. There are no pre-set rules, **except** the volume of water allocated to the catchment is going to be **20 per cent less than required to meet environmental needs and irrigation**. The group's task is to manage the trade-offs between different water users.

Report back on findings and note any challenges faced in the negotiation process (**5 minutes** per group).

Reflection (15 minutes): No reporting required, only thinking about knowledge and how it informs decision-making.

Students should reflect on what knowledge is important in their decision-making – scientific knowledge, traditional Indigenous knowledge, experiential knowledge? What values are considered – care for community and environment versus economic development, for example? What rules will apply – do they include or exclude certain interests and values? How might this affect IWRM implementation processes?

Workshop 3: Unpacking IWRM in an interrupted case study scenario

Learning objective: To examine a case study and identify the key pieces of knowledge required as a starting point for IWRM implementation.

Select a number of case studies from either UNESCO's *IWRM Guidelines at River Basin Level – Part 2-1, Guidelines for IWRM Coordination* and/or the Global Water Partnership IWRM Toolbox website for Asia.

Note: *Only* key background and contextual information should be made available to the students in the first part of this exercise.

To do:

Group work: 30 minutes

Assign a case study to small groups of 4-6 students (depending on class size, the size and number of groups can vary). Each group should read the case study and record the following attributes:

1. What is the water issue(s) in this case study?
2. What do stakeholders need?
3. What sectors are represented and what are their interests in water?
4. How might different sectors or stakeholder interests interact/compete with each other?
5. What is already known and what data is being collected?
6. What knowledge is required?
7. Are there any stakeholder groups that are vulnerable, and if so, who are they and what is the basis of their vulnerability?
8. What is known about the existing governance structure?

Group work: 15 minutes

After answering these questions, students in each group will produce a conceptual framework for an IWRM project for this case study. This can be done on large paper and displayed.

Reporting back to class: 5 minutes per group

Each group to report back to the class, justifying their framework (i.e. who, what, why, and how of the project).

Group work: 30 minutes

After they have completed this exercise, provide each group with case study information that outlines the issues, implementation, stakeholders, process and outcome of the IWRM project. Does this differ from their own conceptual framework for implementation and if so, how? Using all of the information now available to them, how would each group modify or adapt their conceptual framework, or alternatively, how would they modify the actual case study itself if they were the co-ordinator? Use large paper to record these ideas and place next to or underneath the group's conceptual framework sheet.

Learning points: 5 minutes

Record the key takeaway learning points from each group on post-it notes and place on the relevant paper sheets on display.

Workshop 4: Implementing IWRM

Learning objectives: To create a virtual catchment and apply the concepts of IWRM implementation through creative and critical thinking.

The students will create an inland or coastal catchment, heavily urbanized or rural, facing specific climatic extremes or natural disasters. It can have places of environmental and/or cultural significance. The key attributes of the catchment will be based on students' random selection of choices provided by the lecturer.

Prior preparation

Lecturer/tutor prepares a collection of small boxes or bowls with different categories–location; scale; primary water issue; secondary water issue; challenge 1; and challenge 2. For each category, a number of choices are available for students to choose from, each written on slips of paper, then folded. By randomly selecting one slip of paper from each box/bowl, groups will have a virtual catchment on which to develop an idealized IWRM implementation plan.

For example, they may have a catchment described as: small island, Papua New Guinea; primary water issue = access to safe drinking water; secondary water issue = limited water distribution network; challenge 1 = high risks from natural hazards; and challenge 2 = need for institutional framework development.

The types of catchments and their locations across the Asia-Pacific region should be varied and include island, coastal, inland and alpine settings, with challenges that are climatically, demographically, economically, politically and/or socially driven.

To do:

This will be a two-hour development session, with a further hour for presentations and discussion.

Break class into groups of 6-8 students (depending on class size). Each group has the task of creating a virtual catchment based on the random selection of catchment attributes.

1. Design the catchment describing its setting as much as possible using the allocated attributes. Be creative.
2. Once the catchment has been designed, follow the four-phase process of IWRM implementation, and illustrate the process using the spiral model and any other visualizations that are useful. Include descriptions of how the challenges have been addressed, how the system is adaptive to climate, and how it is underpinned by principles of sustainability.
3. Present the IWRM plan to the class.

Field trip 1. Visit to a government department or non-government organization with responsibilities or interest in IWRM

Field trip 2. Visit a field location where an IWRM project is underway.

