Geospatial Analysis of Lake Tonle Sap Health

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GEOG 570

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I. Abstract:

This paper puts forth a remote sensing and geospatial analysis methodology for detecting the hydrological health of Lake Tonle Sap in Cambodia. Lake Tonle Sap is arguably the most important water feature in the whole Lower Mekong River Basin. Its' biodiversity acts as a super-rich food source bioreactor which millions of Cambodians depend on for sustenance. Every year during the rainy season, the Mekong River floods backwards into Lake Tonle Sap. Unfortunately, the Lower Mekong River Basin is adversely impacted by anthropogenic damming and climate change. The damming disrupts the normative flow of water throughout the Lower Mekong River Basin while climate change reduces the needed precipitation and exacerbates the anthropogenic effects. They especially affect the annual backward flow of water up the river into Lake Tonle Sap during the rainy season.

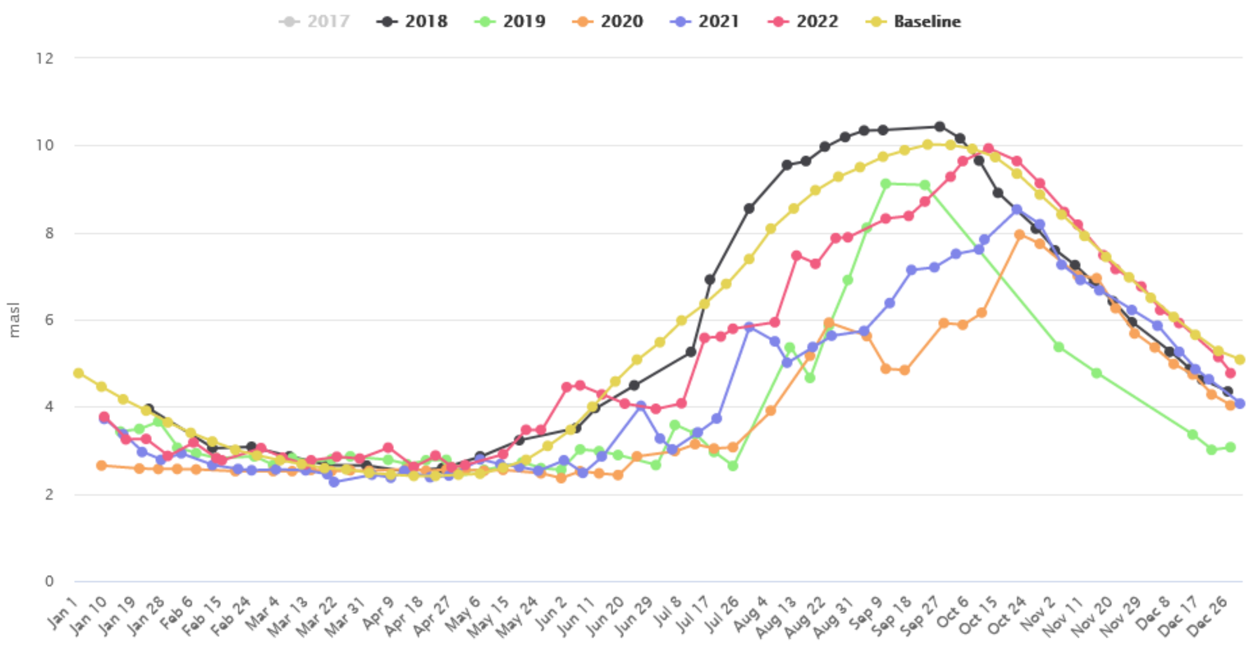


Figure 1 Lake Tonle Sap River Bottleneck (masl) ([Mekong Dam Monitor])

As a result of this unprecedented damming and climate change, the Lower Mekong River Basin is slowly collapsing. Salinization creeping up the Mekong River with the continued damming and reduced water load further disrupts the annual replenishing of waters in Lake Tonle Sap. It becomes necessary to understand the acute stress placed on Lake Tonle Sap and the effects of damming activity. The present study utilizes LandSat 8 imagery to assess health levels of Lake Tonle Sap and geospatial analysis of flow data collected by the Mekong River Commission, Stimson Center, and others, during the month of September from 2018 to 2022. This study provides a method for analyzing the health of Lake Tonle Sap utilizing the Freshwater Health Index promulgated by Conservation International.

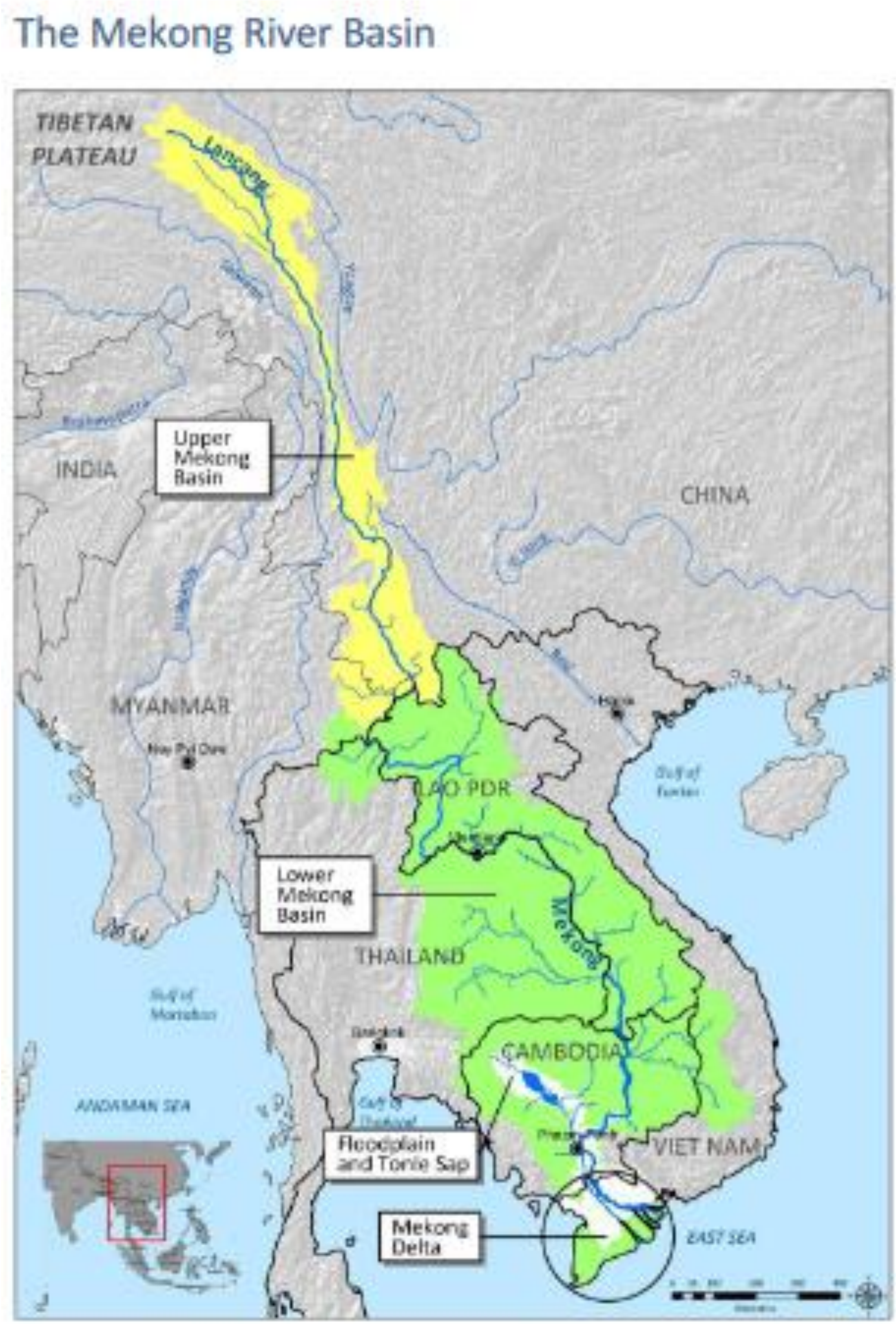


Figure 2 The Mekong River Basin (Mekong River Commission Summary State of the Basin Report 2018)

II. Problem Background:

Lake Tonle Sap is a large fresh-water lake in the south of the Lower Mekong River Basin in Cambodia. The lake is a biodiversity hotspot and the wealthiest fishery on the whole Mekong River (Mekong River Commission, 2020). Approximately 80% of the population of Cambodia depends upon the Mekong on a daily basis (Mekong River Commission, 2020). Lake Tonle Sap is reliant upon annual replenishment of its waters and silts by the monomodal monsoon season surge (Mekong Water Monitor, 2021) (Mekong River Commission, 2020). The accumulated reverse flows to Lake Tonle Sap have been steadily decreasing due to the reduction of base Mekong River water flow (Mekong River Commission, 2020) (Mekong Water Monitor, 2021).

