

# Remote Sensing for Freshwater Habitats

Amber McCullum, Juan Torres-Pérez, Guest Speaker Kashif Shaad (Conservation International)

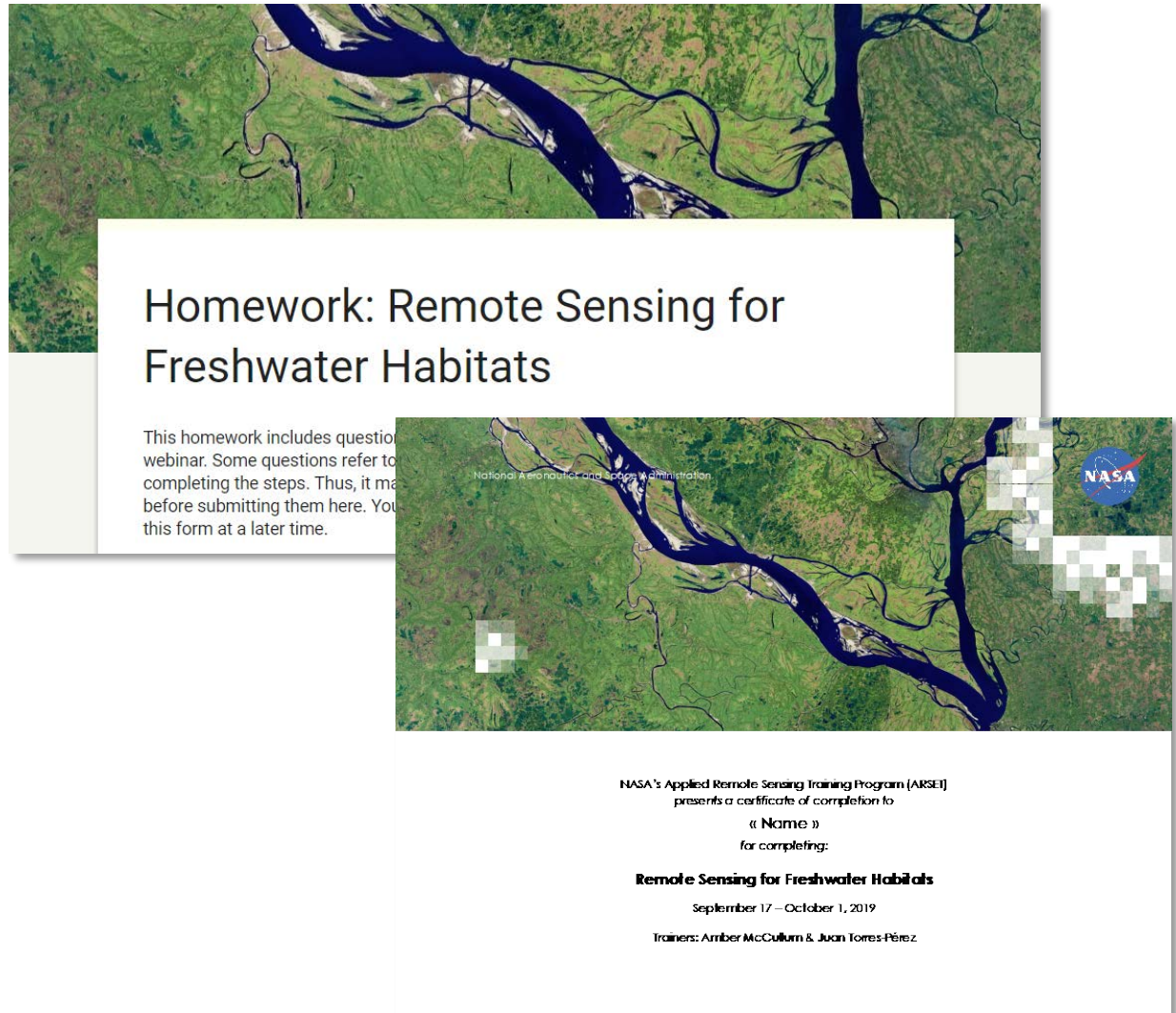
17 September – 1 October, 2019

# Course Structure

- Three, 1-hour sessions on September 17, 24, and October 1
- The same content will be presented at two different times each day:
  - Session A: 10:00-11:00 EST (UTC-4)
  - Session B: 18:00-19:00 EST (UTC-4)
  - **Please only sign up for and attend one session per day**
- Webinar recordings, PowerPoint presentations, and the homework assignment can be found after each session at:
  - <https://arset.gsfc.nasa.gov/land/webinars/2019-freshwater>
- Q&A: Following each lecture and/or by email
  - [amberjean.mccullum@nasa.gov](mailto:amberjean.mccullum@nasa.gov)
  - Or [juan.l.torresperez@nasa.gov](mailto:juan.l.torresperez@nasa.gov)

# Homework and Certificates

- Homework
  - One homework assignment
  - Answers must be submitted via Google Forms
- Certificate of Completion:
  - Attend both live webinars
  - Complete the homework assignment by the deadline (access from ARSET website)
    - **HW Deadline: Tuesday Oct 15**
  - You will receive certificates approximately two months after the completion of the course from:  
[marines.martins@ssaihq.com](mailto:marines.martins@ssaihq.com)



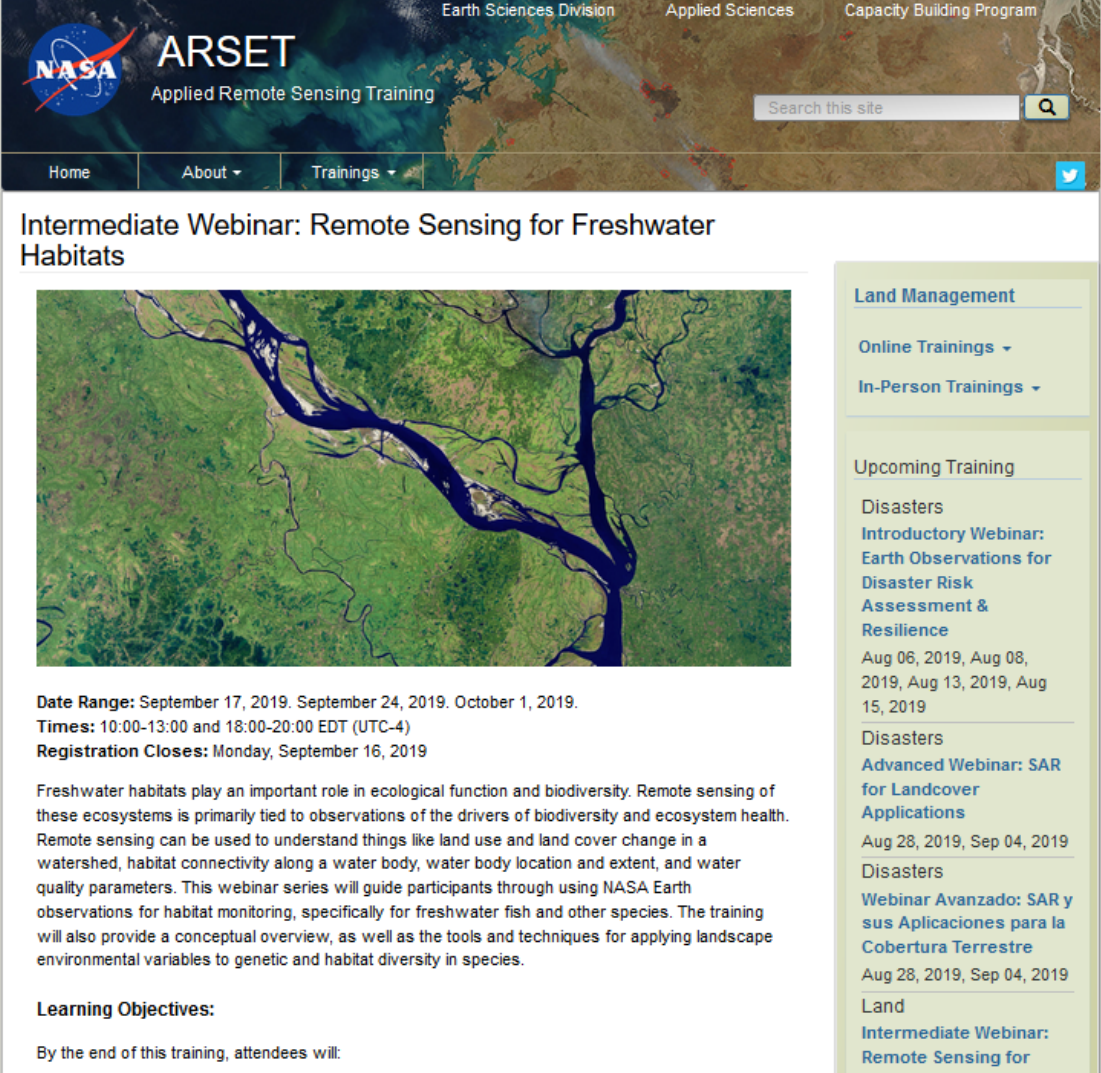
**Homework: Remote Sensing for Freshwater Habitats**

This homework includes questions from the webinar. Some questions refer to completing the steps. Thus, it must be completed before submitting them here. You can submit this form at a later time.

NASA's Applied Remote Sensing Training Program (ARSET) presents a certificate of completion to  
« Name »  
for completing:  
**Remote Sensing for Freshwater Habitats**  
September 17 – October 1, 2019  
Trainers: Amber McCullum & Juan Torres-Pérez

# Prerequisites and Course Materials

- Prerequisite
  - Please complete [Sessions 1 & 2A of Fundamentals of Remote Sensing](#), or have equivalent experience
    - Attendees who do not have this knowledge may not follow the pace of the training
- Course Materials
  - Found here:  
<https://arset.gsfc.nasa.gov/land/webinars/2019-freshwater>



The screenshot shows the NASA ARSET (Applied Remote Sensing Training) website. The header includes the NASA logo, 'ARSET Applied Remote Sensing Training', and navigation links for 'Home', 'About', and 'Trainings'. A search bar is also present. The main content area features a satellite image of a river system and the title 'Intermediate Webinar: Remote Sensing for Freshwater Habitats'. Below the image, the text provides the date range (September 17, 2019, September 24, 2019, October 1, 2019), times (10:00-13:00 and 18:00-20:00 EDT UTC-4), and registration closing date (Monday, September 16, 2019). A paragraph describes the webinar's focus on freshwater habitats and remote sensing applications. A 'Learning Objectives' section begins with 'By the end of this training, attendees will:'. On the right side, there is a sidebar with navigation options: 'Land Management', 'Online Trainings', and 'In-Person Trainings'. Below this, an 'Upcoming Training' section lists several events, including 'Introductory Webinar: Earth Observations for Disaster Risk Assessment & Resilience' and 'Advanced Webinar: SAR for Landcover Applications'.

# Course Outline

## Session 1: Aquatic Remote Sensing

- Satellites and sensors
- Data limitations
- Combining multiple data types for freshwater habitat mapping
- Some case study examples

## Session 2: Riverscape Analysis Project (RAP)

- Case studies
- RAP overview
- Data and analysis with RAP
- RAP demo

## Session 3: Freshwater Health Index

- Freshwater health metrics overview
- FHI overview
- FHI demo

# Session 3 Agenda

- Overview of Freshwater Health Index – Links to social-ecological system
- Conducting an FHI assessment
- FHI tool Demonstration – links to remote sensing data
- Question and Answer session

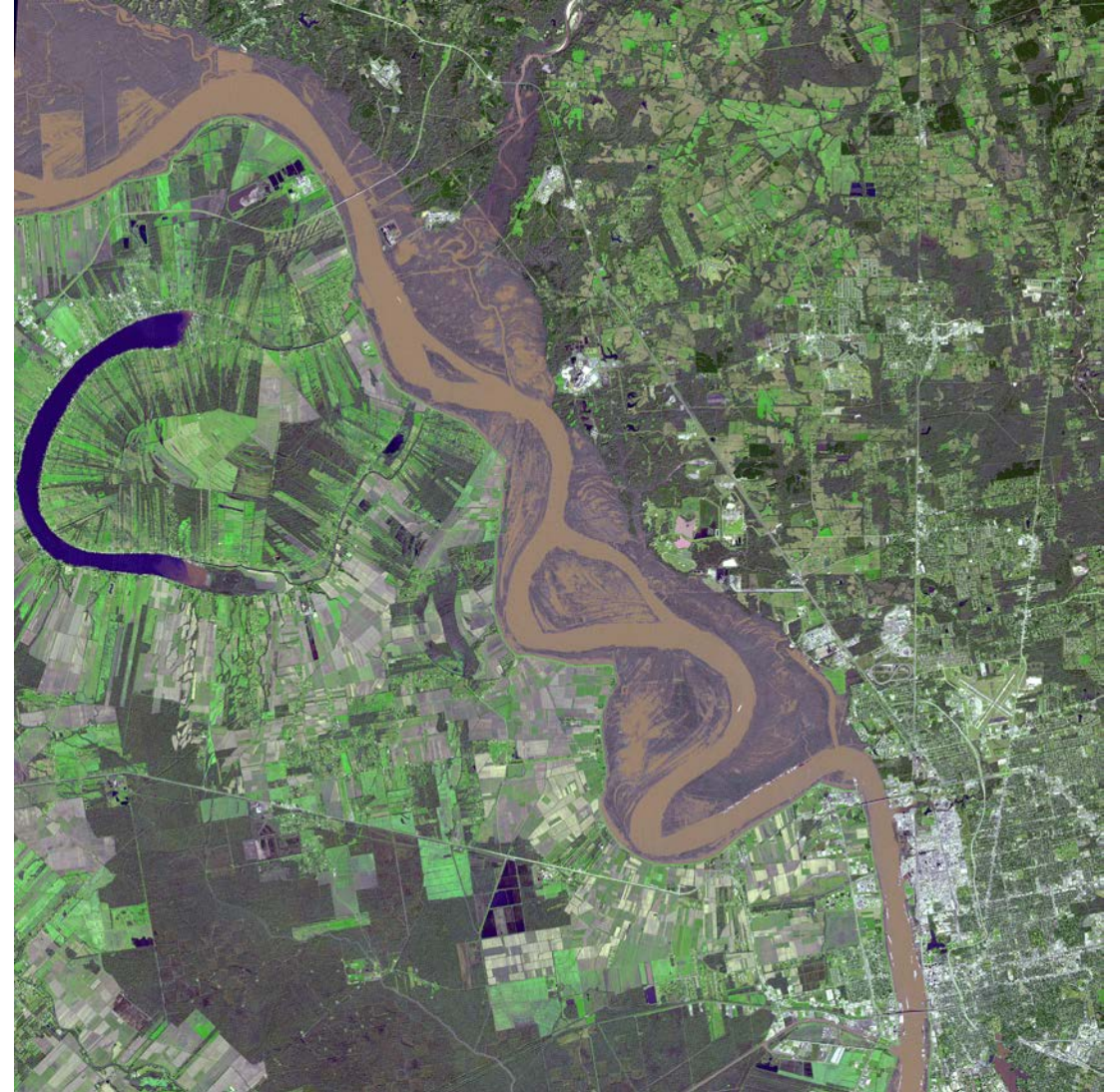


Image Credit: [Jet Propulsion Laboratory](#)

# Review of Session 2

- Landscape genetics can be a powerful tool to study freshwater species and their vulnerability to changing conditions
  - eDNA can be used for elusive and/or sensitive species to estimate abundance and understand genetic diversity
- Remote sensing, GIS, and modeling technology is key in multi-step vulnerability assessments
- The Riverscape Analysis project provides information, opportunities for citizen science, and multiple online tools for acquiring and analyzing freshwater habitats in the Pacific Northwestern region of the U.S.