Organize to have representatives of several stakeholders available to talk with students about the project, and the processes of planning, implementation and monitoring, assessment and evaluation.

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Module 6: Water ethics

Summary

Water is absolutely essential for life on Earth, and as such, having access to safe, clean water is a basic human right. Water is valued across all societies, and is embedded in diverse cultural, religious and spiritual rituals or rites of passage.

Since Peter Gleick of the Pacific Institute first coined the term 'water crisis' in the 1990s, resource scarcity have been the focus of attention. However, often this crisis can be more a question of water access and distribution to meet competing needs, as well as human knowledge and resources for efficient water use. The ethics of water have been articulated through the following comment (UNESCO, 2000):

> "While we all have a need for water, this does not give us the right to have access to as much water as we choose. Society must first ensure that appropriate prioritization of water access be put in place which allows humanity's essential needs to be met as well as those of our ecosystems."

Moving into the future, decision-making that provides for equitable access and use of water should be predicated on an understanding of water ethics principles and practice.

In this module, students learn about those principles, consider the trilogy of limitations on water access, and use a case study approach to identify ethical dimensions to water management and articulate possible solutions. On reflection, students who have undertaken other modules in this programme will recognize the ethical dimensions in much of the content and in numerous case studies. This module is student-focused with one lecture to provide the framework on which student research can build a comprehensive understanding of ethical applications in water management.

Aims and objectives

The aim of this module is to explore and build a robust understanding of the ethical dimensions to water management.

Learning outcomes

On satisfying the requirements of this module, students will have the knowledge and skills to:

Undergraduate learning outcomes 1–3

1. Identify ethical dimensions of case studies.
2. Compare and contrast management decisions that are either ethically sound or questionable.
3. Apply the water ethics principles to case studies of water management across different socioeconomic, environmental and geopolitical settings.

Postgraduate learning outcomes 1–5

4. Reconstruct water management planning to incorporate ethical approaches.
5. Evaluate decision-making and planning on the basis of ethical practice.

Proposed assessment

Assessment task (undergraduate)	Value	Linked learning outcomes
Research forum (assessed on the number and quality of posts) linked to Student Activity 1.	To be assigned by lecturer	1–3
Developing a local water ethics charter (see Student Activity 2).	To be assigned by lecturer	1,3

Assessment task (postgraduate)	Value	Linked learning outcomes
Research paper comparing and contrasting two case studies that differ in the application of water ethics. (3,000 words)	To be assigned by lecturer	1–5
Developing a local water ethics charter (see Student Activity 2)	To be assigned by lecturer	1, 3, 4, 5

Module indicative content

Lecture 1: Water ethics

Topic	Content
Water as an ethical issue	From the late 1990s to the early twenty-first century, UNESCO had a programme in ethics that included, for the first time, substantive acknowledgement of the ethical dimensions to water use, values and protection. In 2012 at the World Water Forum in Marseilles, France, the need for a charter of water ethics was mooted and ultimately generated a draft charter in 2014 (which has not been updated). Decision-making and the management of water should be underpinned by ethical considerations. Water as an ethical issue can be explored through three limiting factors: use; access and distribution; and protection of the resource. ● **Water use**: The major user of water globally is agriculture. This means that food security and water use are intricably bound. How can agricultural water use be constrained when human survival also depends on adequate food? What are the implications of this for population growth into the near future and resilience to climate change effects on food production?

	• **Water access and distribution**: Water is unevenly distributed globally and regionally. Show this distribution and consider the unequal burdens for accessing supply. How does the development of water resources in transboundary systems address this heterogeneity of access? Water should be accessible to all - what are the challenges for intergenerational and women's access to water (and sanitation), and to access by the poor? How can equitable water access be achieved during and after disasters or during epidemics of communicable diseases? Examine the equity of water pricing and how that might limit access for the most vulnerable in a community. Consider the economic and operational aspects of water access including cost-recovery of water services (and the equity where some users pay, and others do not due to poverty of informal settlements). • **Water protection**: Investigate the concept of the environment as a legitimate user of water that must be protected. By what processes might protection be achieved (e.g. water allocations specifically for the environment – environmental flows; protection of water quality through polluter pays processes, or mechanisms that prevent contamination and pollution from occurring).
Water ethics principles	There are a number of publications that set out water ethics principles, and these can vary slightly (see reference list for key publications) but the core principles can be summarized as follows (UNESCO, 2000). Each of these should be explained and supported with an example taken from local or regional case studies. **Respect for human dignity** Access to water of adequate quality is crucial to meeting basic needs and promoting human health and well-being. Water managers should ensure that adequate water is available to meet basic human needs. **Equity and proportionality** When faced with limited resources, it is important to allocate water equitably and to give priority to the least well off, those most immediately at risk, and those who are made vulnerable by past discrimination, exclusion, and powerlessness. **Solidarity** The principle of solidarity recognizes the interdependencies that exist between upstream and downstream water users, and between people and the environment. We must take into account these interdependencies and multiple needs when managing water resources. **Common good** Water is a common pool resource and should be managed for the good of all. Managing water for self-interested ends can lead to 'tragedy of the commons' scenarios.