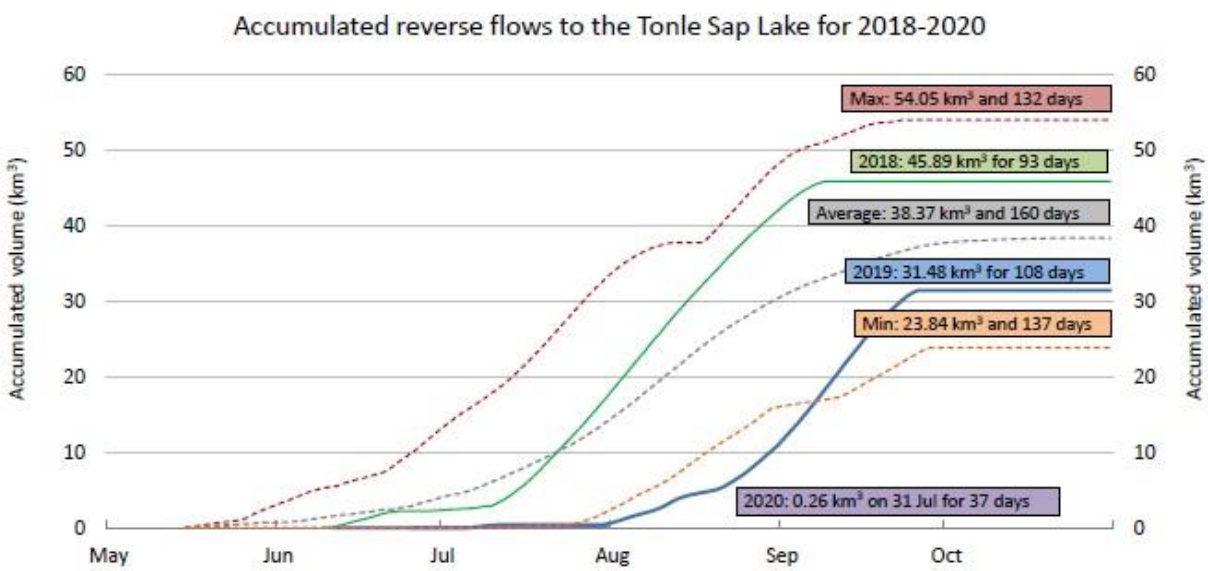


Figure 3. Characteristics of accumulated flows for 2018, 2019, and 2020, compared to the minimum, maximum, and average of 1997-2017 (Mekong River Commission, 2020)

The Upper and Lower Mekong River Basins, as a whole are facing increasing normative water flow disruption due to increased damming within the basins (A. Basist, 2020) (Yuka Kiguchi, 2016) (Mekong River Commission, 2018). The water flow into Lake Tonle Sap is predominantly from the Tonle Sap River, its tributaries, and precipitation (Mekong River Commission, 2020). However, inflow from the Mekong River during the rainy season also occurs; including waters from China. However, China's contribution is predominantly glacier and snow melt from the Tibetan Plateau; not rainfall (Mekong River Commission, 2018) (Yuka Kiguchi, 2016). While this does reduce the total effect of water reduction in the Lower Basin during rainy season precipitation failures, it is most heavily felt during the dry season when this base water pressure is most critical (Mekong River Commission, 2018) (Mekong River Commission, 2021). China has the largest dams and cascade in the entire basin totaling 10 dams with plans to build more (Mekong River Commission, 2018).

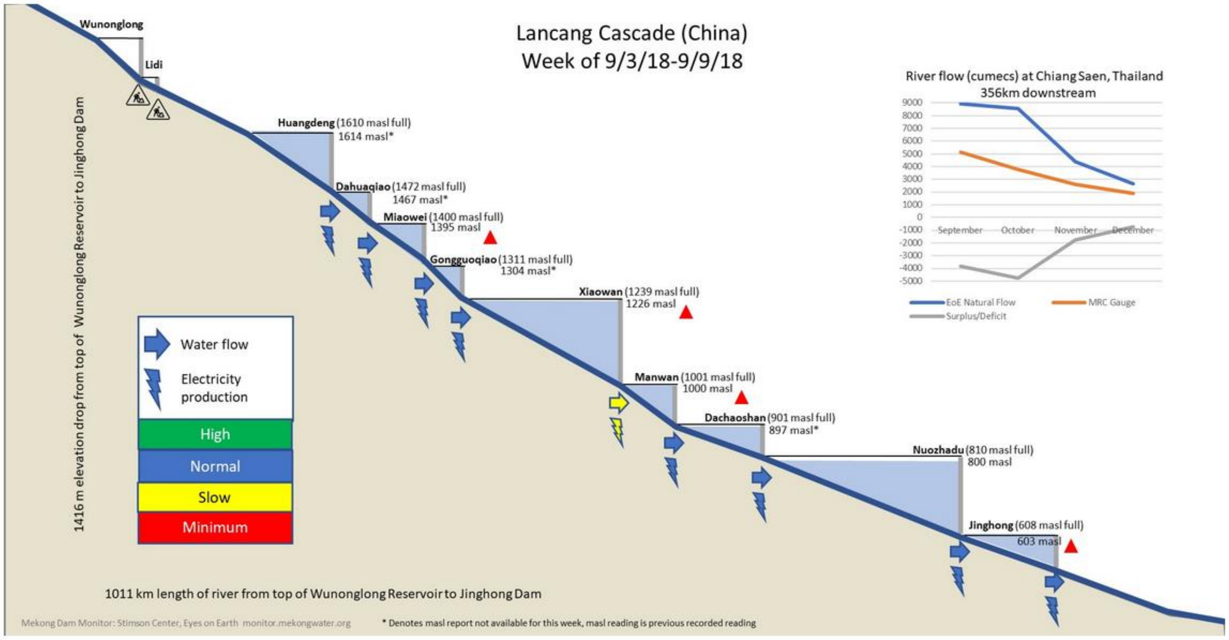


Figure 4 Lancang Cascade (China) 2018 ([Stimson Center](#))

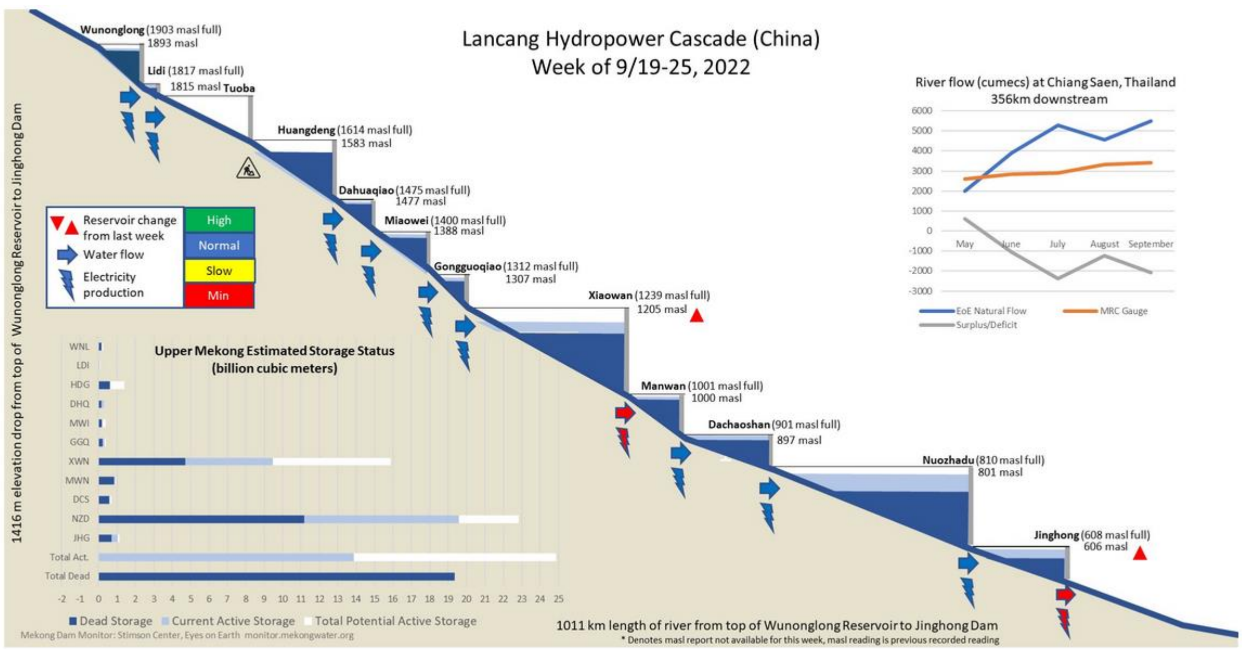


Figure 5 Lancang Cascade (China) 2022 ([Stimson Center](#))

Their biggest impact is in withholding up to 60-70% of life-giving sediments to the rest of the basin, including Lake Tonle Sap (Mekong River Commission, 2018). This reduction negatively impacts the natural geomorphology of the basin and especially impacts the Mekong River Delta shoreline (Mekong River Commission, 2018).