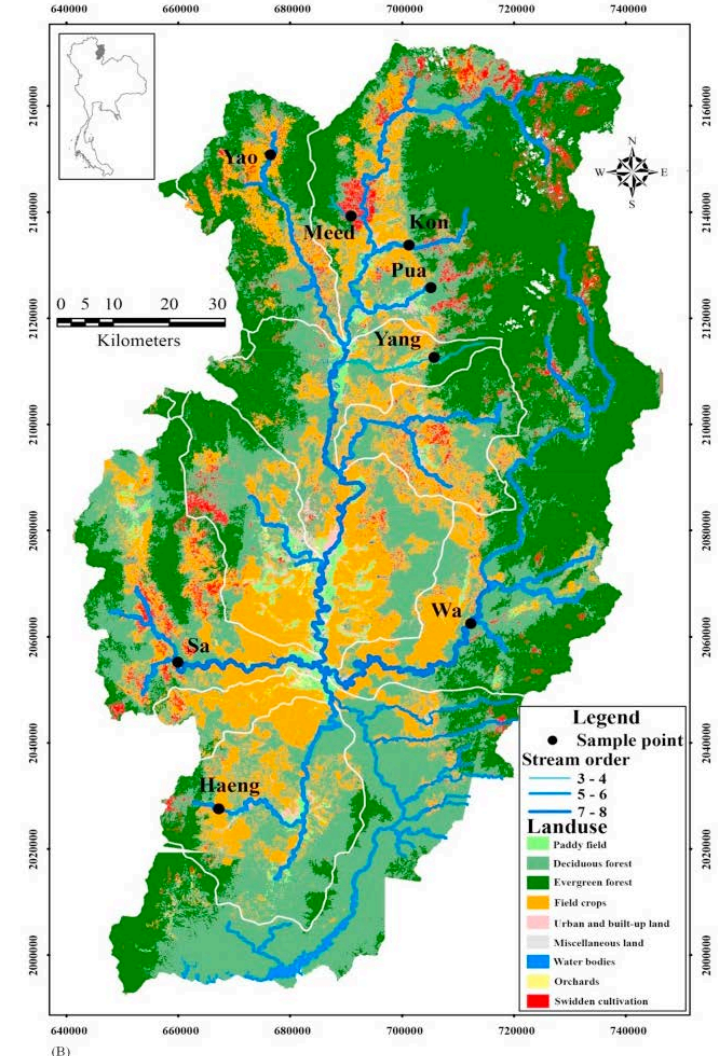
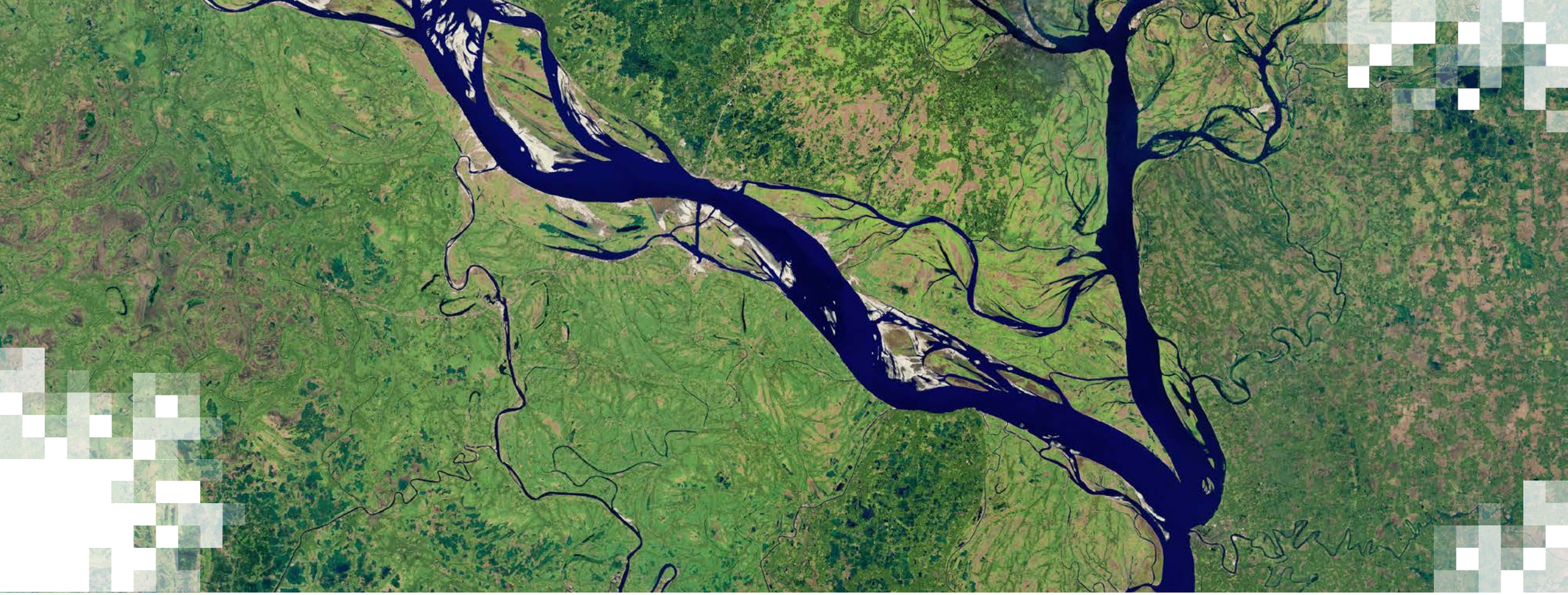


Image Credits: (Top left) [Diszhal.info](http://Diszhal.info); (Right) [Jaisuk and Senanan, 2018](#)



# Freshwater Health Index Overview

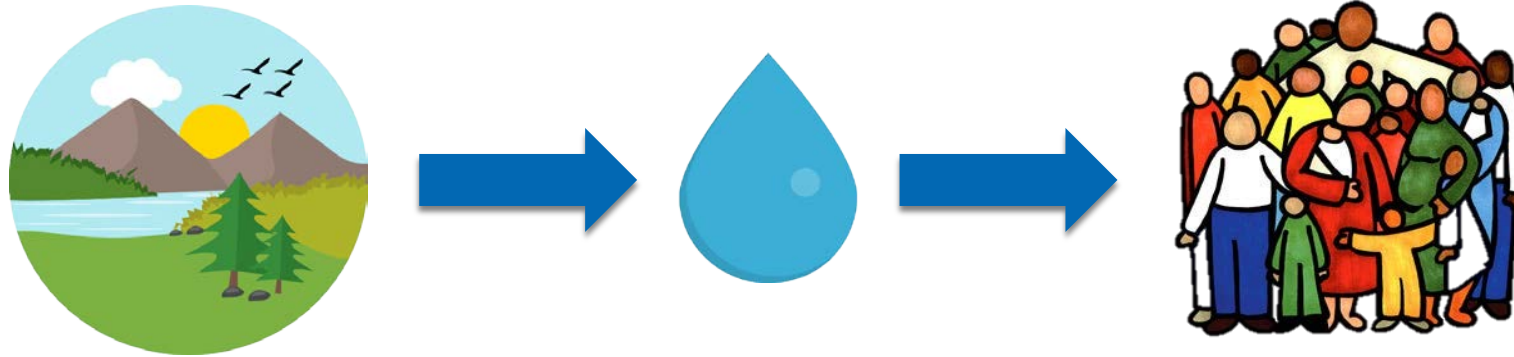
Guest Speaker: Kashif Shaad



# Freshwater Health

- 'Health' is a common shorthand for 'good condition' - grounded in science but accessible to citizens
- Links ecological integrity to ecosystem service delivery, and combines social with ecological dimensions

We define "freshwater health" as the ability to deliver water-related benefits **sustainably and equitably**



Text References: Karr, 1999; Vollmer et al., 2018

# Freshwater Social-Ecological System

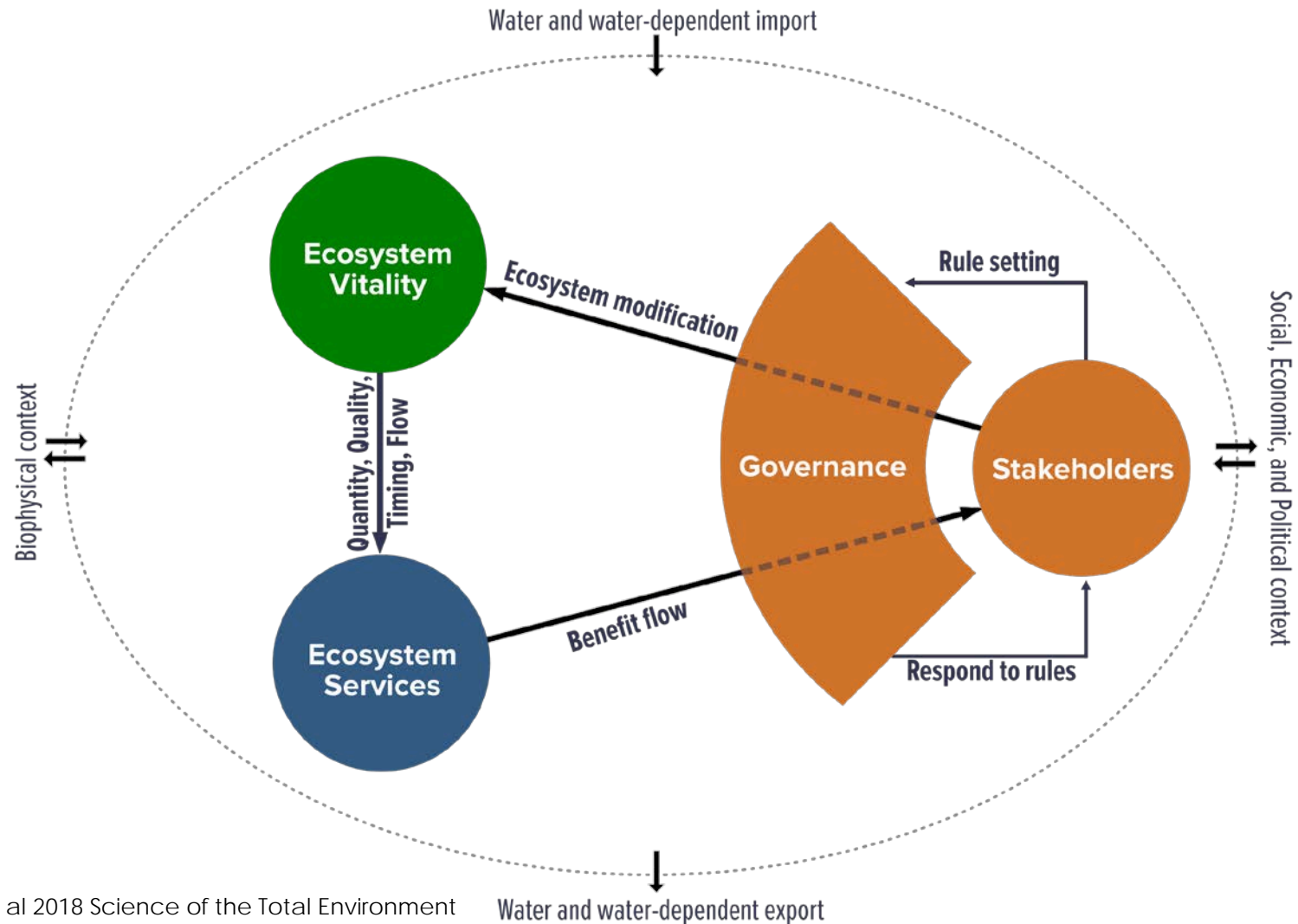


Image Source: Source: Vollmer et al 2018 Science of the Total Environment

# Focus Areas



## Ecosystem Vitality

Maintenance of ecosystems central to freshwater health

Basin Condition

Water Quantity

Water Quality

Biodiversity



## Ecosystem Services

Monitor ability to deliver water-related services

Provisioning

Regulating

Cultural



## Governance & Stakeholders

Gauge responsiveness of governance

Enabling Environment

Stakeholder Engagement

Adaptive Governance

Effectiveness

# Locally Adaptive Sub-Indicators



## Ecosystem Vitality

### Water Quantity

- Deviation from natural flow
- Groundwater Storage Depletion

### Water Quality

- Suspended Solids
- Total Nitrogen
- Total Phosphorus
- Other indicators of concern

### Drainage Basin Condition

- Extent of channel Modification
- Flow connectivity
- Land Cover Naturalness

### Biodiversity

- Species of concern
- Invasive Species

## Ecosystem Services

### Provisioning

- Water supply reliability relative to demand
- Biomass for consumption

### Regulation and Support

- Sediment regulation
- Deviation of water quality from benchmarks
- Flood regulation
- Exposure to water-associated diseases

### Cultural

- Conservation/Cultural heritage sites
- Recreation

## Governance & Stakeholders

### Enabling Environment

- Water resource management
- Rights to resource use
- Incentives & regulations  
Financial & technical capacity

### Stakeholder Engagement

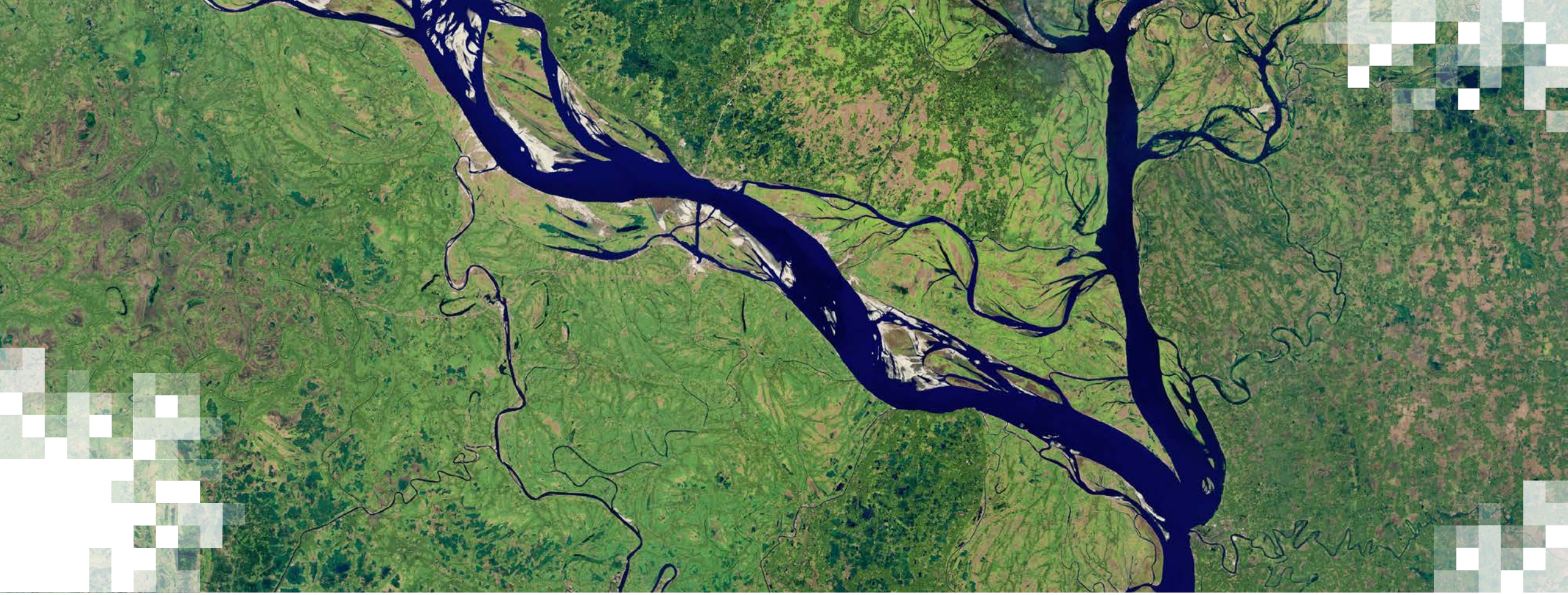
- Information access & knowledge
- Engagement in decision-making