	Responsible stewardship It is important to manage water resources sustainably so that they can continue to be used by future generations. **Inclusive and deliberative participation** Decisions about water resource use and allocation should involve all stakeholders. The interests of the environment should also be represented.
Challenges to ethical resource management	• Legitimate, competing demands for water. How is water shared equitably? Whose interests ultimately define how it is shared? • War and famine – under extreme conditions, access to water can be used as a tool of power and/or control.
Indigenous water knowledge and water rights	Indigenous Peoples have managed water resources sustainably for millennia across diverse environments. Their traditional knowledge, customary laws and belief systems provide for equitable access to water and protection of the environment. Draw attention to the Indigenous Peoples Kyoto Water Declaration (UNESCO, 2002) Section 15 on traditional knowledge: "Our traditional practices are dynamically regulated systems. They are based on natural and spiritual laws, ensuring sustainable use through traditional resource conservation. Long-tenured and place-based traditional knowledge of the environment is extremely valuable, and has been proven to be valid and effective. Our traditional knowledge developed over the millennia should not be compromised by an over-reliance on relatively recent and narrowly defined western reductionist scientific methods and standards. We support the implementation of strong measures to allow the full and equal participation of Indigenous Peoples to share our experiences, knowledge and concerns. The indiscriminate and narrow application of modern scientific tools and technologies has contributed to the loss and degradation of water." Indigenous knowledge and rights to water are often secondary to management processes, or even excluded. They often have to conform to the water knowledge, values and legal frameworks of the dominant culture, but ethical practices can create pathways by which: i. Acknowledgement and valuing of culturally diverse water knowledges, and recognition of customary law are embedded in water planning and management, through effective participatory processes and shared decision-making. ii. Indigenous water rights are articulated within mainstream policy instruments, with Indigenous water planning and management being based on Indigenous ethics.

	• Provide examples of Indigenous knowledge, values and use of water referring to groups such as the New Zealand Maori, Fijian i-Taukei, Filipino Lumad and Manobo, Japanese Ainu and Australian Aboriginal Peoples. • Pose the questions: How is 'Western' knowledge and Indigenous knowledge integrated in water management? To what extent are Indigenous water rights currently acknowledged (and embedded in water management decision-making) across the region? **View the video**: Aboriginal water values and management in northern Australia: https://www.youtube.com/watch?v=XMKYybtUJ-o
Case studies	Use one or two case studies and describe these in some detail, pointing to the relevant principles that apply. Ideally case studies should be from a developing country and a developed country, or one that refers to internal water resources and one that involves transboundary water. These case studies should be contentious, for example, the Sardar Sarovar Dam, India; Israel versus Palestine's access to water; the Texaco-Chevron oil contamination of freshwaters in Ecuador; cholera in Yemen and the supply of bottled water by Saudi Arabia. The case studies must easily draw students into the principles of water ethics.

Quick quiz

Question	Answer
What is the difference between morality and ethics?	Morality refers to guiding principles for normative behaviour by an individual that are generally accepted by a society. Ethics refers to *specific* codes, rules or behaviours that often apply at a collective or professional level.
What is meant by 'water ethics' and what is the aim of its application?	Access to safe drinking water is a basic human right recognized by the United Nations. Thus access, use and management of water should be underpinned by ethical principles of practice that protect human health and well-being (and the environment). By applying water ethics, decision-makers, managers and communities can address water issues in a responsible and equitable manner.