Vietnam loses approximately 500 hectares of land annually in the Delta alone costing Vietnam at least $12.5 million USD annually (Mekong River Commission, 2018). The absence of this sedimentary flux will contribute to the acidification and possibly salinized wasting of the land in the Lower Mekong River Basin (Zhuoran Wang, 2016) (Singh, 2020) (Stimson Center, 2021) (Gao Fan, 2011).

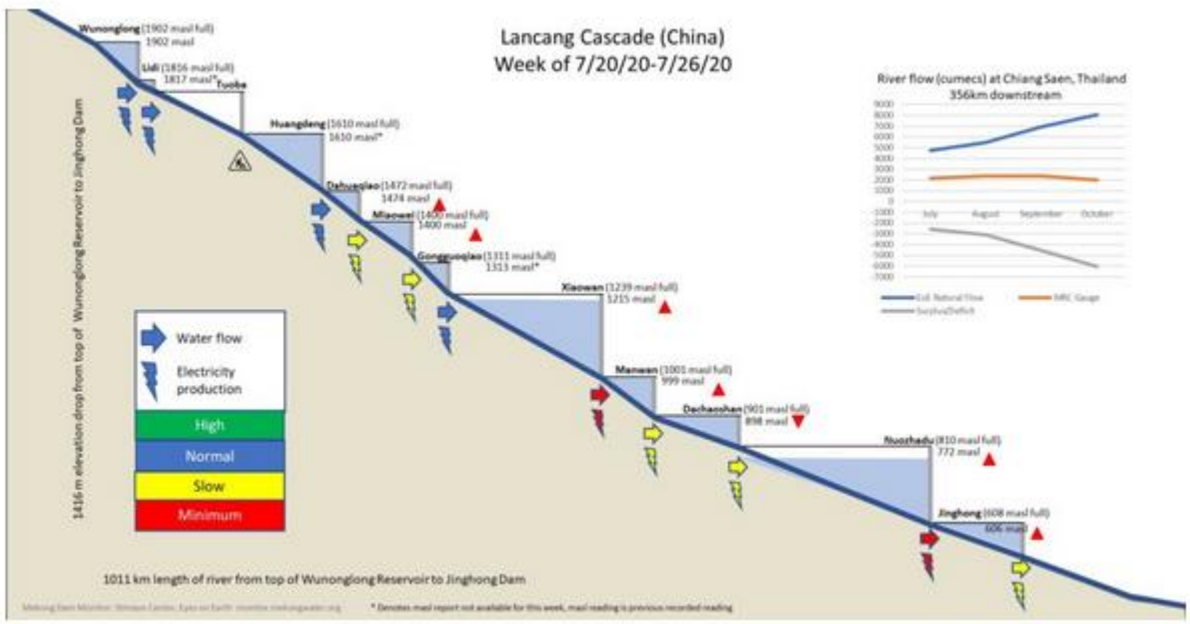


Figure 6 Illustrative example of Lancang Cascade analysis from week of 7/20/2020-7/26/2020. The example below shows China's Lancang Cascade restricting downflow from seven of the eleven dams in the cascade noting a turning point in the annual, coordinated operations of this cascade. Outlets at the two major reservoirs at Xiaowan and Nuozhadu are restricted to create minimum flow conditions to allow the reservoirs to recharge during the Upper Mekong's wet season. All dams around Xiaowan and Nuozhadu must also reduce outflow in order to coordinate and respond to the restrictions of the major dams. During this time hydropower production is analyzed as minimal. Past observations suggest this pattern of restriction will persist into September or later until the reservoirs fill to their normal maximum levels. - *Stimson Center*

The consequence of damming extends beyond the retention of waters in the Lower Mekong River Basin; they are also prone to evaporation and seepage (Mekong River Commission, 2020).

Lake Tonle Sap lies in the Stung Treng sub-basin of the Lower Mekong River basin. The Stung Treng sub-basin is the Mekong River Basin's southernmost and final sub-basin. Flow is carefully monitored here to ensure accurate readings for the benefit of Lake Tonle Sap's health. It is possible to utilize this flow data to be used in conjunction with the remotely sensed data points collected by the Mekong River Dam Monitor to gauge the health of Lake Tonle Sap (Stimson Center, 2022).

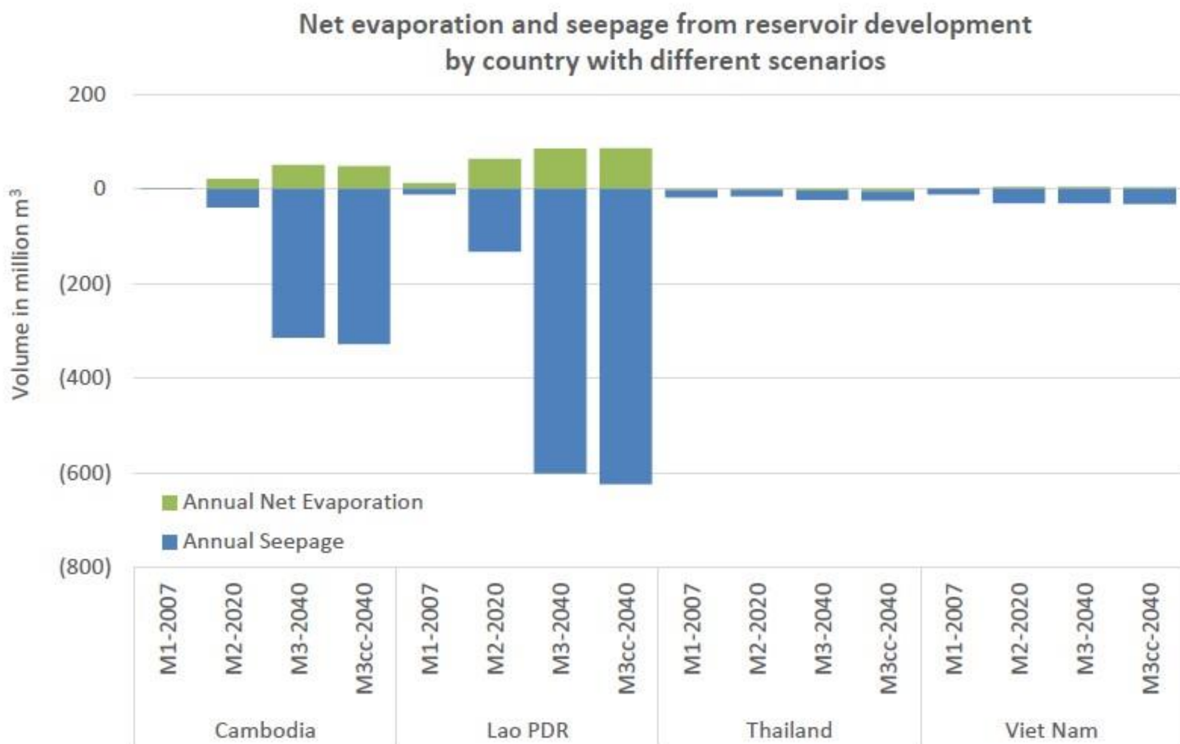


Figure 7 Annual Net Evaporation (sum of evaporation and rainfall and seepage from reservoir by country with different scenarios) ([Mekong River Commission, 2020]())