### Vision & Adaptive Governance

- Strategic planning & adaptive management
- Monitoring & learning mechanisms

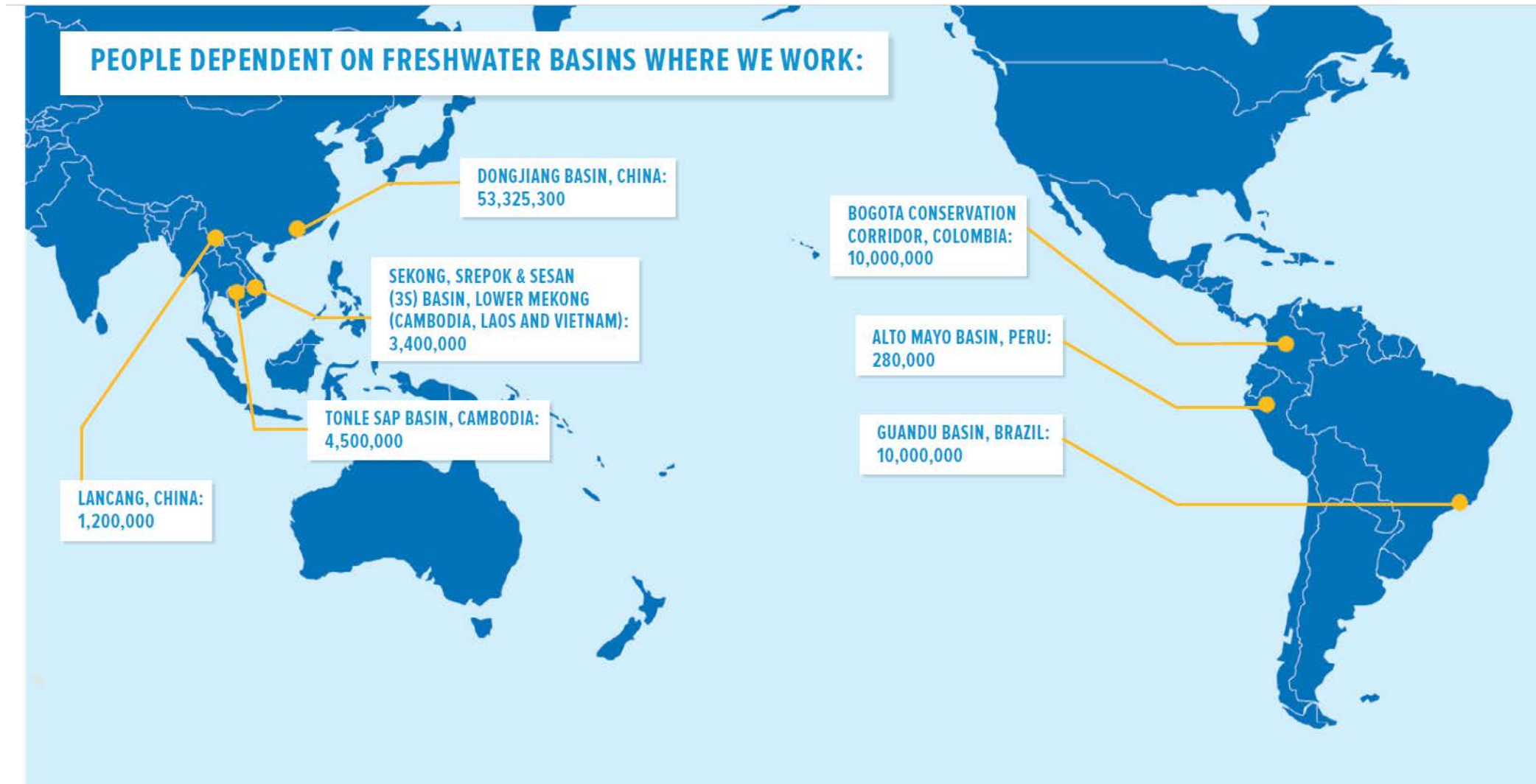
### Effectiveness

- Effectiveness & compliance
- Distribution of benefits from ecosystem services
- Water-related conflict



# Conducting a FHI Assessment

# [1] Define Scope and Engage Stakeholders

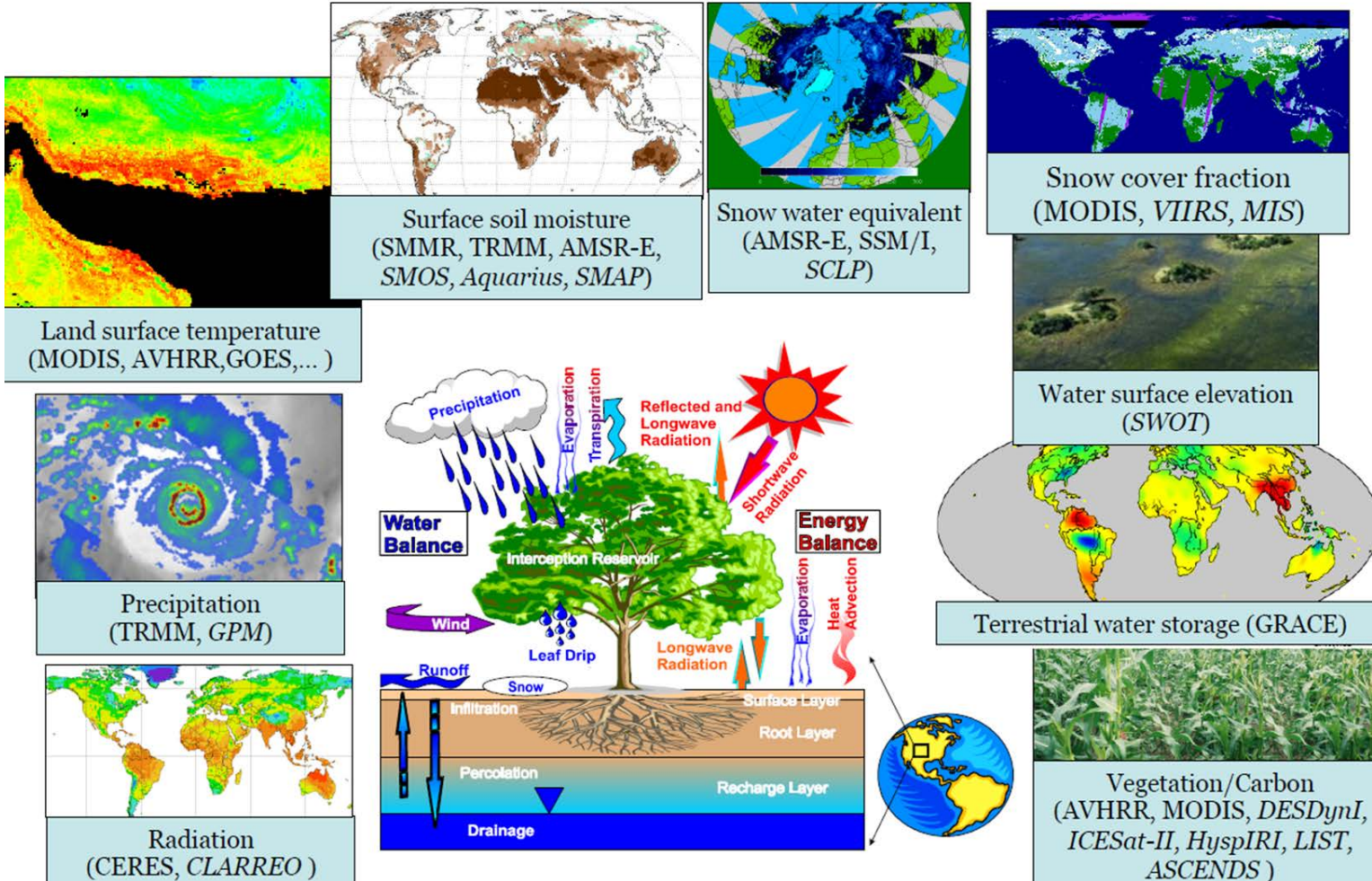




A Freshwater Health Index assessment is a standardized way to involve multiple agencies and stakeholders in setting priorities for better water resource management.

Image Credit: [Nine dragons](#)/Gisling

# [2] Data Gathering



**In-Situ Measurements**  
 “Real” data **but** labor intensive/quality control issues

**Remote Sensing**  
 Good spatial coverage **but** resolution and sensing limitations

**Numerical Models**  
 Continuity **but** quality limited by input/assumptions



# [3] Indicator Calculation

<https://www.freshwaterhealthindex.org/tool/>

Freshwater Health Index

Ecosystem Vitality > Water Quantity (WQT) > Deviation from Natural Flow Regime(DvNF)

March 28, 2019 at 7:43 PM

*Deviation from natural flow regime* measures the degree to which current flow conditions have shifted from historic natural flows. The greater the deviation from natural flow indicates a higher risk of damage to the freshwater ecosystem (Poff and Zimmerman 2010). This measure can be derived from a wide range of variables, including deviation in annual mean, minimum and maximum discharge in the basin, proportion of the year that annual mean discharge was exceeded, etc.

| Attributes   |  |
|--|--|
| <b>Scale of calculation:</b>                                     | Sub-basin, aggregate to basin;   |
| <b>Range of Output:</b>  | 100 indicates near natural conditions, 0 indicates high deviation; 100-80: Indicates that the seasonal pattern and magnitude of flow/levels resemble a natural flow regime; 80-50: Regulated flow which is likely to maintain seasonal pattern however, magnitudes (especially at peak and ebb points) show marked deviation from natural flow regime; Below 50: Indicates significant deviation in both seasonal pattern and magnitudes from natural flow regime. |
| <b>Reference:</b>  | Ladson et al (1999), Gehrke et al. (1995), Gippel et al (2011)   |
| <b>Type/Class of Input required:</b>                             | Monthly flow data for both current and natural conditions, over either the same period or before and after major hydrological change (e.g. dam construction).  |
| <b>Suggested source of 'minimum' data to enable calculation:</b> | Modeled monthly flow data for 5 years with/without all modifications to basin. Actual flow data before and after major hydrological change.  |

**Calculation in FHI Toolbox:**

*Amended Annual Proportion of Flow Deviation (Gehrke et al. 1995, Gippel et al 2011):*

$$AAPFD = \sum_{j=1}^p \frac{\sqrt{\sum_{i=1}^{12} \left[ \frac{m_i - n_i}{\bar{n}_i} \right]^2}}{p}$$

Where,  $m_i$  is monthly flow data accruing to current condition,  $n_i$  is modeled natural flow for the same period.  $p$  is the number of years and  $\bar{n}_i$  is mean reference flow for month  $i$  across  $p$  years (Note: in ephemeral streams, this should be changed to incorporate annual average flow to avoid extremely large values). Values are normalized as follows using thresholds reported in Gehrke et al. 1995 and Gippel et al 2011:

$$D_{mNF} = \begin{cases} 100 - 100 \times AAPFD & \text{for } 0 \leq AAPFD < 0.3 \\ 85 - 50 \times AAPFD & \text{for } 0.3 \leq AAPFD < 0.5 \\ 80 - 20 \times AAPFD & \text{for } 0.5 < AAPFD < 2 \end{cases}$$

**Navigation:** > About FHI, > Indicator System, > Getting Started, > Setting up a Basin Study, > Ecosystem Vitality, Guidelines, > Water Quantity (WQT), > Deviation from Natural Flow Regime(DvNF), Groundwater Storage Depletion(GwSD), Water Quality (WQL), > Drainage Basin Condition (DBC), > Biodiversity (BIO), > Ecosystem Services, > Governance and Stakeholders, Weighting Indicators, Evidence Levels in FHI, > Scenarios in FHI, References

**Links:** FHI Website, Publications, Help/Support/Bugs, Conservation International

# Collaborating for an Enhanced Exchange: Dongjiang Basin




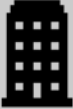
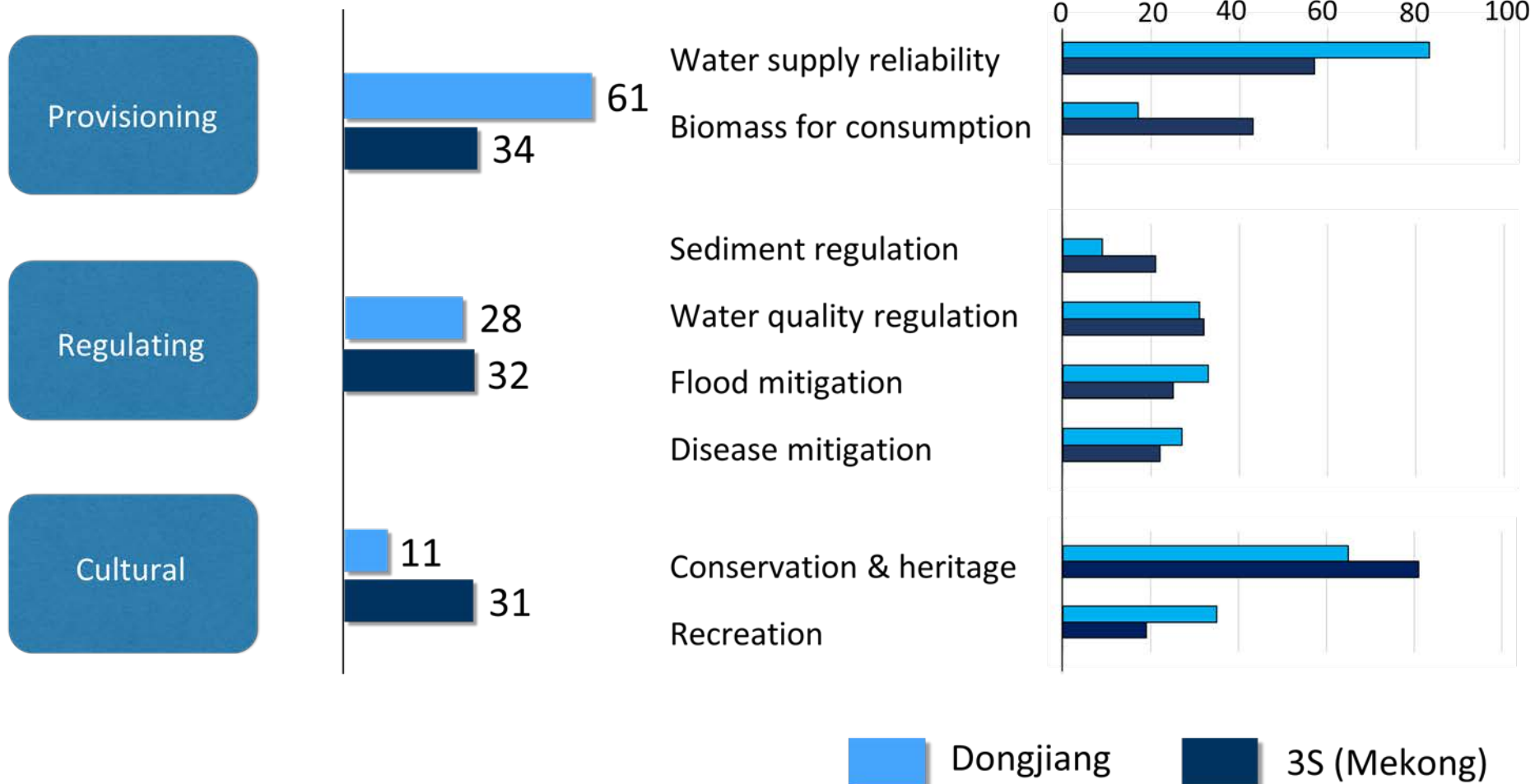
|   | Indicator Domain                        | Champion Organization                    |
|---|---|--|
|    | Water discharge and quality             | South China University of Technology     |
|    | Basin Biodiversity information          | IUCN Guangzhou, China                    |
|    | Flooding, Water supply & other services | Pearl River Hydraulic Research Institute |
|    | Fisheries                               | Pearl River Fisheries Research Institute |
|  | Water Governance                        | Sun Yat-sen University                   |