What are the six principles of water ethics?	1. Respect for human dignity 2. Equity and proportionality 3. Solidarity 4. Common good 5. Responsible stewardship 6. Inclusive and deliberative participation
Under what conditions can the application of water ethics be challenging?	• Critical levels of water scarcity, for example, during prolonged severe drought and famine; or after catastrophic natural disaster such as tsunamis, earthquakes, or tropical cyclones. • During periods of political instability including but not limited to war, political coups, or externally imposed sanctions. • Where there are legitimate competing needs in sharing a limited resource.
What are cultural rights to water?	Cultural water rights provide for access to and use of water for spiritual, cultural, social, economic and environmental uses by Indigenous Peoples.
How can Indigenous knowledge be integrated into water management?	Through participatory processes including engagement, shared decision-making, and leadership by and with Indigenous Peoples.

Student-focused learning activities

Activity 1: Four-way water moot

Learning objectives:

i. To expose students to the complexity of water management from an ethical perspective.
ii. To identify the key ethical principles and how these might be applied in managing water resources.

Materials required before moot: A number of case studies, with one case study assigned to four groups of 4–5 students. Each group will represent a specific stakeholder interest but this should not be revealed until the workshop. Students will research all possible stakeholder interests before the workshop. The four groups should work separately.

In this activity it is essential that students have a week or more to undertake group research. If students have access to computers and internet, set up an online forum using a Moodle or Facebook, for example. The tutor can moderate and support students who post resource material, questions, ideas and comments relevant to the case study.

Each case study will have a relevant question to give to students in class. Student responses should include references to key principles of water ethics as outlined in the lecture.

To do:

Divide class into their case studies, four groups per case study. Assign each group with a stakeholder interest (this might be central government, irrigators, non-government organization representatives, industry representatives, government agencies, local community members, Indigenous elders, members of different villages or kinship groups, United Nations, farmer groups, Human Rights Commission etc).

Each case study should now have a question posed that the groups need to answer. Allow 15 minutes preparation time, and then let the groups participate in a four-sided discussion with each group addressing the question from their own interests.

Note, multiple groups will be talking at once, but this should be dynamic, and full student engagement is expected and encouraged. The lecturer and tutor(s) should be supporting these group discussions with further probing questions and prompts.

After discussions have continued for 15 minutes, the opposing groups should change their stakeholder allegiance. This should be managed by the lecturer/tutors and be organized prior to class. Discussions should then continue for 15 minutes with groups being forced to take positions that may be opposite to their previous positions.

Reflection: Do the students find the ethical basis for their arguments shift or are malleable according to the stakeholder interests in water?

Activity 2: Developing a local water ethics charter

Learning objective: To construct a water ethics charter specific to a known locality, in order to build knowledge around the integration of ethics into resource planning and management at a local scale.

Note: this exercise can be a group-based assessment option.

Preparation:

Provide students with copies of the Water Culture Institute's *Handbook for crafting a local water ethics charter* ***prior to class*** (Water Culture Institute, 2015). Access to Google Earth is useful for initial class discussions.

The lecturer/tutor should access and read the *Santa Fe Local Water Ethics Charter* to help guide the class in developing their own charters (Water Culture Institute, 2016). Note that the paper by Groenfeldt and Schmidt (2013) also refers to Santa Fe as a case study.

To do: 60–90 minutes Discuss with students a range of local water issues within their own region. Out of this discussion, develop a number of 'case studies' on which students undertake further research to understand the region's environmental features (climate, demography, services, landuse etc) and water supply, access and use. This information provides the baseline for developing the charter. Split the class into small groups, one group per 'case study'.

60 minutes. Students should all have a hardcopy of *Handbook for crafting a local water ethics charter* for reference. Groups need to refer to this handbook and the compiled information on their allocated local case study to develop a step-by-step charter that is informed by water ethics principles.

To get started, the students should pose questions about the relevant water issues now and in the future, and considering which ethical principles might apply to their case study. What are the water issues? Who are the stakeholders? What are their needs? What are the ethical dimensions to those issues and their management?

Each group type up their charter to share with the class and/or submit for assessment.

References

Groenfeldt, D. and Schmidt, J. 2013. Ethics and water governance. *Ecology and Society*, 18 (1): 14. http://dx.doi.org/10.5751/ES-04629-180114

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UNESCO. 2000. The ethics of freshwater use. https://www.protos.ong/sites/default/files/library_assets/men_e5_ethics-freshwater.pdf

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SECTION 3
OTHER RESOURCES FOR TEACHING AND LEARNING

Curriculum and teaching evaluation

Student evaluation of teaching and learning is used to inform the educator/curriculum developer about the effectiveness of a course or module. It can also involve separate evaluation of the teaching staff. Examples of both evaluation forms are provided below as a guide.