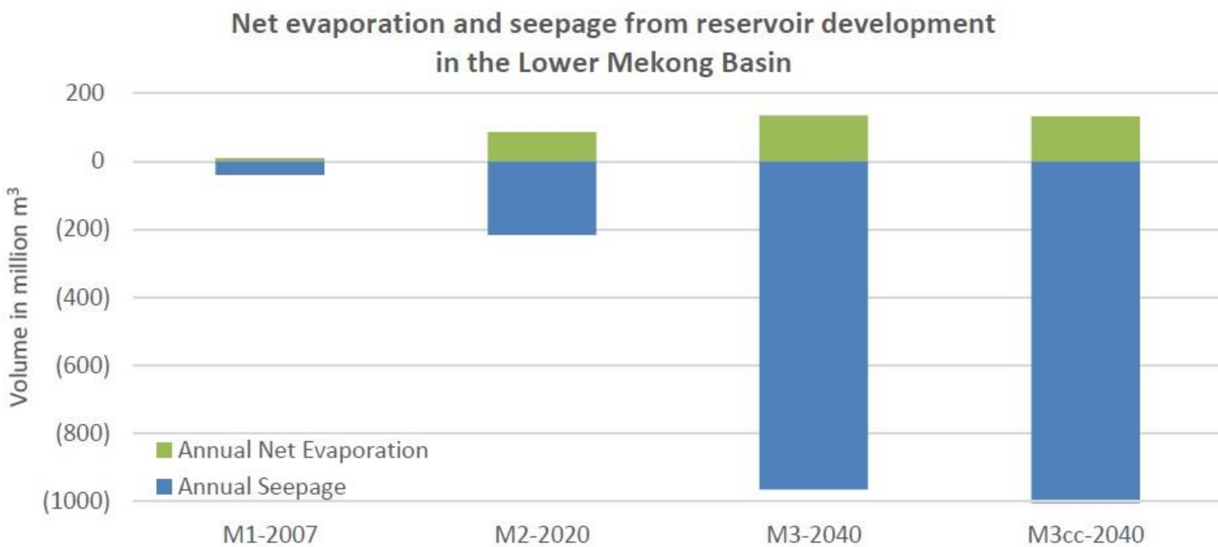


Figure 8 Annual net evaporation (sum of evaporation and rainfall) and seepage from reservoir development in the Lower Mekong Basin. ([Mekong River Commission, 2020]())

III. Maps & Descriptive Statistics:

Historically, China has utilized the Dry Season as an opportunity to release impounded water but is increasingly disruptive of its flow. The Dry Season being the most acutely devastating time of year to disrupt flow due to the base load consisting of glacier melt, a far less susceptible source of precipitation to climate change.

Cooler		Hot/Dry			Wet				Cooler		
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
NE monsoon		Transition		SW monsoon						NE monsoon	

Table 1 Mekong River Basin Seasons (Mekong River Commission, 2021)

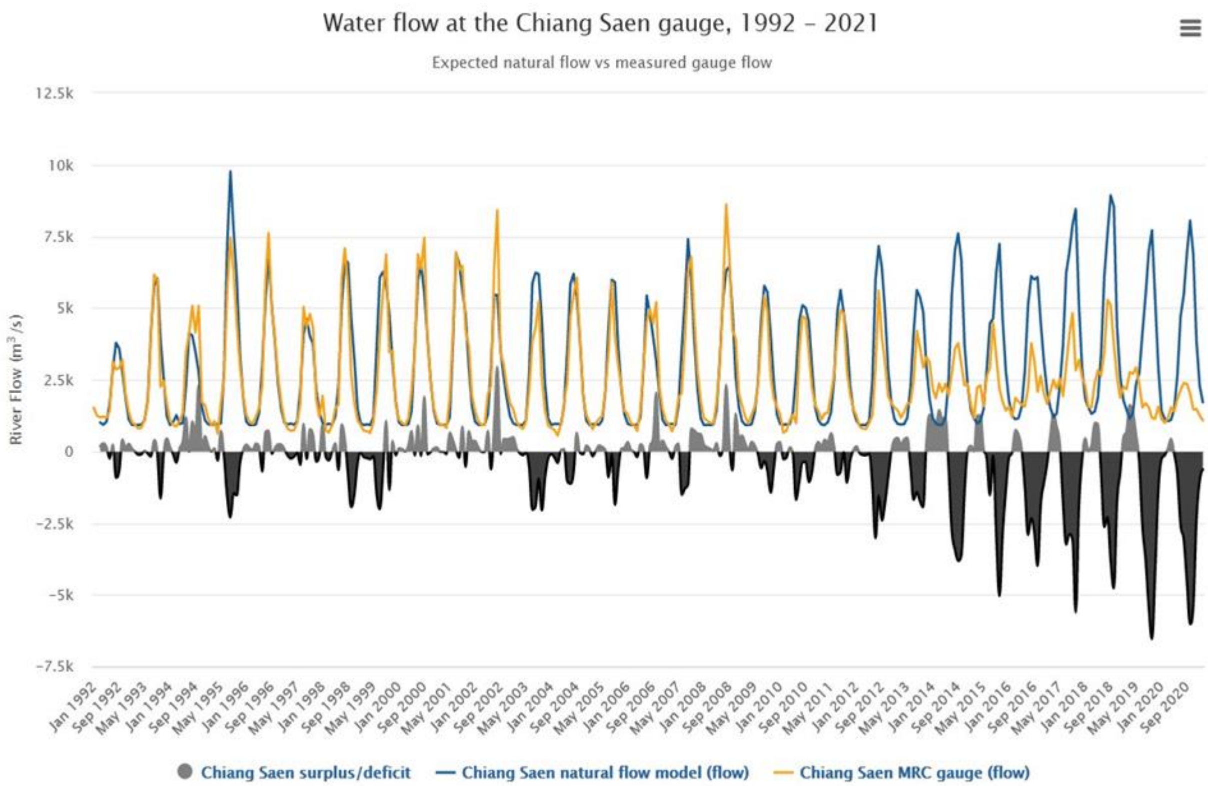


Figure 9 Water flow at the Chiang Saen Gauge, 1992-2021, courtesy of the Stimson Center & Mekong River Commission.

The Chiang Saen gauge is the northernmost-lying device in the Lower Mekong River Basin. Thus, it provides the most accurate reading of PRC released waters and provides a reliable indicator of water movement south, into the nations compromising the Mekong River Commission.

Country	2007	2020	2040
Cambodia	1	9	*13
Lao PDR	6	*60	*85
Thailand	12	12	12
Viet Nam	5	13	13

Figure 10 Proposed Reservoir Development in the Four Countries (Mekong River Commission, 2020) (including mainstream reservoirs)*

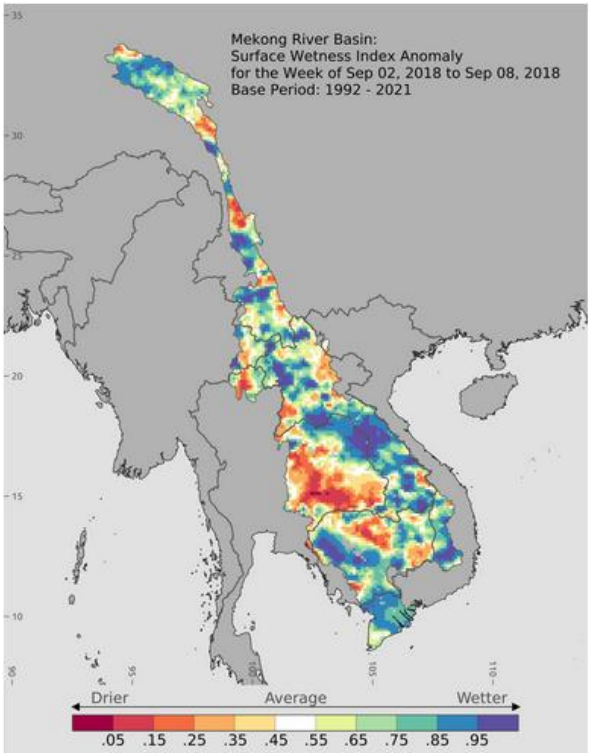
Despite the obvious deleterious effects of out of control damming on the Lower Mekong River, member nations of the Mekong River Commission continue to contribute to the destruction of the basin. The worse offender by far being Lao PDR.