Photo Credits: CI

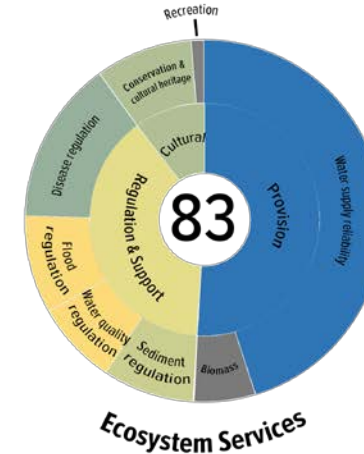
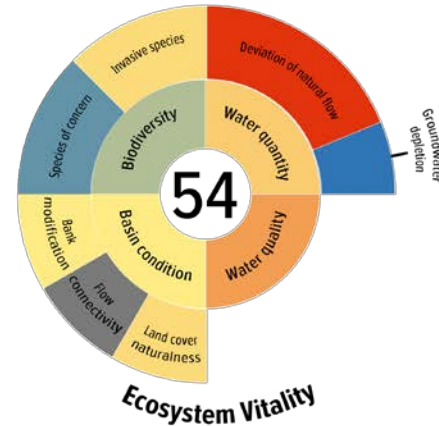
# [4] Perception Surveys



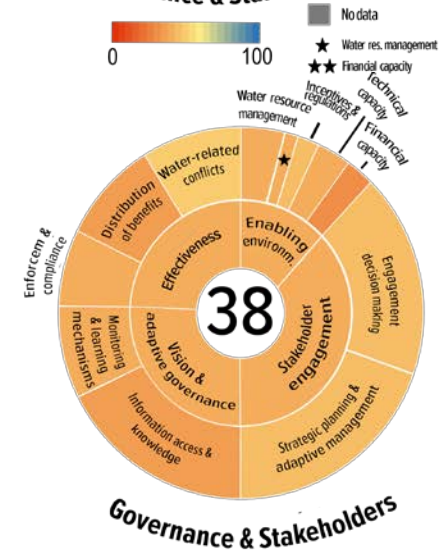
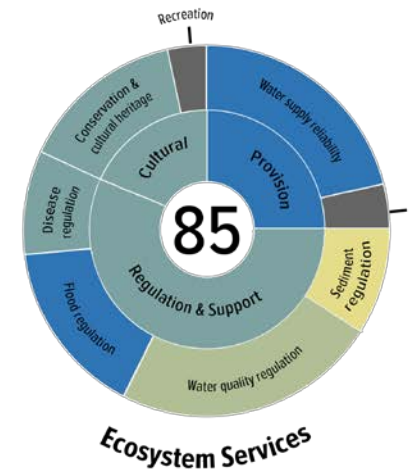
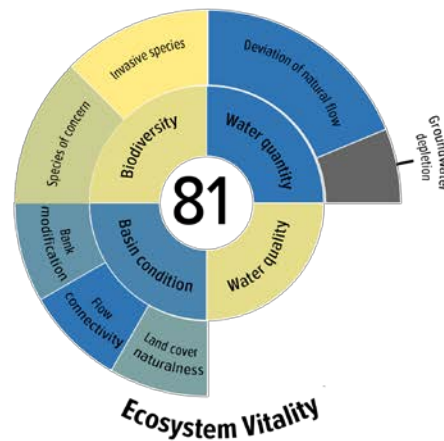
# [5] Put It All Together



Guandu Basin, Brazil

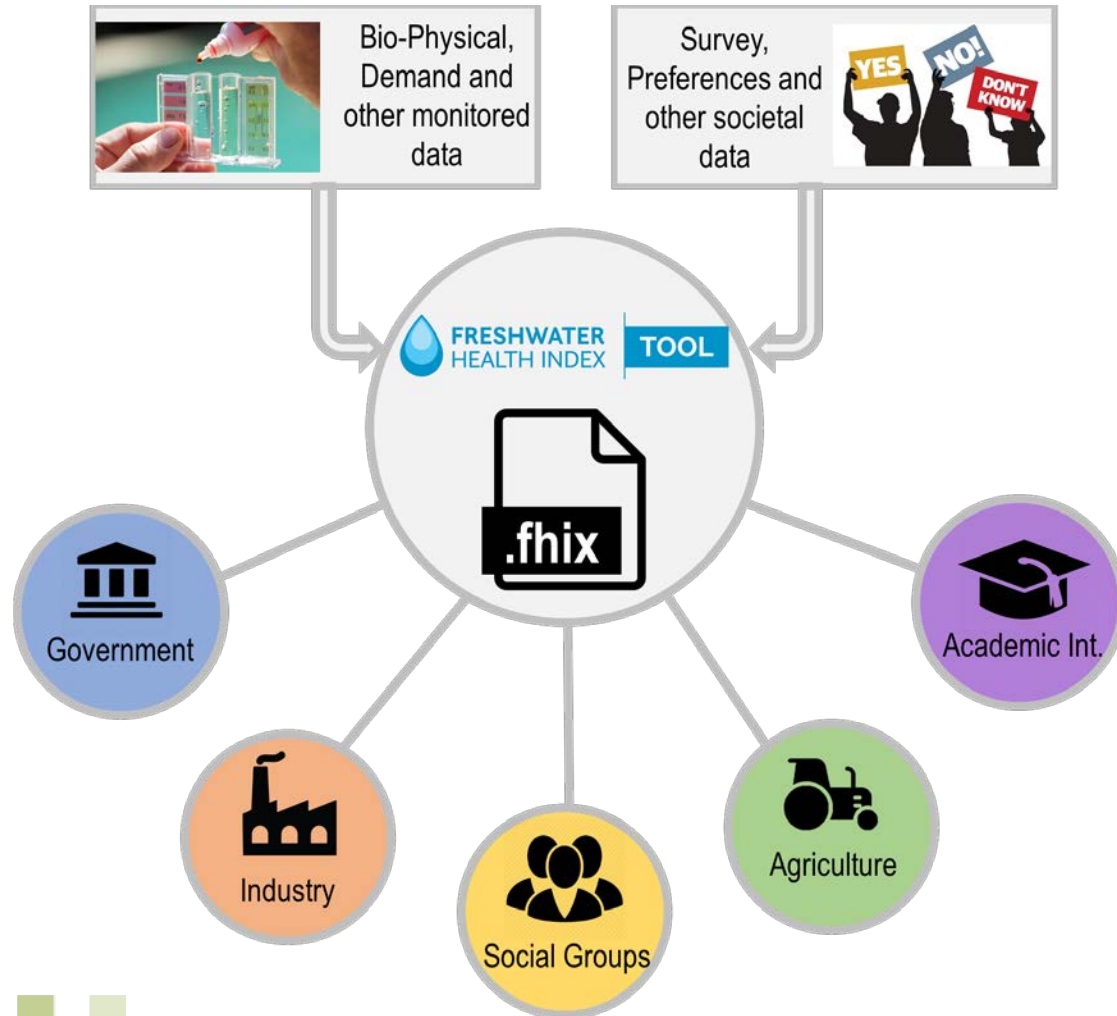


Alto Mayo, Peru



# FHI Desktop Tool

<http://freshwaterhealthindex.org/fhi-tool-download>

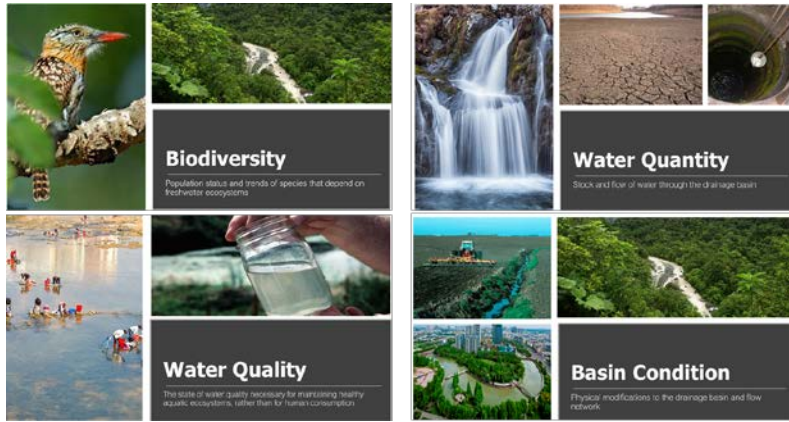


## Key ideas behind the tool

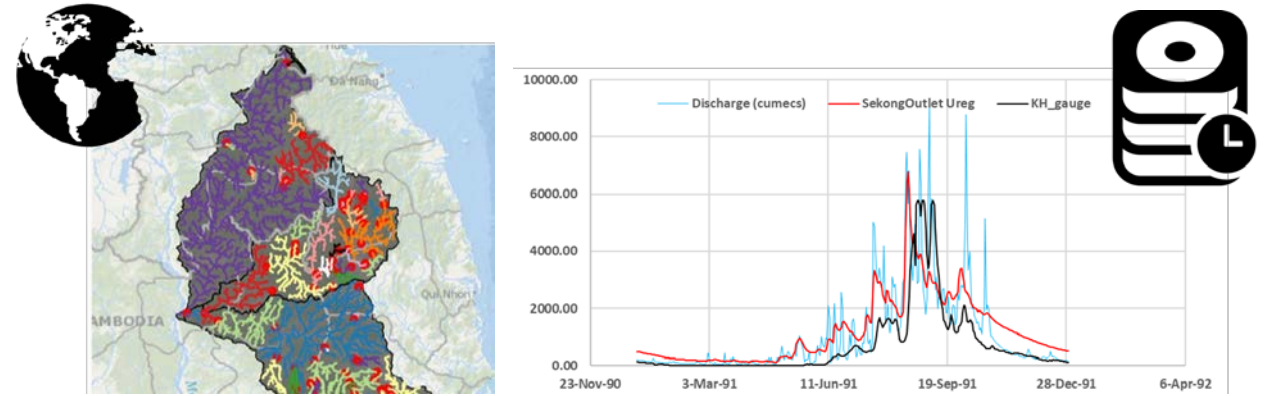
1. Ease of adoption
2. Common platform
3. Cumulative impact
4. Reusability of results

# Tool Features

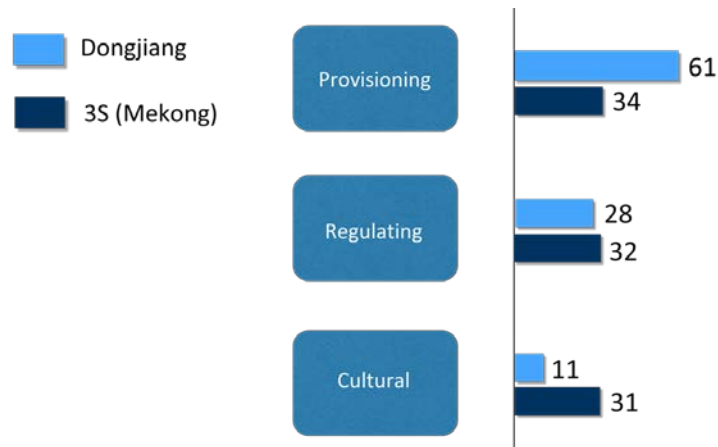
## 1. Classification of Data



## 2. Archiving Data



## 3. Integration of Information



## 4. Report Generation





# FHI Tool Demonstration

# Tool Tutorial

<https://www.freshwaterhealthindex.org/fhi-tool-tutorial>

The screenshot shows the Freshwater Health Index website. At the top, there is a navigation menu with links for HOME, METHODOLOGY, ASSESSMENTS, RESOURCES, TEAM, and CONTACT US. Below the navigation, there are tabs for GENERAL FEATURES, ECOSYSTEM VITALITY, ECOSYSTEM SERVICES, and GOVERNANCE & STAKEHOLDERS. The main content area is titled "GENERAL FEATURES" and contains two video thumbnails. The first video is titled "1.1 Introduction to the Freshwater Health Index (FHI) toolbox (2:00)" and the second is "1.2 How to apply weights to indicators (1:02)".