Evaluation of these water curriculum modules will provide immediate feedback to further refine or develop the modules by course convenors, lecturers and tutors to make it 'their own'. The evaluation will also provide feedback to UNESCO so that, periodically, the whole curriculum can be revised and updated, creating an educational resource that is both dynamic and adaptive.

Module student evaluation form

Questions	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
1. The connections between the learning outcomes, activities and assessment of this module/course were clear to me.					
2. The module/course was intellectually stimulating.					
3. The module/course supported the development of my ability to think critically.					
4. The resources provided in this module/course (e.g. online, videos, hardcopy) were useful and supported my learning.					
5. The workload required was appropriate for the level of this module/course.					
6. I received constructive feedback on the work that I undertook for this module/course.					
7. I received feedback on my work in time to improve.					
8. Overall, this module/course was a valuable learning experience.					

Open-ended questions	Response
1. What were the best aspects of this module/course?	
2. Please provide any suggestions on how this module/course can be improved.	

Teaching evaluation form

Questions	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
1. The lecturer demonstrated a comprehensive knowledge of the subject.					
2. The lecturer made effective use of teaching aids, resources and/or media.					
3. The lecturer encouraged questions and participation in class.					
4. The lecturer provided answers to questions that were easy to understand.					
5. The lecturer treated all students with courtesy and respect.					
6. The lecturer was available for consultation where needed.					
7. The lecturer effectively facilitated my learning.					

Open-ended questions	Response
1. What were the strengths of the lecturer in this module/course?	
2. Please provide any suggestions on how the lecturer in this module/course could make improvements to their teaching approach or methods.	

Online water games for active learning

There are a number of open access games and resources available online which can be used to support student learning. These games and tools can be employed to (i) provide students with the opportunity to understand the complexities in water resources decision-making, and (ii) to experience the processes employed in stakeholder participatory decision-making, capacity building, and knowledge acquisition. A list of these games and resources are provided below.

- **CoOPLAaGE** comprise a set of integrated tools and resources that can be used to support stakeholder groups (communities, decision-makers and policymakers) as they engage in participatory processes to develop change strategies in socio-environmental systems, such as water resources management. The different tools available include:
  - » Designing a procedure for decision making (*PrePar*)
  - » Modelling (**WAG**)
  - » Framing the principles of social justice (*Just-a-Grid*)
  - » Identifying and developing pathways for change and change management (*WAG*)
  - » Action planning (**Cooplan**)
  - » Evaluation techniques (*Encore-Me*)

  https://sites.google.com/site/watagame2/cooplaage-tools

- **Catchment Detox** is an online game where players manage a virtual river catchment over a fifty-year period with expected outcomes to be a healthy sustainable ecosystem and the provision of food and water security. Aimed at Australian schools, this is also highly relevant for tertiary students engaged in active elearning. Note that this game can also be accessed through Games4Sustainability (see below).

  https://www.abc.net.au/science/catchmentdetox/files/home.htm

- **Games4Sustainability** comprises thirty-three online water games including simulations, board games and role play covering a wide range of topics. A few of these games are briefly described below to indicate the breadth of topics and type of games. All are open access. Note that some games on the website have 'price not specified'.
  - » P.I.P.E.S – Public infrastructure participatory engagement simulation game.
  - » Nexus Challenge – Explores the resilience of the water-food-energy nexus. Board game
  - » Game of Floods – Sustainable cities and communities on a virtual island. Board game
  - » River Basin Game – Decision-making in a water-scarce setting from a farming perspective. Simulation and role play.
  - » New Shores – Settlement of an island rich in natural resources that can be exploited or conserved or managed sustainably. Simulation.
  - » Flood Resilience Game – Flood risk and resilience of communities living on a floodplain. Role play.
  - » AWQA Water – Water pollution exercise exploring the connection between landuse and nutrient enrichment of waterways. Online game for one player only.
  - » Lords of the Valley – Provides learning around risk management collaborative decision-making and conflict resolution. Role play and simulation.