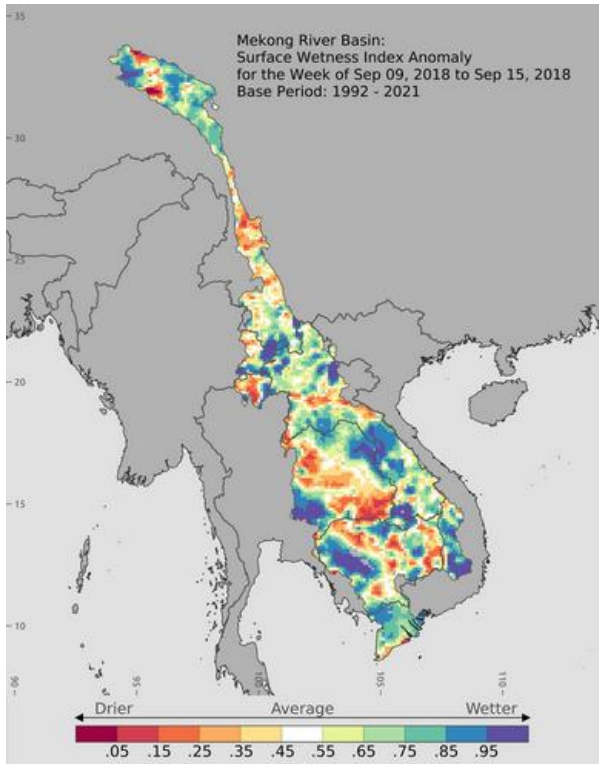
Scenario	Description	Detail Information
M1-2007	Baseline 2007	Infrastructures of six related sectors in 2007
M2-2020	Development 2020	Infrastructures of six related sectors in 2007, currently under construction and planned for 2020
M3-2040	Development 2040	Infrastructures of six related sectors in 2007, currently under construction and planned for 2040
M3cc-2040	Development 2040 with climate change	Infrastructures of six related sectors in 2007, currently under construction and planned for2040 with climate change

Table 2. Considered development conditions of 2007, 2020 and 2040 courtesy of the Mekong River Commission Water-Loss From-LMB-Reservoirs-Technical-Not, (Mekong River Commission, 2020)

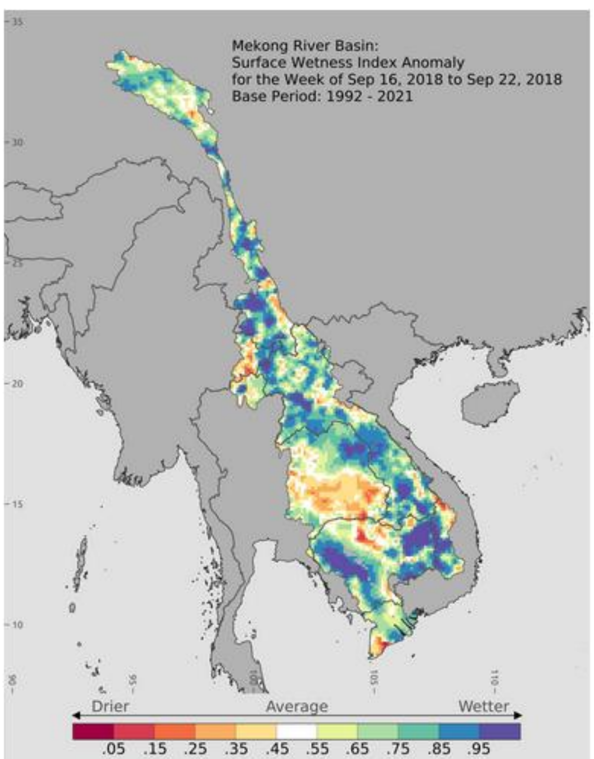
The Stimson Center has developed several advanced remote sensing and geospatial analysis processes to capture the health of Lake Tonle Sap and the Mekong River Basin for the benefit of the Mekong Dam Monitor (Stimson Center, 2020). The Surface Wetness Index Anomaly is a remote sensing process which utilizes an algorithm to process microwave satellite measurements collected at various frequencies and polarization (Stimson Center, 2020). The process calculates the magnitude of liquid water near the surface then uses the Basist Wetness Index (BWI) to derive a linear relationship between the two. This results in the ability to determine less-normative patterns of surface patterns as deviations from observed averages emerge (Stimson Center, 2020)

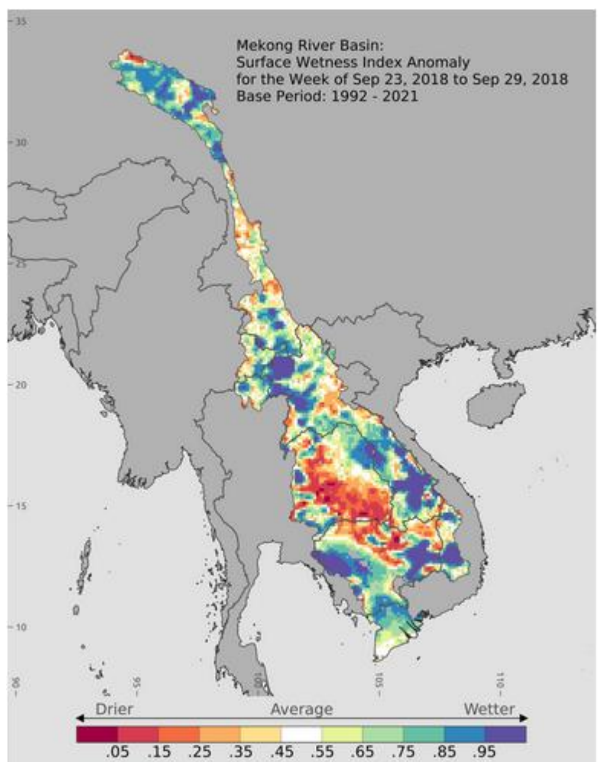
In figures 11-30, the Surface Wetness Index Anomaly is illustrated for the entire Mekong River Basin courtesy of the Mekong Dam Monitor website of the Stimson Center. Note the more normative, less disrupted wetness in 2018, the disproportionate capture of wetness in Lao PDR in 2019, the unusual aridness of 2020 brought in part by the La Nina Effect, a step towards normalcy in 2021, and a continued approach towards stability in 2022.



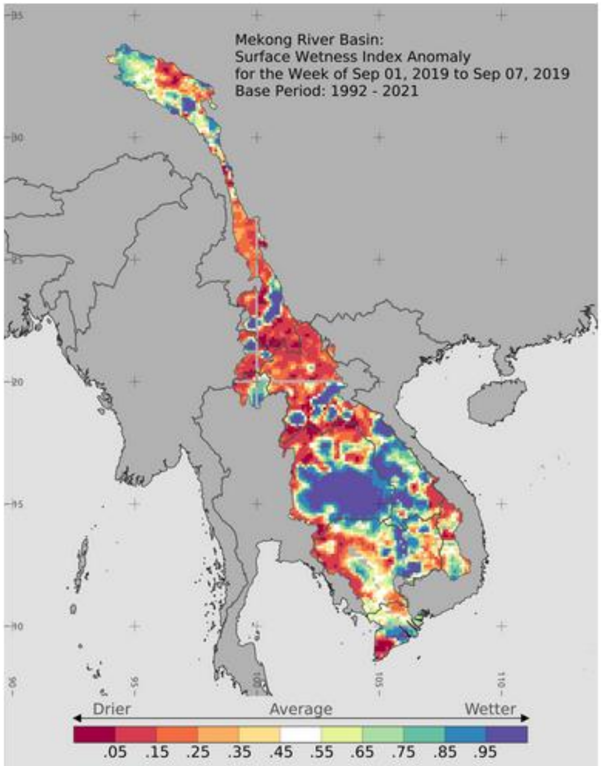


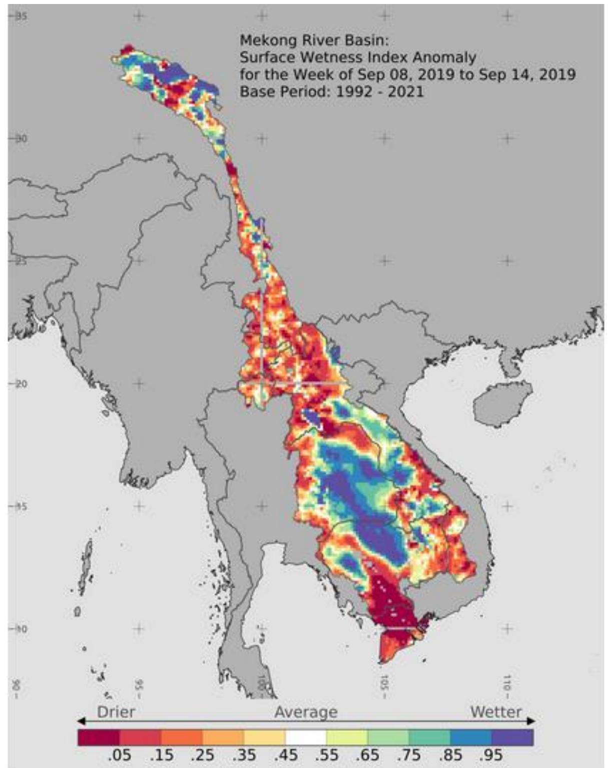
Figures 11 & 12 Surface Wetness Index Anomaly First Half of September 2018 ([Mekong Dam Monitor])