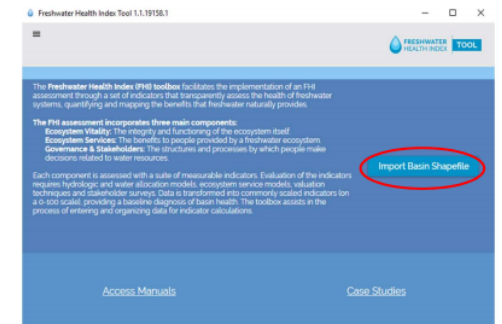
## 2. Introduction to Freshwater Health Index Toolbox

### 2.1 Download and install the FHI toolbox

1. Download the **open source FHI toolbox installer** for Windows from the webpage: <https://www.freshwaterhealthindex.org/fhi-tool>
2. Run the installation file (.msi) once downloaded.  
**Note: User will require admin rights on the system for successful installation.**

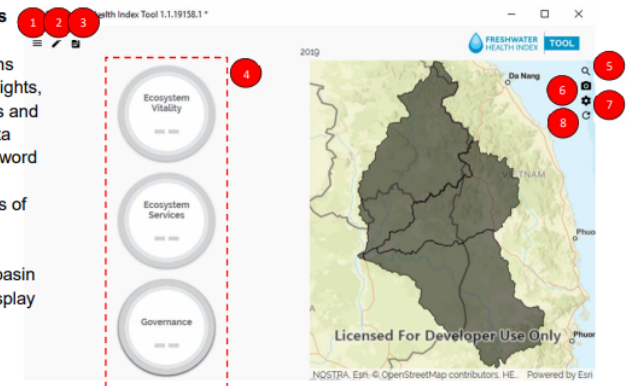
### 2.2 Uploading Basin Shapefile

1. To begin using the FHI tool, **import** your basin shapefile.  
(Note: Mock data can be found under O1\_Introduction folder as basin.shp)



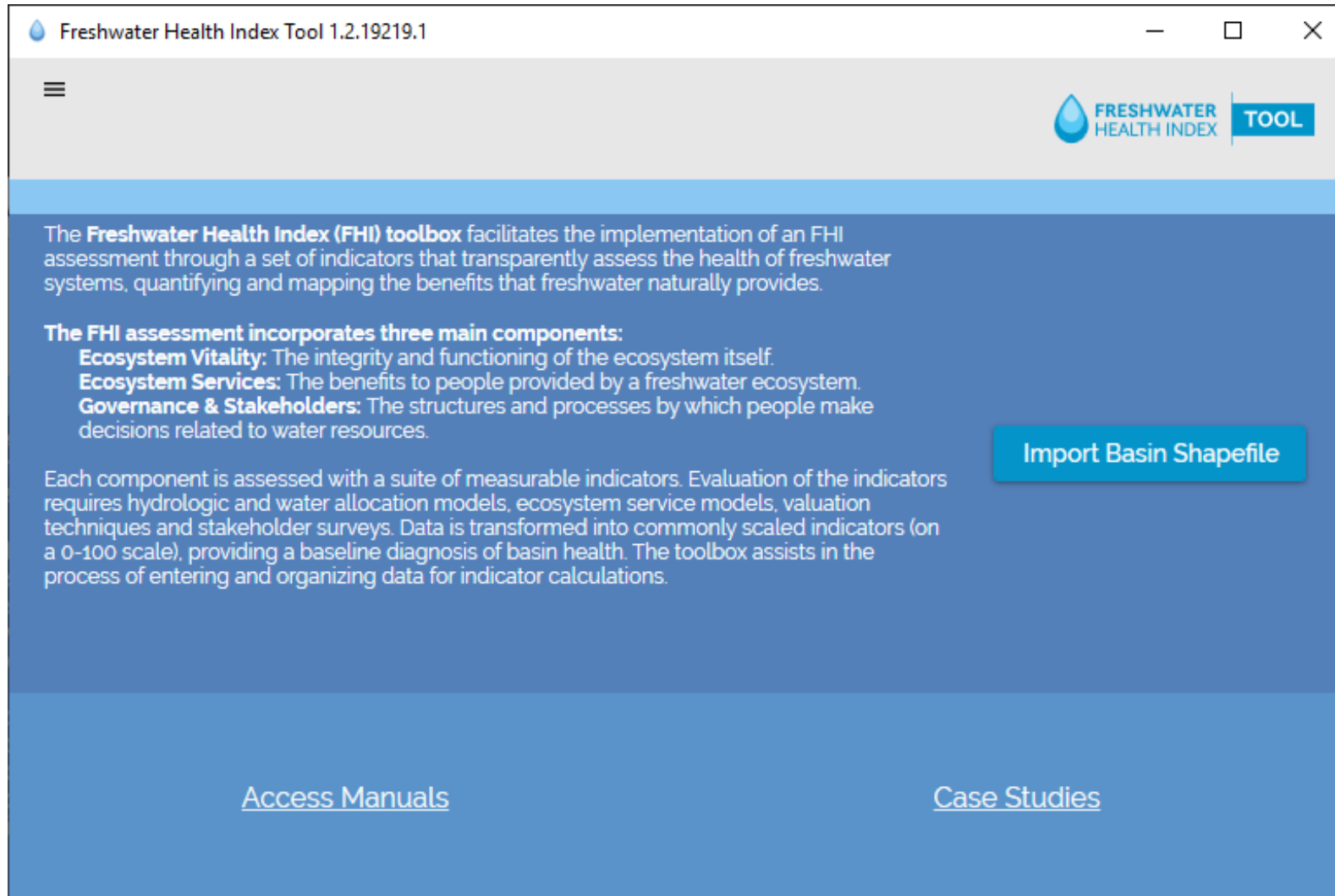
### 2.3 General Features

1. File menu options
2. Set indicator weights, import indicators and change metadata
3. Generate a MS word report
4. Summary scores of indicators
5. Zoom to basin
6. Export PNG of basin
7. Change map display settings
8. Refresh map





# [1] Start an Assessment



The screenshot shows a web browser window titled "Freshwater Health Index Tool 1.2.19219.1". The interface features a header with a hamburger menu icon on the left and the "FRESHWATER HEALTH INDEX TOOL" logo on the right. The main content area has a blue background and contains the following text:

The **Freshwater Health Index (FHI) toolbox** facilitates the implementation of an FHI assessment through a set of indicators that transparently assess the health of freshwater systems, quantifying and mapping the benefits that freshwater naturally provides.

**The FHI assessment incorporates three main components:**

- Ecosystem Vitality:** The integrity and functioning of the ecosystem itself.
- Ecosystem Services:** The benefits to people provided by a freshwater ecosystem.
- Governance & Stakeholders:** The structures and processes by which people make decisions related to water resources.

Each component is assessed with a suite of measurable indicators. Evaluation of the indicators requires hydrologic and water allocation models, ecosystem service models, valuation techniques and stakeholder surveys. Data is transformed into commonly scaled indicators (on a 0-100 scale), providing a baseline diagnosis of basin health. The toolbox assists in the process of entering and organizing data for indicator calculations.

At the bottom of the main content area, there are two links: [Access Manuals](#) and [Case Studies](#). A prominent blue button labeled "Import Basin Shapefile" is positioned to the right of the text.

# [1] Start an Assessment

Freshwater Health Index Tool 1.2.19219.1

FRESHWATER HEALTH INDEX TOOL

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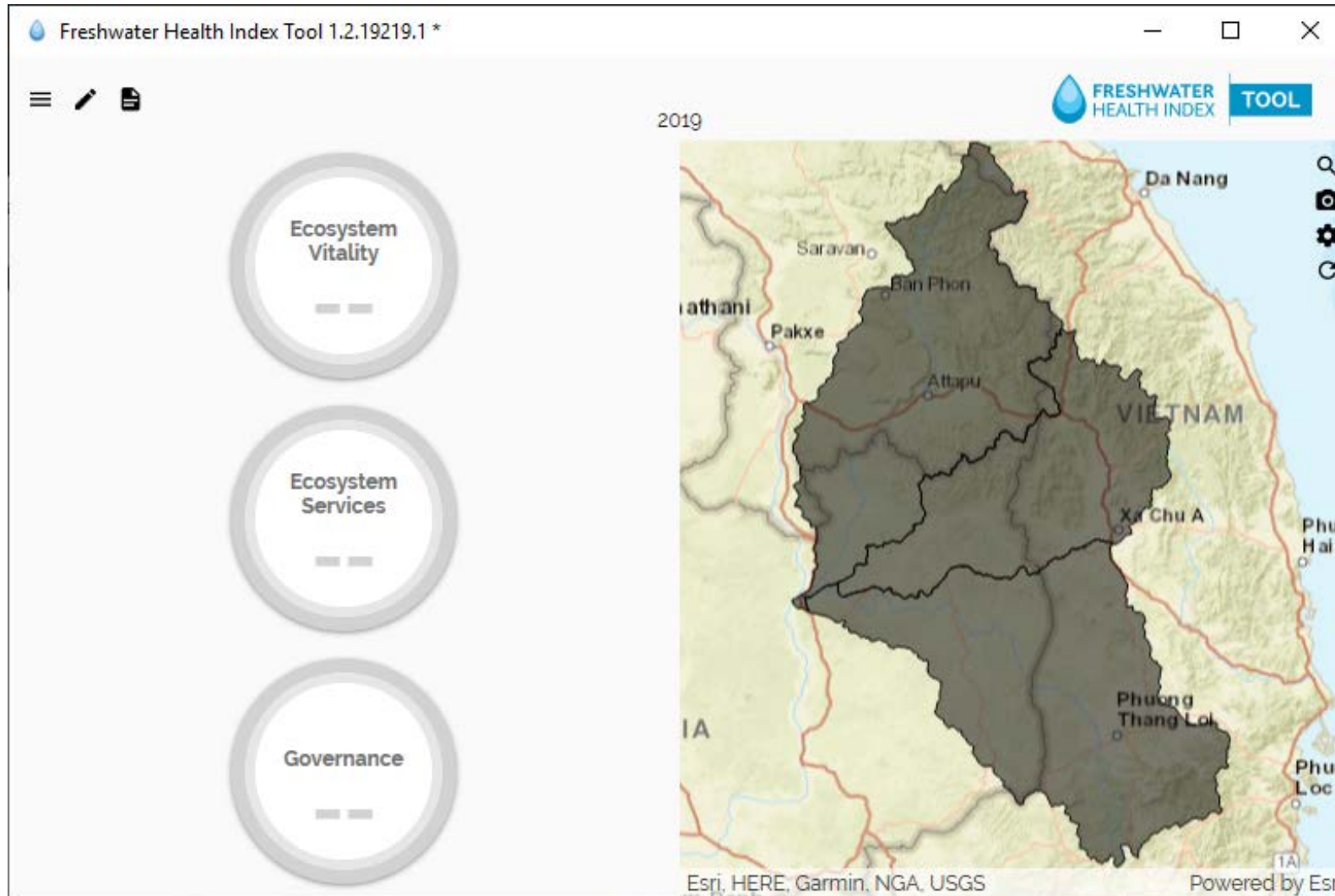
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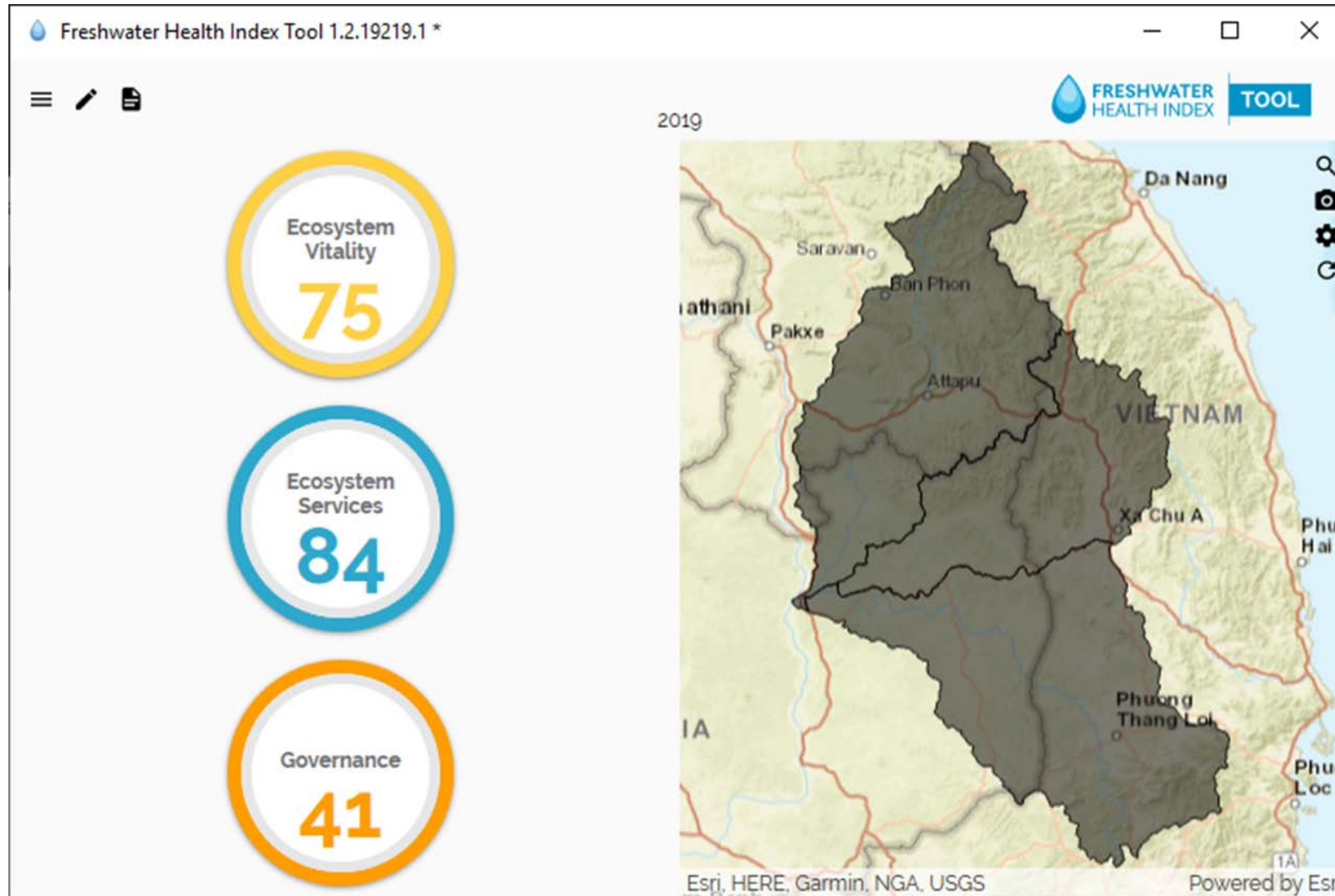
[Import Basin Shapefile](#)

[Access Manuals](#) [Case Studies](#)