» Climate and Gender – Understanding the gendered vulnerabilities of women and men during floods and drought. Dice game.

https://games4sustainability.org/water-games/

Work-integrated learning

Work-integrated learning (WIL) is the outcome of work-integrated education by which students gain specific skills and knowledge that improves their employability on graduation (Cooper et al. 2010; HEQCO, 2016). The concept of WIL involves work *readiness*, where student having a suite of literacies and authentic learning experiences that support their transition from university into the workplace.

Graduate attributes are identified in Section 1. A subset of attributes provides for education that allows a student to enter the workforce capable of acting professionally and having professional integrity, flexibility, resilience, and team work capabilities. As an integral part of tertiary education, therefore, WIL involves authentic learning experiences in which students are in control of their learning and can apply it meaningfully in novel and unanticipated ways. As such, WIL involves the parallel practices of pedagogy *and* heutagogy, the latter being self-determined learning.

WIL can be embedded into the whole curriculum to provide students with a broader set of capabilities. The graduate attributes that are associated with these capabilities include:

- Depth of disciplinary knowledge
- Critical thinking and communication skills
- Information and digital literacies
- Inventiveness/creativity
- Interdisciplinary effectiveness
- An integrated professional, ethical, and personal integrity
- Cultural competence

A curriculum framework that can capture these attributes comprises four pillars: academic rigour; cultural and global perspectives; cross-disciplinary learning; and authentic learning experiences through real world projects.

For this curriculum, opportunities for project-based work can complement any of the modules and include internships (including virtual) and placements within institutions that have established research/work experience partnerships with the teaching institution. Partnerships with industry, government, non-government organizations and businesses are critical for these student activities to take place, and are founded on *reciprocal benefits* to both host and university (Orrell, 2004). This reciprocity is the basis for overall success at an individual module, whole-of-course and even institutional scales, so network/partnership construction and maintenance need to be planned and supported with due diligence.

Measuring success for students undertaking such projects requires learning outcomes based on complex, integrative tasks. Here, two key concepts apply: (i) that key capabilities in employability are embedded in the curriculum, rather than being co-curricular activities; and, (ii) 'positive failure' in which students who have not managed to meet their own expectations in learning can reflect on their experiences, and build new understandings from apparent 'failure'.

Students assessing their own WIL literacies can use an online self-assessment tool through Curtin University's employability free access programme (http://developingemployability.edu.au)[1]. This examines a student's stage of development in key literacies including literacy and numeracy, ethical/social, rhetorical, personal and cultural. Outputs include achievement plotted in a spider chart so students can readily identify their strengths as well as areas for development.

References

Cooper, L., Orrell, J. and Bowden, M. 2010. *Work-integrated learning: a guide to effective practice.* Routledge.

Higher Education Quality Council of Ontario (HEQCO). 2016. A practical guide for work-integrated learning. HEQCO. 192 pp. http://cva-acfp.org/article/canadaontario-a-practical-guide-for-work-integrated-learning-effective-practices-to-enhance-the-educational-quality-of-structured-work-experiences-offered-through-colleges-and-universities/

Orrell, J. 2004. 'Work-integrated learning programmes: management and educational quality'. Proceedings of the Australian Universities Quality Forum. AUQA Occasional Publication. http://scholar.google.com.au/scholar_url?url=http://www.academia.edu/download/33250937/Orrell.pdf&hl=en&sa=X&scisig=AAGBfm1dex4mrFfcrbbwzx4iZ9cPQRNvqQ&nossl=1&oi=scholarr

1 Educators should sign into student page as 'test' to explore this site.

Conceptual Site Model

Fill in the table below to help create a conceptual site model by identifying the different sources of risk to water quality, the potential contaminants, the pathways that the contaminants take (for surface runoff on catchment slopes, or roads; groundwater; streamflow etc) and who/what will be impacted)

Source of risk	Contaminants	Conditions that optimise the risk	Pathways	Who will be impacted?

Water Education for Climate Resilience in Asia and the Pacific - a Regional Curriculum

This regional curriculum is a result of a multi-year project supported by the Government of Japan through UNESCO Funds-in-Trust under the title "International Hydrological Programme Water Informatics for Sustainability and Enhanced Resilience in Asia and the Pacific".

It draws on important developments in ecohydrology, integrated water resources management (IWRM) and sustainability science, with particular emphasis on climate change impact resilience and on the linkages between science and policy.

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