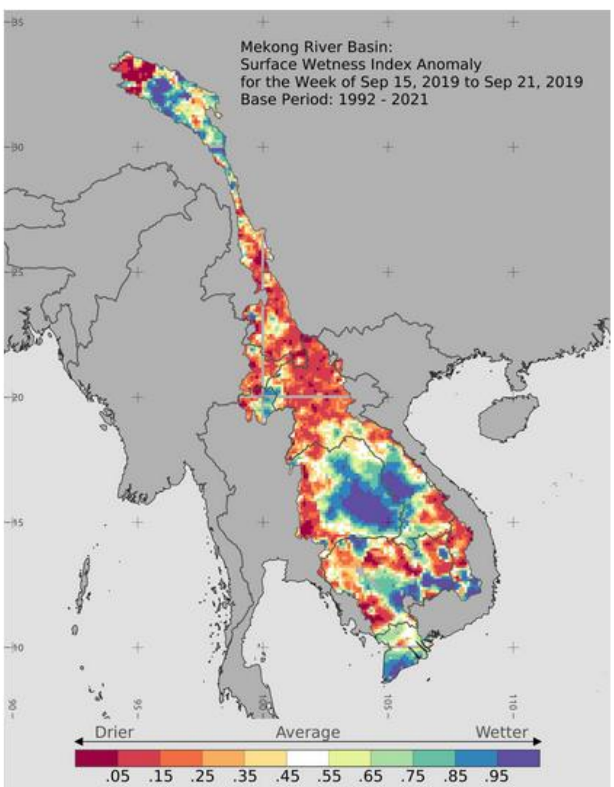


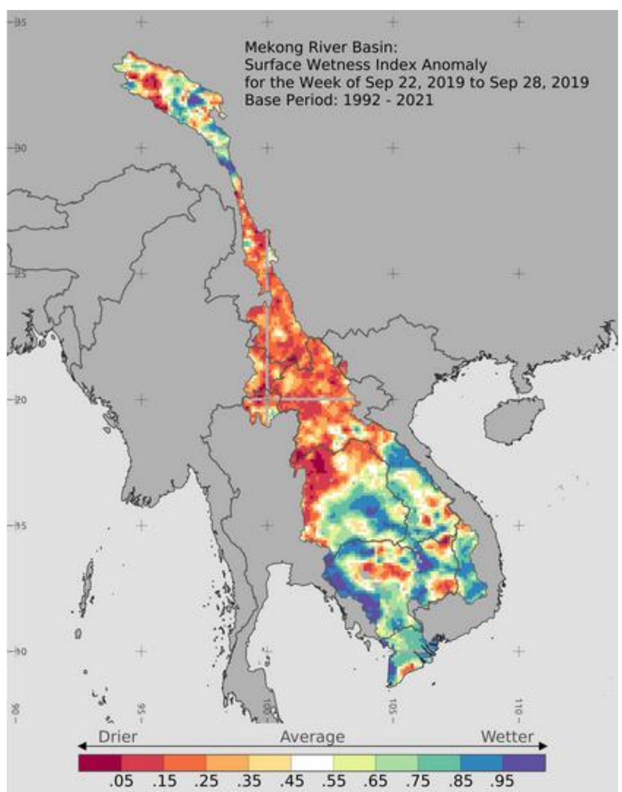
Figures 13 & 14 Surface Wetness Index Anomaly Second Half of September 2018 ([Mekong Dam Monitor])



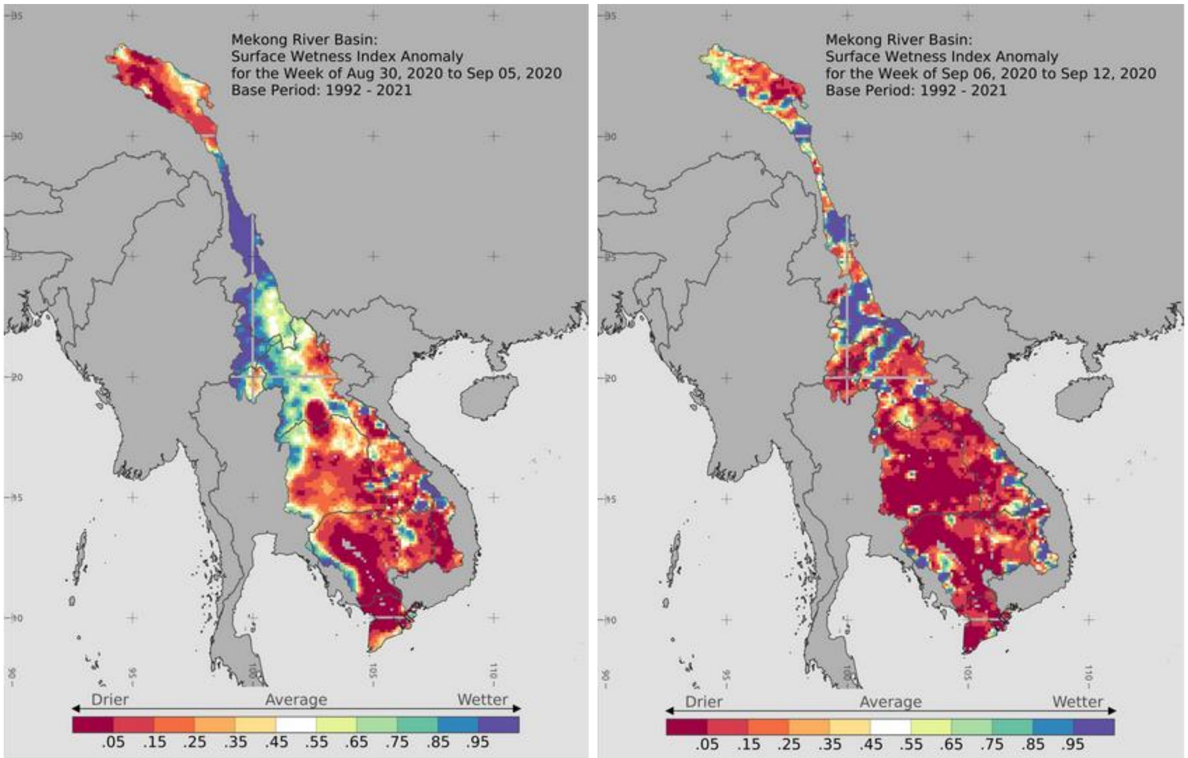


Figures 15 & 16 Surface Wetness Index Anomaly First Half of September 2019 ([Mekong Dam Monitor]())