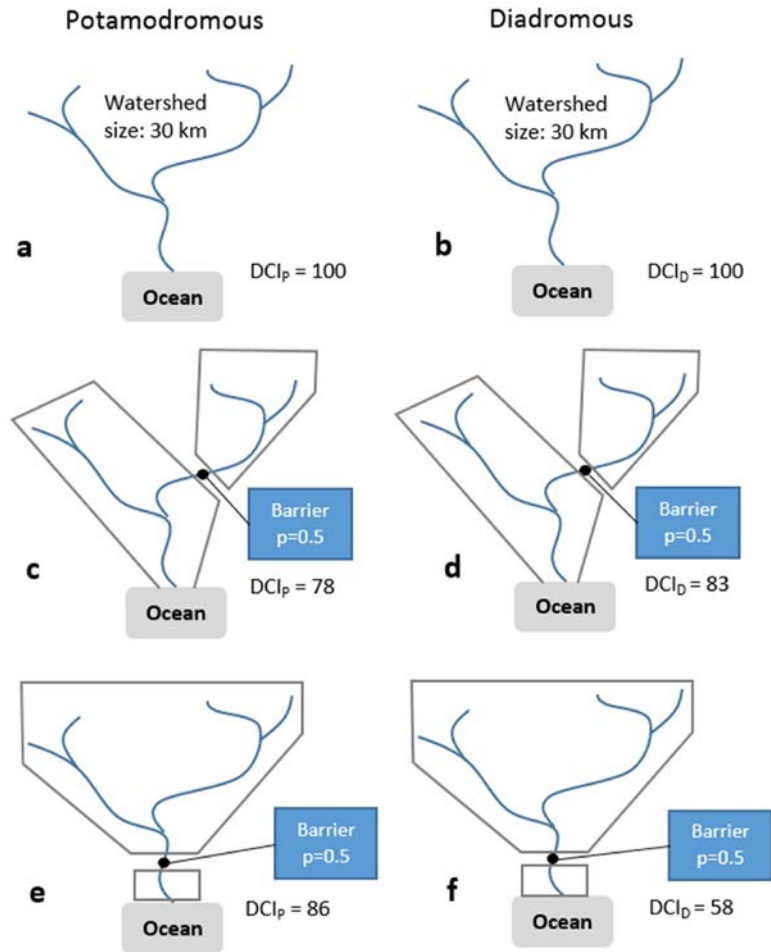
# [2] Start an Assessment



# [3] Populated Assessment



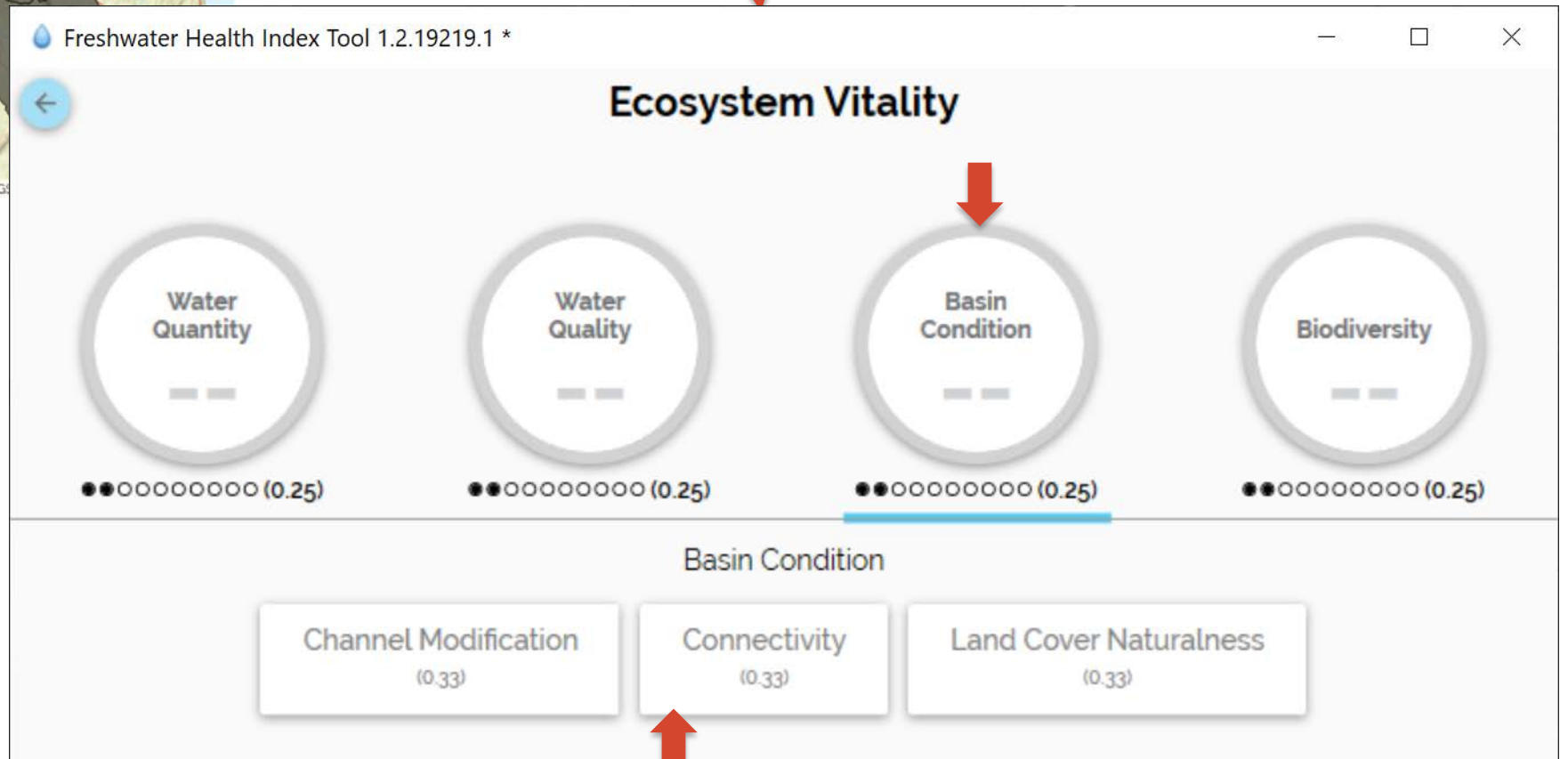
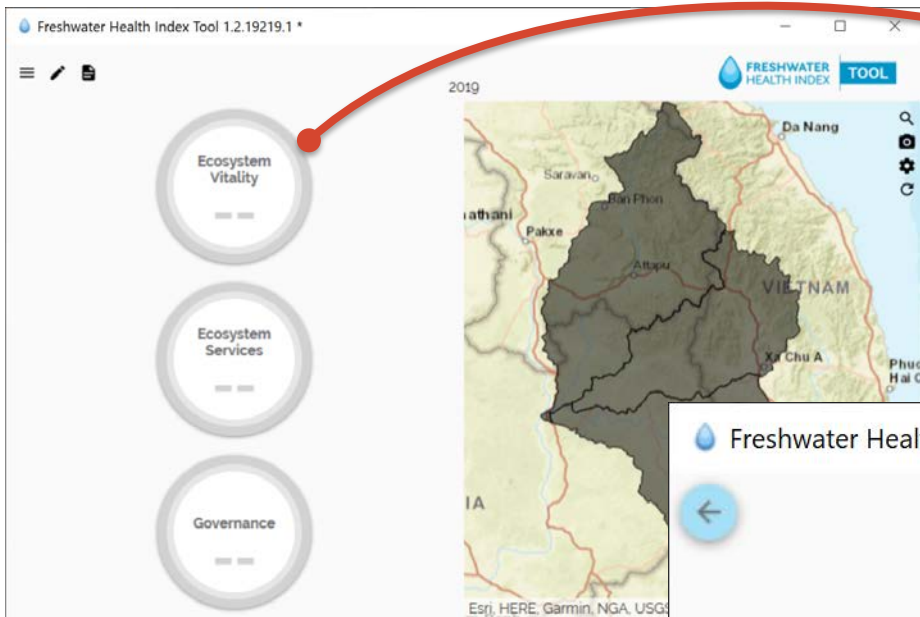
# Drainage Basin Condition: Connectivity



“Habitat connectivity is a central factor in shaping aquatic biological communities.”



**Reference:** Cote, David, Dan G. Kehler, Christina Bourne, and Yolanda F. Wiersma. 2009. “A New Measure of Longitudinal Connectivity for Stream Networks.” *Landscape Ecology* 24 (1): 101–13. Image Credit: © Copyright [Walter Baxter](http://www.geograph.org.uk/p/3191870) - geograph.org.uk/p/3191870



# [1] Import Vector River Network

Import Reaches

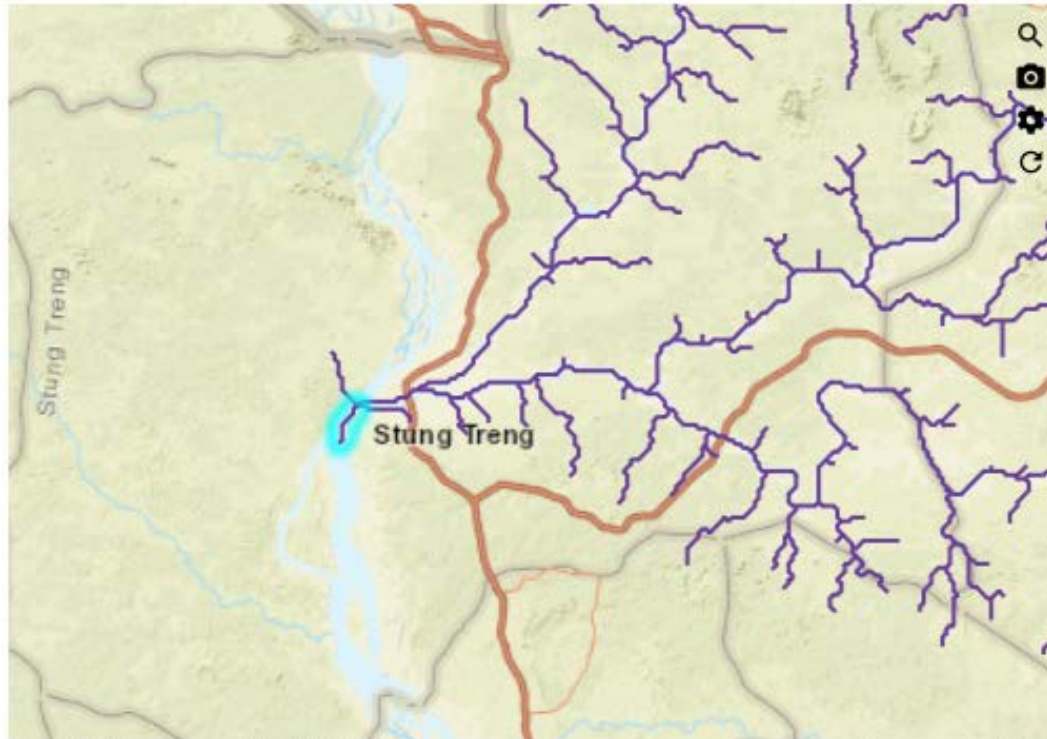
Step 3: When you're happy with your selection, click 'Outlet Selected'

Outlet Selected

Reaches Imported

You have imported 2115 reaches.

OK



Esri, HERE, Garmin, NGA, USGS

Powered by Esri

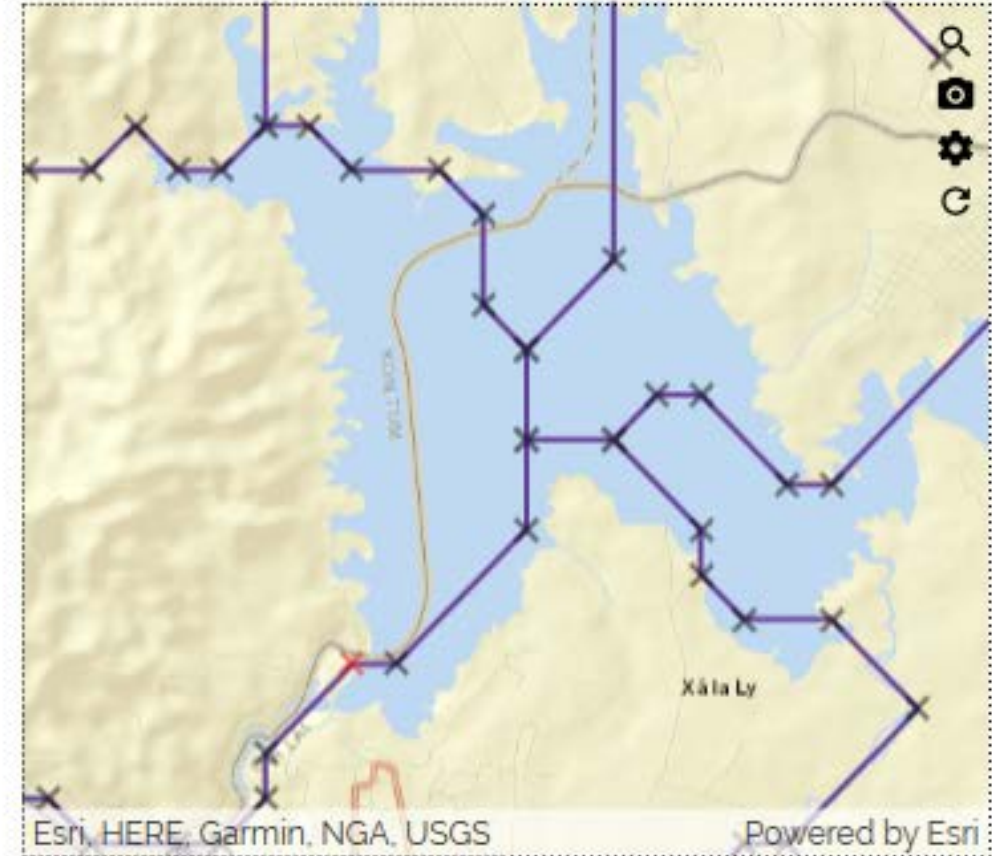
Cancel

Ok



## [2] Import Vector Barrier Location

You have imported your river network. The average length of a reach is 0.1m the maximum is 0.4 m and the minimum is 0.0m, with 2115 total reaches. There are 59 dams in this river network.



Cancel

Back

Done



# [3] Apply "Passability" for Structures

Freshwater Health Index Tool 1.2.19219.1 \*

Connectivity: 65

| Dam Name | Dam Passability |
|----------|-----------------|
| WLE34    | 0.5             |
| L012     | 0.5             |
| Log8     | 0.5             |
| WLE8     | 0.5             |
| WLE18    | 0.5             |
| WLE27    | 0.5             |
| WLE60    | 0.5             |
| WLE54    | 0.5             |

Potadromous value  
DCIp: 56 Weight (0.50)

Diadromous value  
DCId: 74 Weight (0.50)

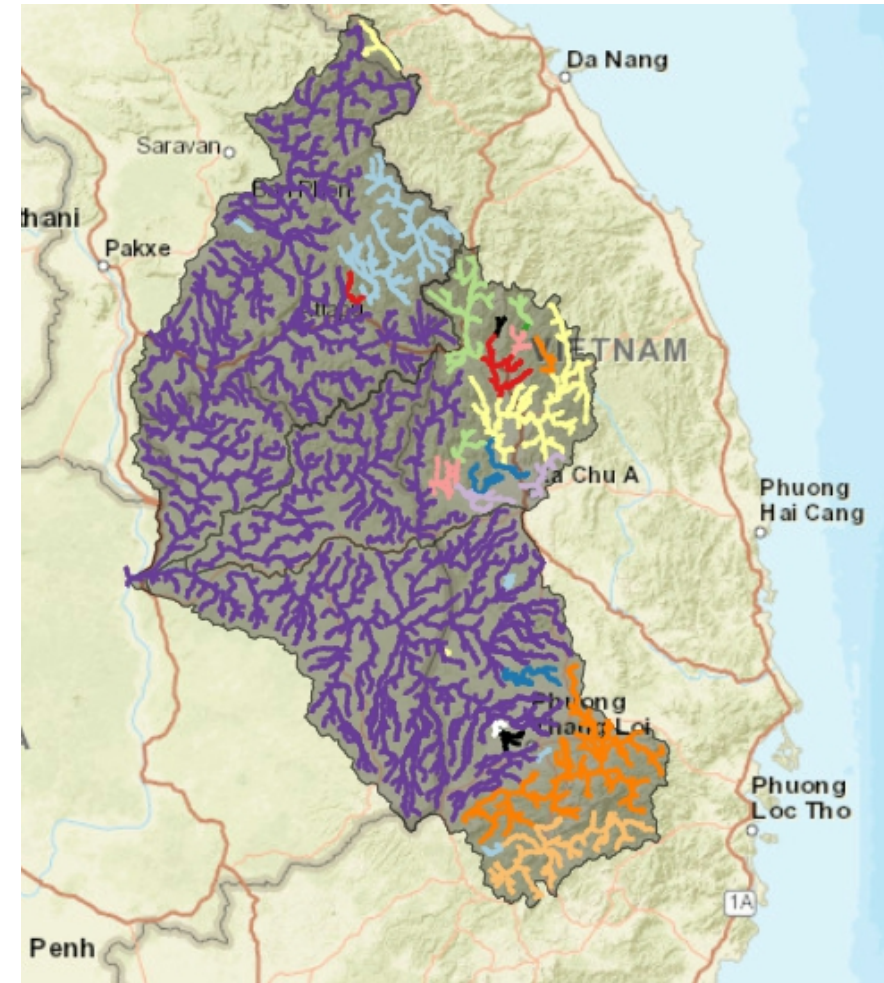
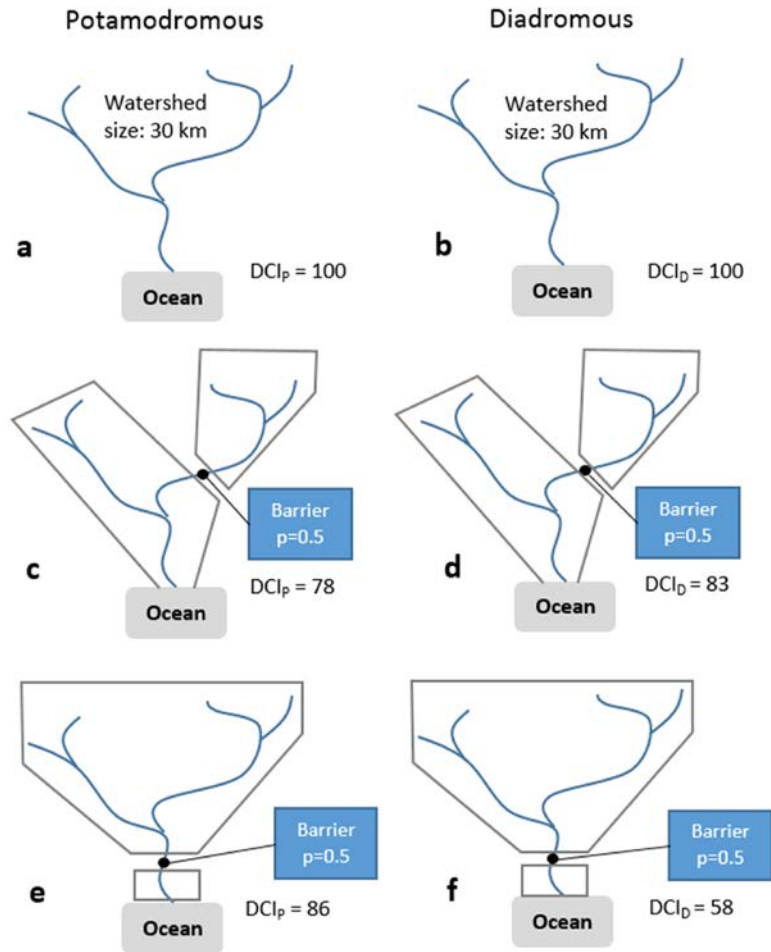
To set all the dam passabilities to the same value, enter the value below and click the button:

Set All Values: 0.5

Changes to dam passability values require a recalculate in order to be reflected in indicator values.

