Water-Energy-Food Nexus Assessment in the Lower Mekong Basin

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The Mekong Region

- Population: 186.5 M
- Area: 1,262,165 sq km
- Highest point: Mt Fansipan, Vietnam (3144 m)
- Biggest cities: Bangkok (9.3 Million); Ho Chi Minh City (7.4 Million)

Population/sq km:

- USA: 35
- CHINA: 140
- MEKONG: 140

Source: Basic Geographic Locations
The Mekong River

- 12th largest in world & 7th largest in Asia
- 6 nations in southeast Asia
- Drainage area: ~765,000 sq.km.
- Annual mean flow: ~15,000 cu.km./yr
- Length: **UMRB:** ~2200 km. + **LMRB:** ~2600 km.
- Dams: Total 456 nos.

LCLUC has the potential to alter irrigation water demands which will have a direct impact on the water and energy fluxes.

Climate change is modifying the hydrologic responses of the basin.
Required Understanding on:

Basin hydrology using macroscale hydrological models

Changing precipitation, temperature and land-use patterns in LMB.

Baseline sub-basin scale water budget and storage using in-situ, remote sensing and modeling outputs
The Mekong: Physiography

IGBP Land Cover Type classification
Year: 1992

Legend
- Watershed
- Water
- Bare soil
- Evergreen Needleleaf
- Evergreen Broadleaf
- Deciduous Needleleaf
- Deciduous Broadleaf
- Mixed Cover
- Closed Shrublands
- Open Shrublands
- Grasslands
- Cropland

DEM

Legend
- DEM Value
  - High: 8900
  - Low: -45

Watersheds
Land cover and Land use change

Vegetation: Landsat 8
Met data: Multiple
Fluxes: MODIS 16, GRACE, AMSR-E
Hydrology: Variable Infiltration Capacity (VIC) Model

- Semi-distributed physically based hydrological model.
- Solves water and energy balance for each grid-cell.
- Grid based land surface representation and each grid is independently simulated.
- Water enters only from atmosphere (precipitation).
- Multiple soil layer depths. (Generally 3 layers).
- Daily or sub-daily time steps.
- Sub-grid vegetation/land cover representation.
- Sub-grid elevation variability (snow band) representation.
- Developed by UW and Princeton Univ but has gone through substantial changes since its original implementation.

\[ P - ET - R - \Delta S = 0 \]
\[ R_{net} - LH - SH + GH + \Delta Q / \Delta t = 0 \]
Calibration/Validation

Streamflow (cumec)

Chaeng Saen

Observed
Simulated

NSE=0.90
r=0.96

Mukdhan

Observed
Simulated

NSE=0.90
r=0.97

Luang Prabhang

Observed
Simulated

NSE=0.84
r=0.96

Pakse

Observed
Simulated

NSE=0.89
r=0.96

Vietianne

Observed
Simulated

NSE=0.87
r=0.96

Kratie

Observed
Simulated

NSE=0.89
r=0.95

Nakhon Phanom

Observed
Simulated

NSE=0.91
r=0.96
Change in total runoff

- Total Runoff 1992
- Total Runoff 2015
Seasonal change in the precipitation and temperature

- Highest precipitation occurs in the months, June to September.
- Lowest precipitation occurs during November to March.
- Increases in precipitation for future period is plausible.
- Increases in temperature is higher during the period April-September.
- Increases in temperature is higher for RCP8.5 as compared to RCP4.5.
Water Budget Estimation

Change in the Water Budget Components between 1992 and 2015

- Precipitation
- Evapotranspiration
- Runoff
- Irrigation

Change in streamflow

- RCP4.5
- RCP8.5
The Landsat 8 mission objective is to provide timely, high quality visible and infrared images of all landmass and near-coastal areas on the Earth, continually refreshing an existing Landsat database.
Sentinel-2 is an Earth observation mission developed by ESA as part of the Copernicus Programme to perform terrestrial observations in support of services such as forest monitoring, land cover changes detection, and natural disaster management.
Envisat ("Environmental Satellite") is a large inactive Earth-observing satellite which is still in orbit. Operated by the European Space Agency (ESA), it was the world's largest civilian Earth observation satellite.
Jason-3 is the fourth mission in U.S.-European series of satellite missions that measure the height of the ocean surface. Launched on January 17, 2016, the mission will extend the time series of ocean surface topography begun by the TOPEX/Poseidon satellite mission in 1992 and continuing through the Jason-1 (launched in 2001) and the currently operating OSTM/Jason-2 (launched in 2008) missions.
Lam Pao
Surface Area and Water Level variation of Lam Pao

Lam Pao Surface Area variation from 2013 to 2018

Lam Pao Water level variation from 2013 to 2018
Streamflow simulation for Mekong river basin (SWAT)

- Forcing: 1948 to 2016 from Sheffield's data
- 0.25 X 0.25 degree resolution
- 6 existing dams
### Sub-watershed and dams (Six dam application)

- **2141 Sub-watersheds**
- **1147 climate grids (0.25 X 0.25 degree)**
- **1948-2016 forcing (Sheffield’s)**