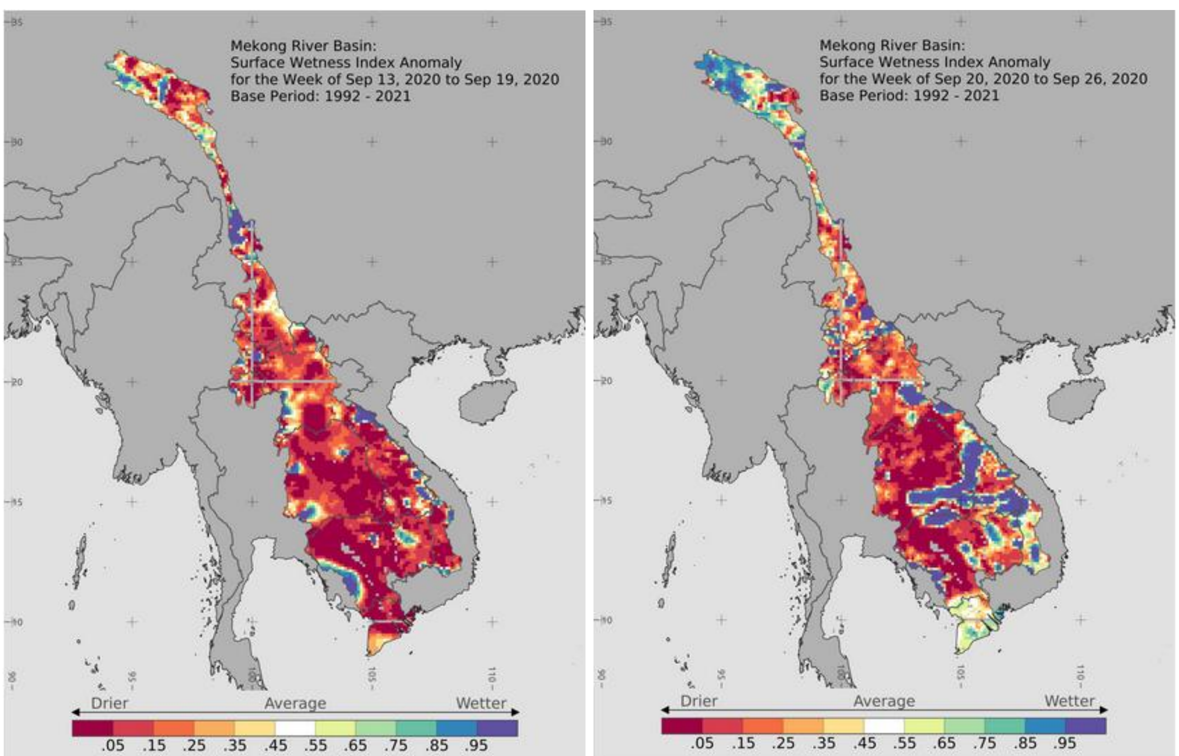




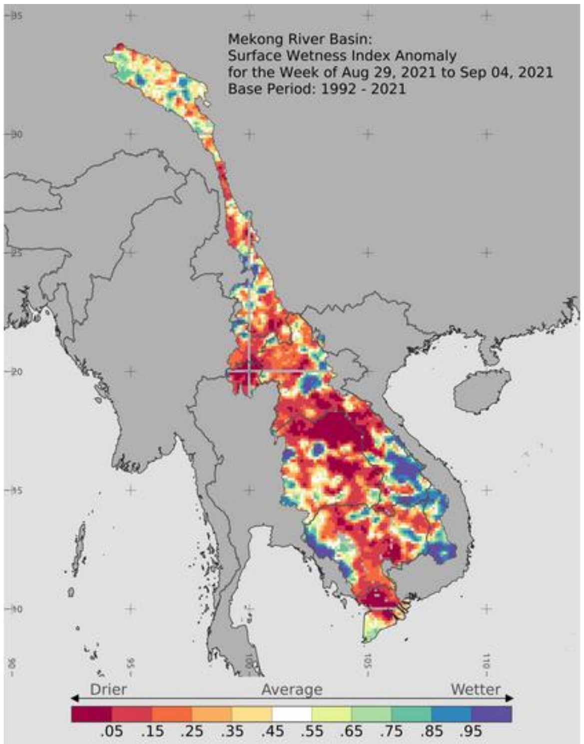
Figures 17 & 18 Surface Wetness Index Anomaly Second Half of September 2019 ([Mekong Dam Monitor]())

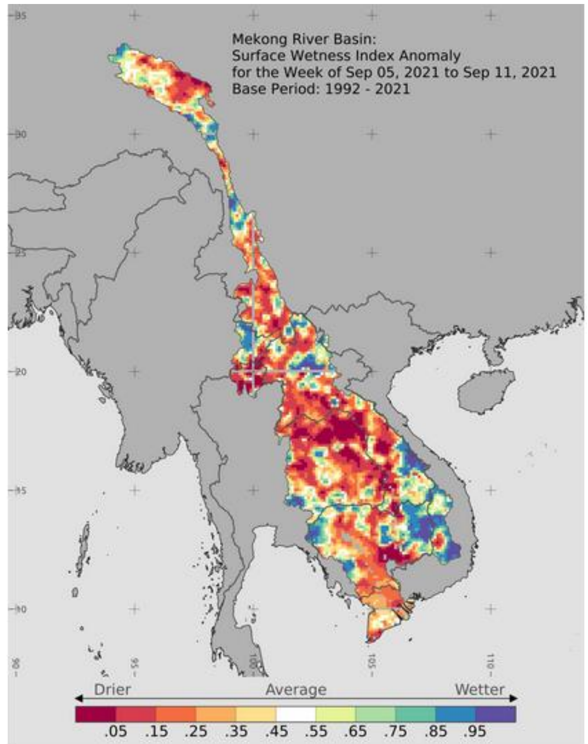


Figures 19 & 20 Surface Wetness Index Anomaly First Half of September 2020 ([Mekong Dam Monitor]())

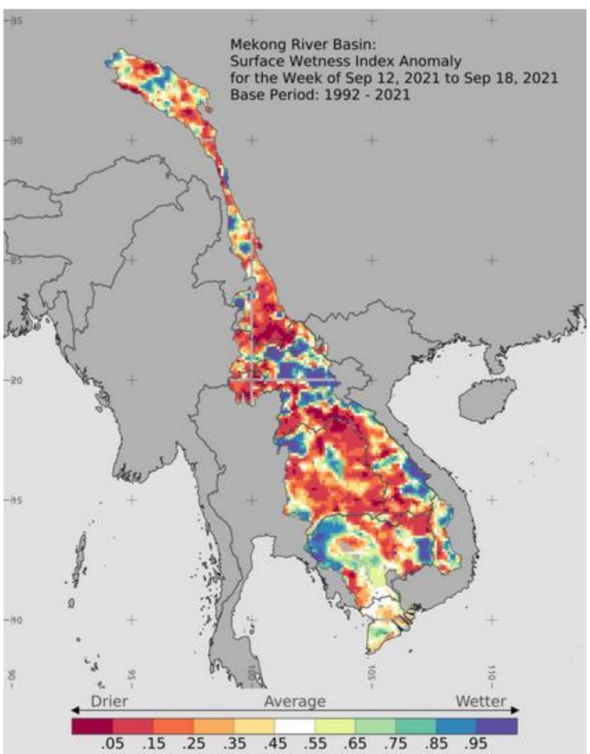


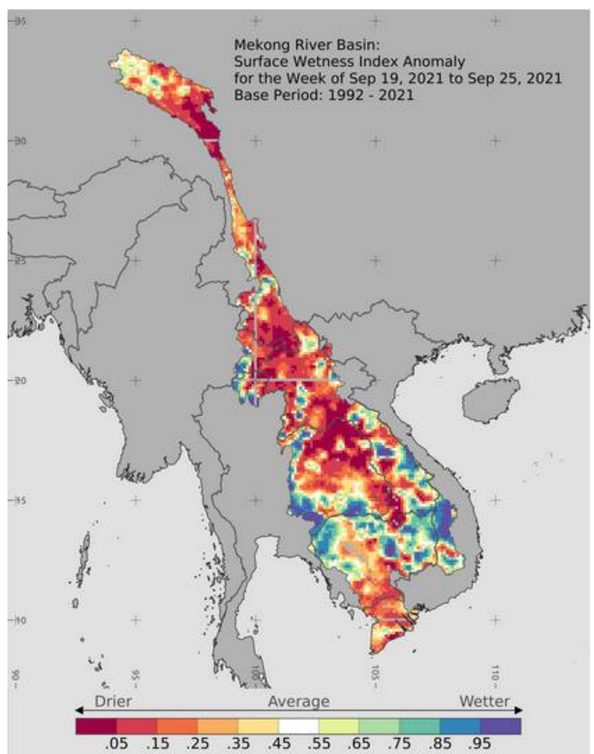
Figures 21 & 22 Surface Wetness Index Anomaly Second Half of September 2020 ([Mekong Dam Monitor]())



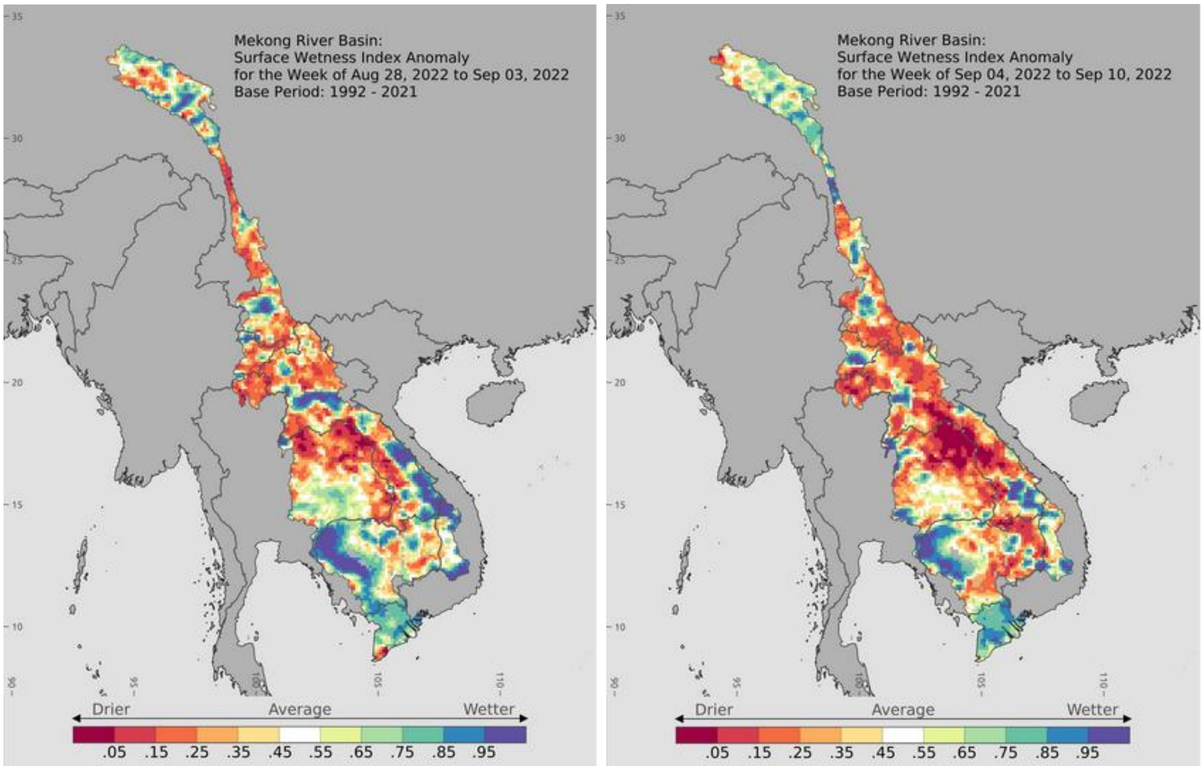


Figures 23 & 24 Surface Wetness Index Anomaly First Half of September 2021 ([Mekong Dam Monitor]())