Recalculate

# Dendritic Connectivity Index

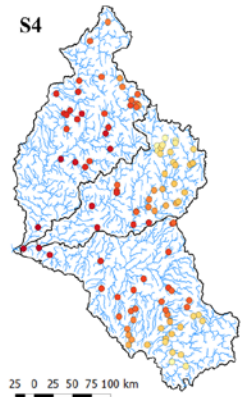
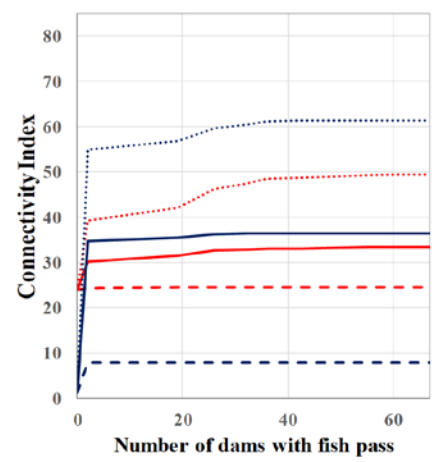
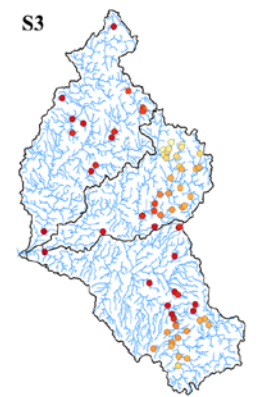
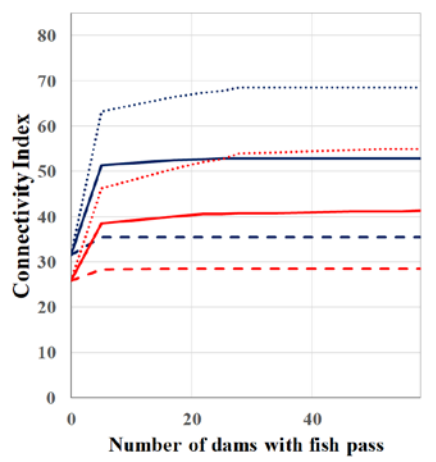
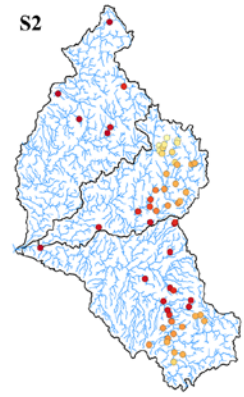


**Reference:** Cote, David, Dan G. Kehler, Christina Bourne, and Yolanda F. Wiersma. 2009. "A New Measure of Longitudinal Connectivity for Stream Networks." *Landscape Ecology* 24 (1): 101–13.

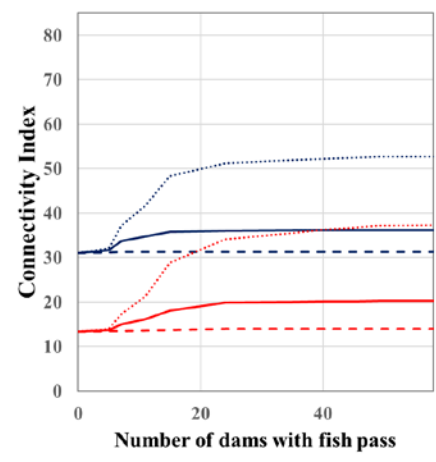
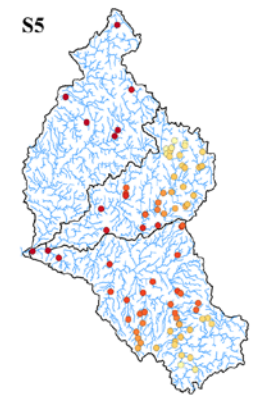
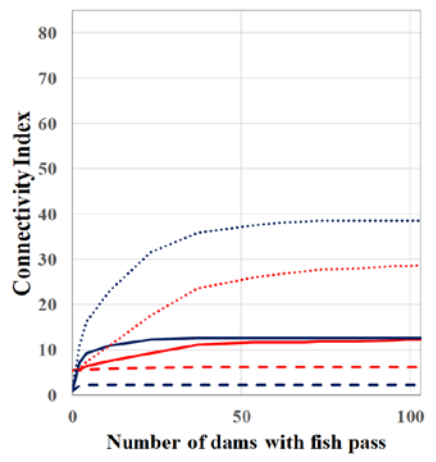
# Indicators & Scenarios

**Dam cascade position**  
 Low High

--- p = 0.1    — p = 0.5    ..... p = 0.8  
 ■ DCId    ■ DCIp

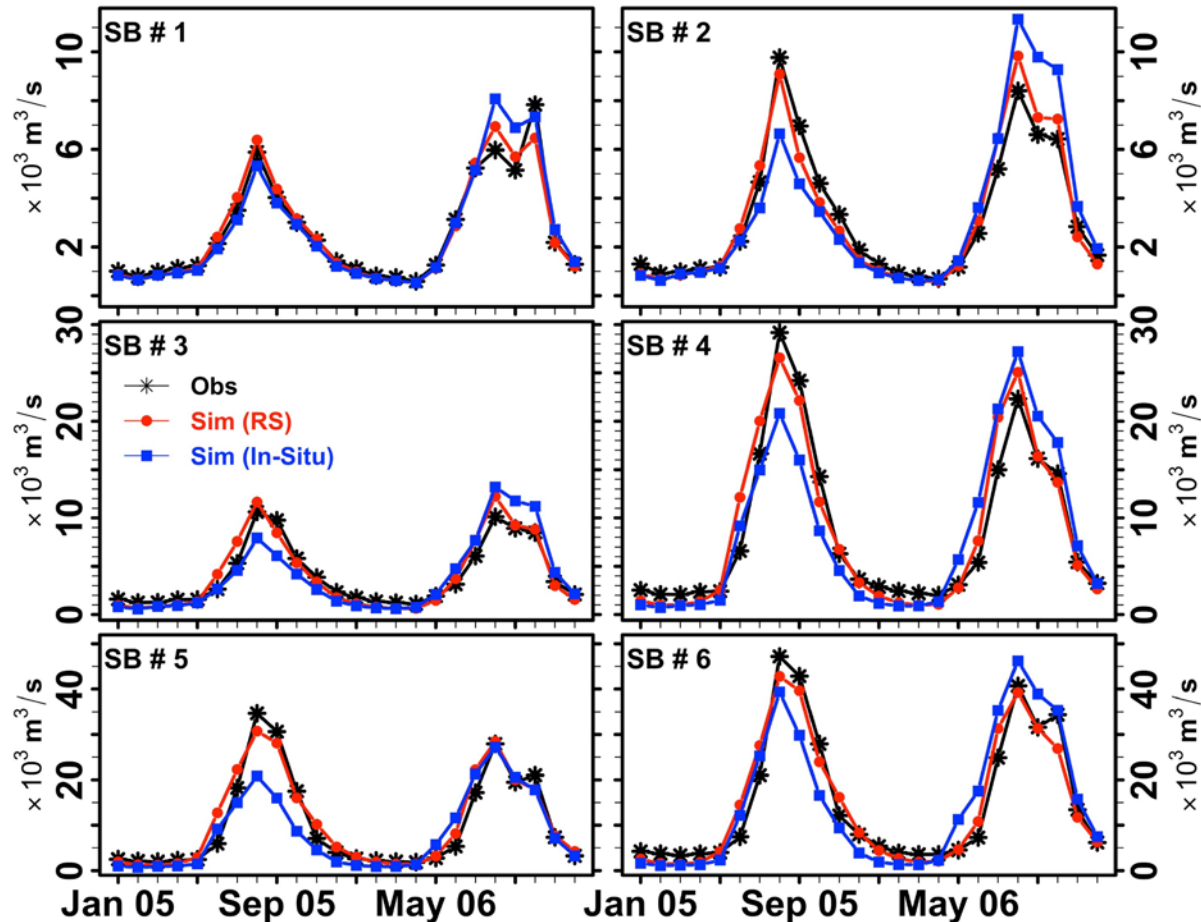


25 0 25 50 75 100 km



**Reference:** Shaad et al (2018). "Evaluating the sensitivity of dendritic connectivity to fish pass efficiency for the Sesan, Srepok and Sekong tributaries of the Lower Mekong." *Ecological Indicators* 91: 570-574.

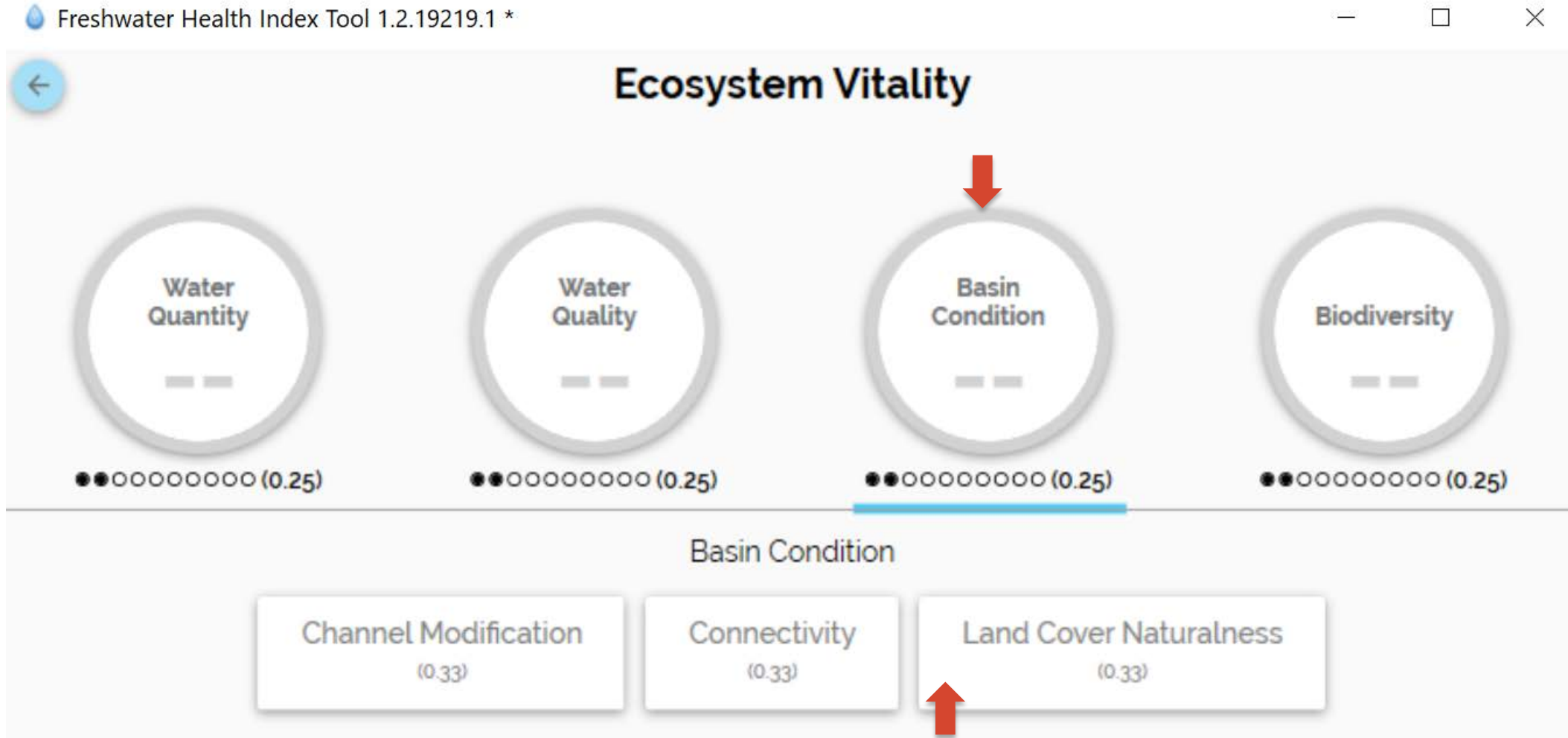
# Hydrological Modelling Using Satellite-Based Earth Observations



- NASA has worked to calibrate and validate a hydrological model leveraging the proper utilization of available in situ and satellite-based Earth observations.
- These models attempt to compensate for insufficient coverage by local gauge data

Reference: Mohammed, I.N. et al (2018). Improved Hydrological Decision Support System for the Lower Mekong River Basin Using Satellite-Based Earth Observations. Remote Sensing, 10 (6), 885

# Drainage Basin Condition: Land Cover Naturalness



Reference: Machado, A. 2004. An index of naturalness. Journal for nature conservation, 12(2):95-110.