#### Reservoir Details

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<th>Name</th>
<th>Country</th>
<th>sub</th>
<th>RES_ESA</th>
<th>RES_EVO</th>
<th>RES_PSA</th>
<th>RES_PVOL</th>
<th>RES_VOL</th>
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**RES_ESA**: Reservoir surface area when the reservoir is filled to the emergency spillway [ha]

**RES_EVOL**: Volume of water needed to fill the reservoir to the emergency spillway \( (10^4 \text{ m}^3) \)

**RES_PSA**: Reservoir surface area when the reservoir is filled to the principal spillway [ha]

**RES_PVOL**: Volume of water needed to fill the reservoir to the principal spillway \( (10^4 \text{ m}^3) \)

**RES_VOL**: Initial reservoir volume \( (10^4 \text{ m}^3) \)
After dam construction....(1992) 17.2% decrease
Dam and streamflow

After dam construction... (1971)

5.6% decrease
After dam construction... (1968)

6.5% decrease
A drought is characterized by severity, duration, and intensity.

Drought occur with deficit rainfall and increased temperature and identified by climatological drought indices.

Climate change is expected to intensify drought.
Drought incidents:
- Vietnam – 1997-98
- Cambodia – 2002

15 GCMs data from NEX-GDDP: Future –
- 2016-2057 RCP 4.5
- 2058-2099 RCP 4.5
- 2016-2057 RCP 8.5
- 2058-2099 RCP 8.5
Methods

- Characteristics of droughts
  - SPI-3 months with truncation level for drought as -1.
  - Long-term record of monthly precipitation was fitted to a gamma distribution, which was then transformed to a normal distribution.

- Univariate and multivariate analysis
  - Return period is the average interval between occurrence of an event with a particular magnitude or greater.
  - Univariate return period:
    \[ T = \frac{E(L)}{1-F(s)} \]
  - Trivariate joint occurrence probability:
    \[ P(S \geq s \text{ or } D \geq d \text{ or } PK \geq pk) = 1 - F(s) - F(d) - F(pk) + C[F(s), F(d)] + C[F(s), F(pk)] + C[F(d), F(pk)] - C[F(s), F(d), F(pk)] \]
The identified threshold were 3.13 for severity, 4 months for duration and 1.47 for the peak (95th percentile).

14 of the 15 GCMs indicated increased probabilities of drought in the Mekong Delta.

Increased probability of drought in the most part of the Upper LMB estimated by at least 11 of the 15 GCMs.

6 of 15 GCMs projected a reduction in drought magnitudes in Chi-Mun in all future scenarios.

MIROC-ESM-CHEM (RCP4.5) – Precipitation

1966-2005: historic (40 years)
2020-2059: future1 (40 years)
2060-2099: future2 (40 years)

Historic annual Precipitation (mm)

Future1 (40 years)

Future2 (40 years)

Change in Precipitation (f1)

Change in Precipitation (f2)

Legend:
- Change in Precipitation
  -5.0
  -4.9 -3.0
  -2.9 -1.0
  -0.9 -0.0
  0.1 -1.0
  1.1 -3.0
  3.1 -5.0
  5.1 -

1966-2005: historic (40 years)
Decrease in precipitation led to increases in drought occurrences, but temperature should be considered for the MSDI estimations. MSDI is based on the joint probability of precipitation and temperature.

Drought occurrences based on the MSDI estimations - MIROC-ESM-CHEM (RCP4.5)

1966-2005: historic (40 years)
2020-2059: future1 (40 years)
2060-2099: future2 (40 years)

Decrease in precipitation led to increases in drought occurrences, but temperature should be considered for the MSDI estimations. MSDI is based on the joint probability of precipitation and temperature.
Snake River Basin, Idaho, USA

Basin irrigated area = 13,468 km$^2$
Groundwater-Surface water Exchanges (MODFLOW-VIC)
Groundwater Level

The Snake River Planning Modeling is developed

1. Parallel structure
   - Natural flow river (theoretical)
   - Regulated flow river (actual)

2. Response Functions
   - Groundwater entities (GWSIM)
   - Surface Entities (SD-SRPM)

3. Flood control operations
   - Flood control curves (MODSIM)

Hoekema and Sridhar, 2013 (J. American Water Resources Association); Hoekema and Sridhar, 2011 (Water Resources Research)
Improved Drought Prediction Using Ne: Climate Forecasts and Simulated Hydrologic Conditions

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Abstract: Short-term drought forecasting is helpful for establishing drought management plans that are better suited to different water resource systems. Additional rainfall forecast data is used to simulate the energy balance, including runoff, baseflow, and soil moisture, which are used in this study. The Soil and Water Assessment Tool (SWAT) and Variable I models are used for short-term drought forecasting in the contiguous and non-contiguous regions. As many areas in this region are frequently affected by varying drought impacts, these meteorological inputs are provided by the Climate Prediction Center (C period January 2012 to July 2017) and Climate Forecasting System vi forecasting period (August 2017 to April 2018), and these inputs are used in groundwater drought conditions. For drought assessment, two drought indices are calculated.
Hydrology and water resources in the Mekong basin needs a careful review on a regular basis.

Obtaining reliable precipitation for drought and floods in the future is critical for water supply and demand management.

Monitoring, modeling (physically-based and stochastic) is required.

Taking examples of managed basins can be helpful to minimize the unintended consequences.
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