# [1] Map Landcover Raster to “Degree of Naturalness”

Land Cover Settings

Note: Changes to settings will require importing the GeoTIFF file again.

| Degree of naturalness    | Vegetation characteristics            | Examples   | Weight | GeoTIFF Pixel Values   |
|--------------------------|---------------------------------------|--|--------|--|
| Natural and semi-natural | Native                                | Forest (primary and secondary); lakes (natural) and wetlands; native grasslands; native shrublands | 100    | 50, 60, 61, 62, 70, 71, 72, 80, 81, 82, 90, 100, 110, 120, 121, 122, 130, 140, 150, 151, 152, 153, 160, 170, 180 |
| Cultural assisted system | Mixed, high diversity                 | Mosaic native vegetation (>50% vegetation cover <50%)  | 70     | 40   |
| Cultural assisted system | Mixed, moderate diversity             | Mosaic cropland (>50% natural vegetation <50%)   | 60     | 30   |
| Transformed system       | Permanent cover with atypical species | Permanent pasture land; agroforestry; tree crops   | 50     |  |
| Transformed system       | Seasonal cover with atypical species  | Non-irrigated arable land  | 40     | 10, 11, 12   |

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# [1] Map Landcover Raster to "Degree of Naturalness"

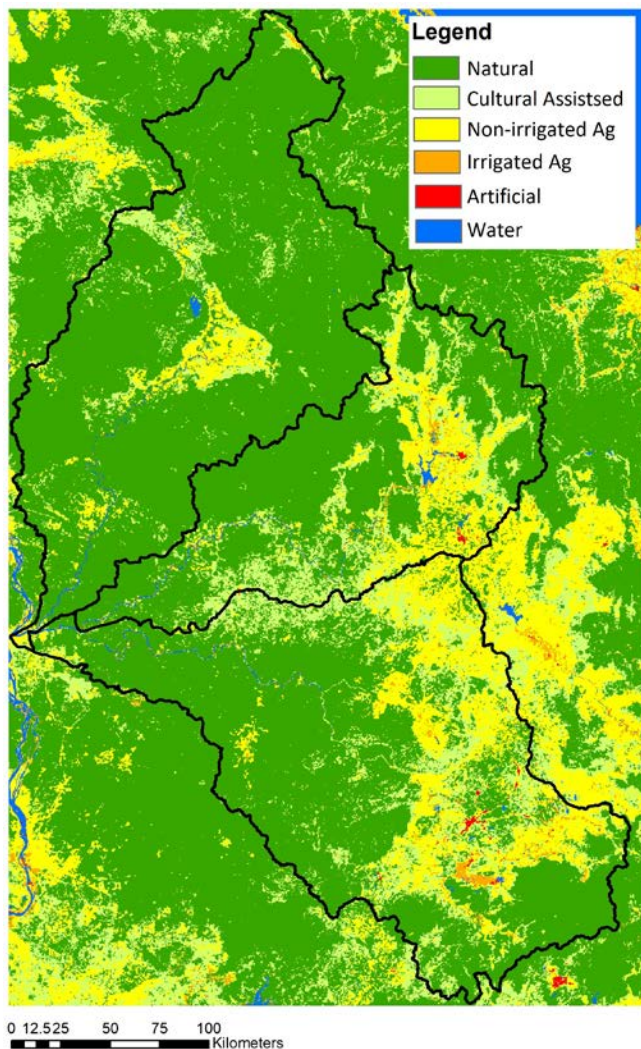
Land Cover Settings

Note: Changes to settings will require importing the GeoTIFF file again.

| Degree of naturalness    | Vegetation characteristics            | Examples   | Weight | GeoTIFF Pixel Values   |
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| Natural and semi-natural | Native                                | Forest (primary and secondary); lakes (natural) and wetlands; native grasslands; native shrublands | 100    | 50, 60, 61, 62, 70, 71, 72, 80, 81, 82, 90, 100, 110, 120, 121, 122, 130, 140, 150, 151, 152, 153, 160, 170, 180 |
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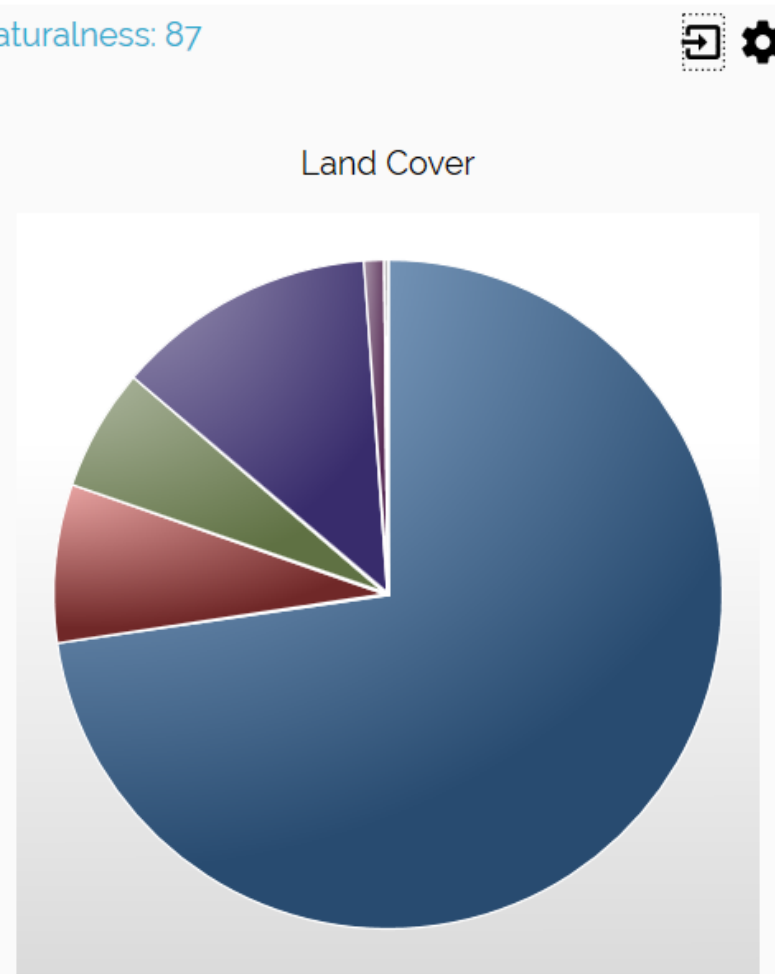
# [2] Import Raster



Freshwater Health Index Tool 1.2.19219.1 \*

Land Cover Naturalness: 87

| Degree of naturalness / Vegetation                        | % Coverage |
|---|------------|
| Natural and semi-natural: Native                          | 72.7       |
| Cultural assisted system: Mixed, high diversity           | 7.6        |
| Cultural assisted system: Mixed, moderate diversity       | 5.9        |
| Transformed system: Permanent cover with atypical species | 0.0        |
| Transformed system: Seasonal cover with atypical species  | 12.7       |
| Transformed system: Seasonal cover with atypical species  | 1.0        |
| Completely artificial: Sparse cover with grass            | 0.0        |
| Completely artificial: None                               | 0.2        |



# Biodiversity: Species of Concern

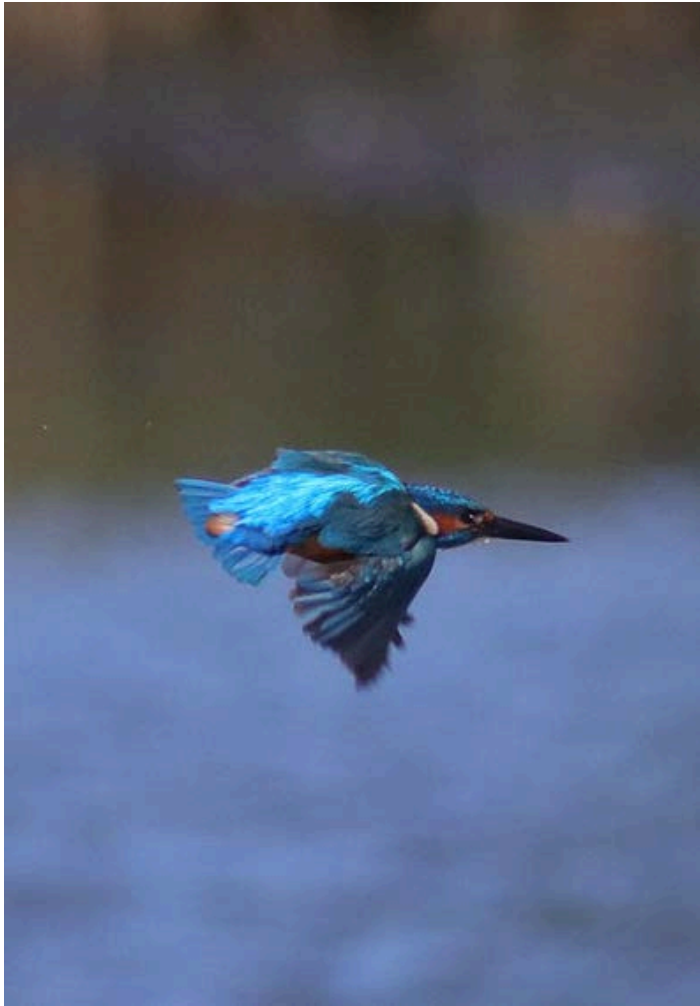


Image Credit: [Kingfisher](#) by Mark Kilner (Flicker)

- Threatened aquatic or riparian (water-dependent) species and other species of interest (such as keystone or umbrella species) that will be affected by changes in habitat condition.
- Assess species presence/absence and population trends.

## 3 STEP PROCESS

1. Assess **proportion of threatened and endangered freshwater species**, of the total freshwater species assessed in the basin

2. Assess **change in the number of species of concern**

3. Assess **change in population trends**

# Ecosystem Services

## Provisioning Services



Reliability of water supply



Biomass for consumption

Direct tangible benefits from water-related Ecosystems

## Regulating Services



Flood Regulation



Deviation of water quality metrics



Sediment Regulation



Exposure to water-associated diseases

Indirect benefits and support from water-related Ecosystems

# Ecosystem Services

## Demand & Supply

How much of the region has a gap between demand-supply?

How often are the demands not met?

How large is the gap between demand and supply?

## Data Requirement

Area Affected: Just a village or the whole province?

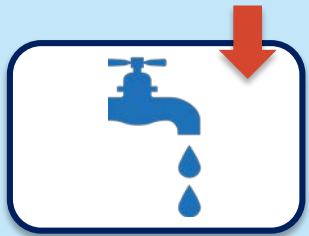
Duration Affected: Sometimes or all the time?

Extent of Gap: by a little or by a large amount?

# Ecosystem Services

Initial estimates or diagnostic values can be derived using RS data of floods, droughts, water quality, etc.

## Provisioning Services



Reliability of water supply



Biomass for consumption

Direct tangible benefits from water-related Ecosystems

## Regulating Services



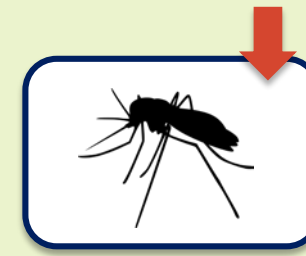
Flood Regulation



Deviation of water quality metrics



Sediment Regulation



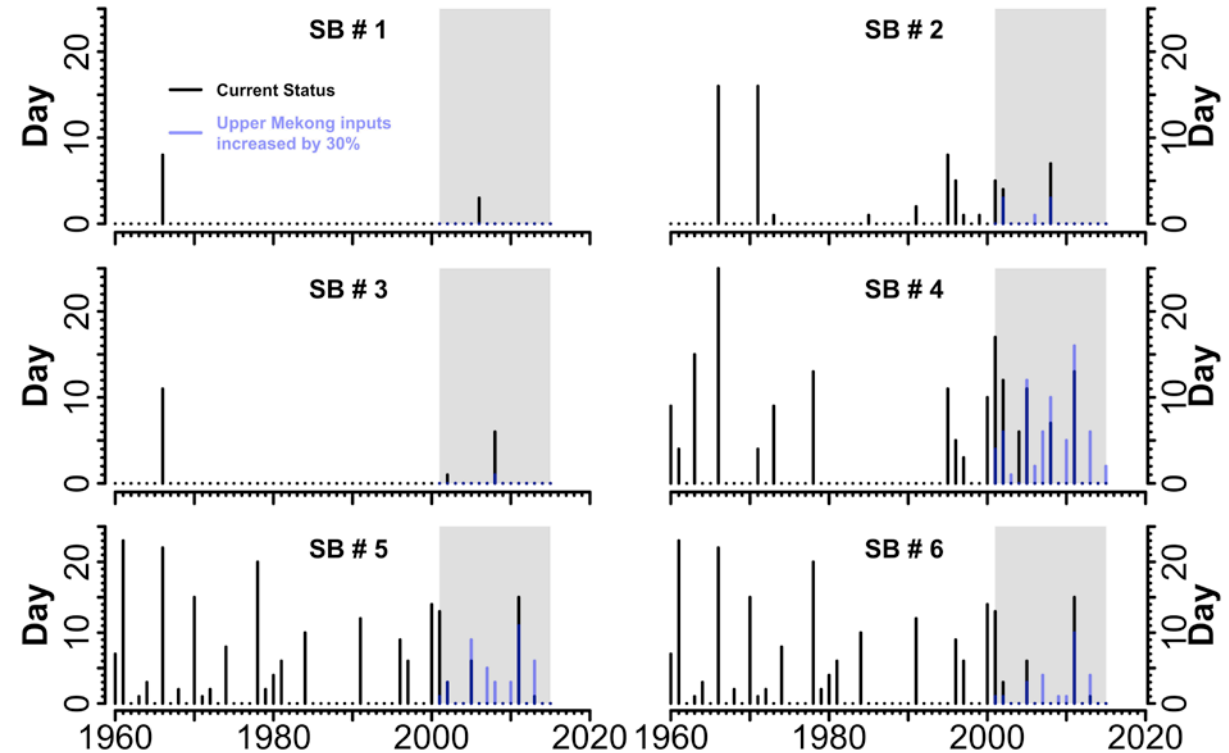
Exposure to water-associated diseases

Indirect benefits and support from water-related Ecosystems

# High Flow Disturbance Analysis for the Lower Mekong River Basin

## Flood Duration Analyses:

- The flood duration (in days) are the number of days when discharge equals or exceeds a threshold discharge magnitude causing floods.
- Black bars give flood duration in days for the 1960–2015 time period using observed discharges.
- Blue bars give flood duration calculated from simulated discharges with the Upper Mekong inflow increased by 30%



Reference: Mohammed, I.N. et al (2018). Satellite observations and modeling to understand the Lower Mekong River Basin streamflow variability. *J. Hydrol.* 564, 559-573

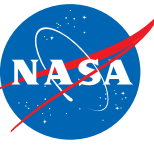
# Summary

- Thinking of freshwater as a social-ecological system helps define water management goals beyond a narrow range of water requirement objectives and consider the inherent long and short terms trade-offs within a basin.
- The Freshwater Health Index draws on a wide range of products available via remote sensing, GIS and numerical models. These, in combination with local knowledge and data, help communicate the state of the freshwater system to stakeholders via simplified metrics.
- The FHI desktop tool is a recent effort to provide a platform to calculate and collate basin-level social-ecological indicators for freshwater.

# Contacts

- ARSET Land Management & Wildfire Contacts
  - Amber McCullum: [AmberJean.Mccullum@nasa.gov](mailto:AmberJean.Mccullum@nasa.gov)
  - Juan Torres-Perez: [juan.l.torresperez@nasa.gov](mailto:juan.l.torresperez@nasa.gov)
- General ARSET Inquiries
  - Ana Prados: [aprados@umbc.edu](mailto:aprados@umbc.edu)
- ARSET Website:
  - <http://arset.gsfc.nasa.gov>





# Homework Due: Tuesday October 15<sup>th</sup>

Amber McCullum & Juan Torres-Pérez

1 October, 2019



Thank You!