Figures 25 & 26 Surface Wetness Index Anomaly Second Half of September 2021 ([Mekong Dam Monitor]())



Figures 27 & 28 Surface Wetness Index Anomaly First Half of September 2022 ([Mekong Dam Monitor])

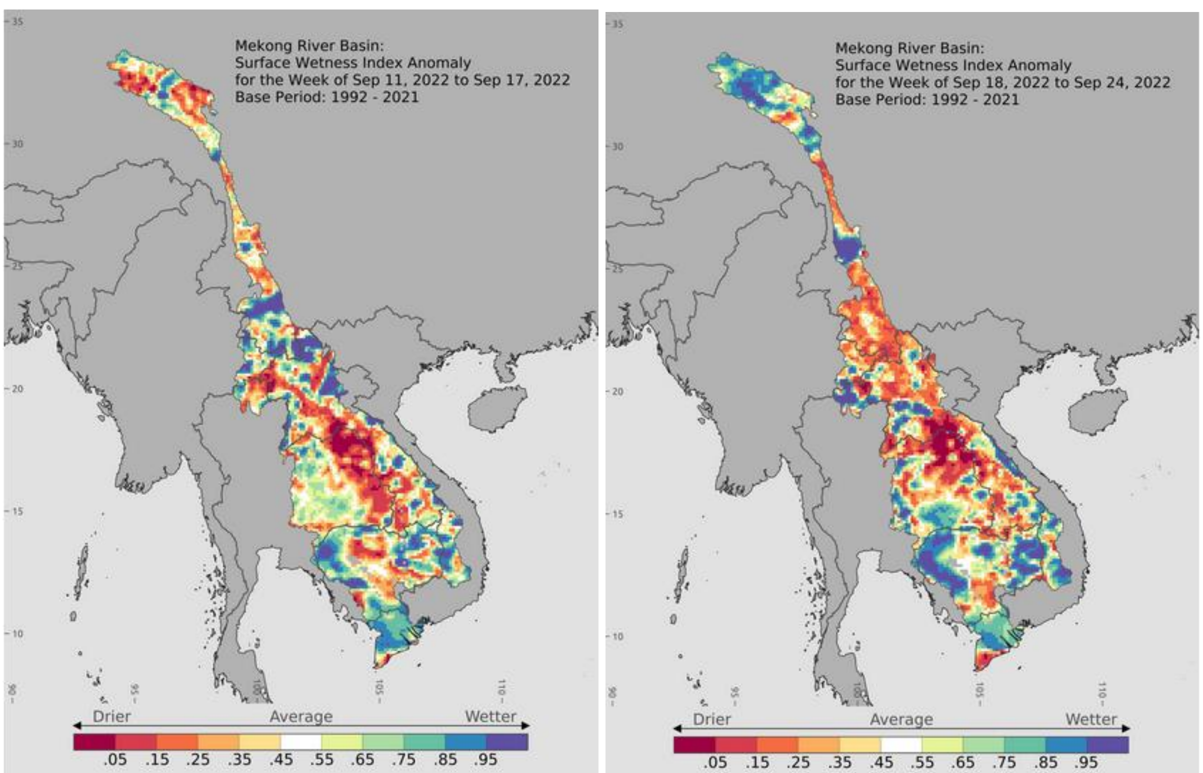


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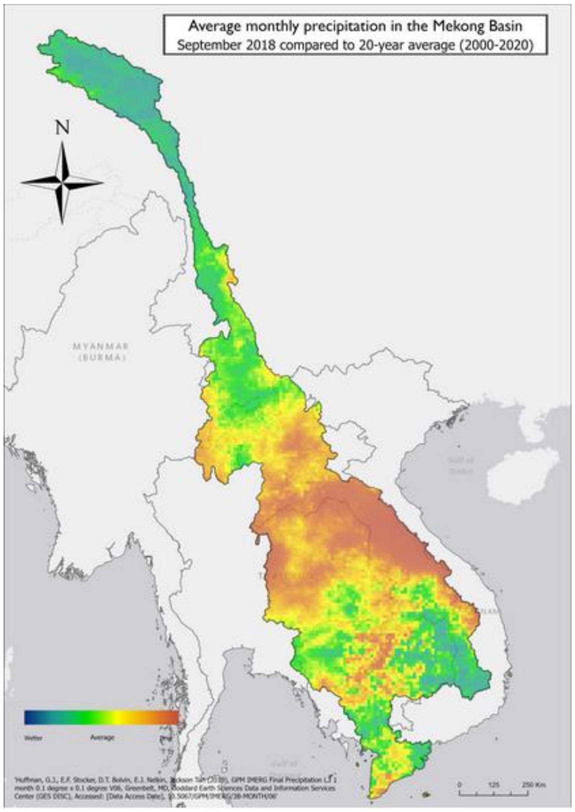
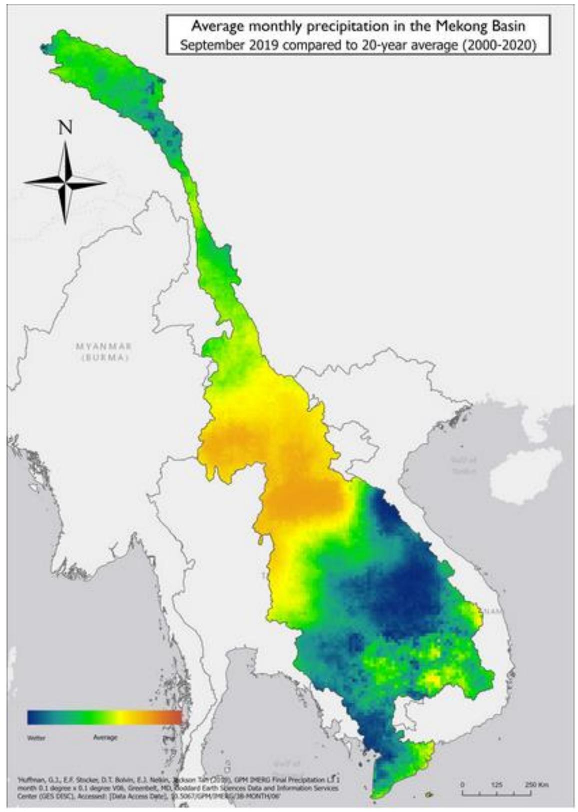
Figure 29 & 30 Surface Wetness Index Anomaly Second Half of September 2022 ([Mekong Dam Monitor])





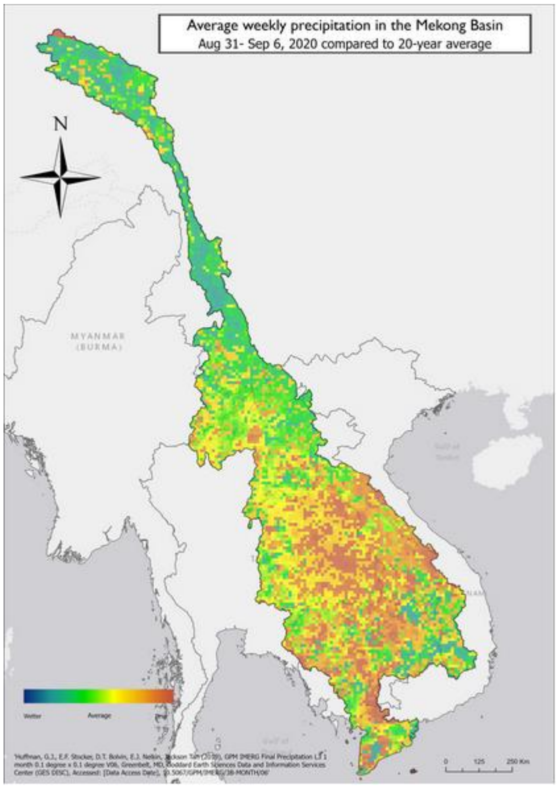
Figures 31 & 32 Average Monthly Precipitation September 2018 & 2019 ([Mekong Dam Monitor])

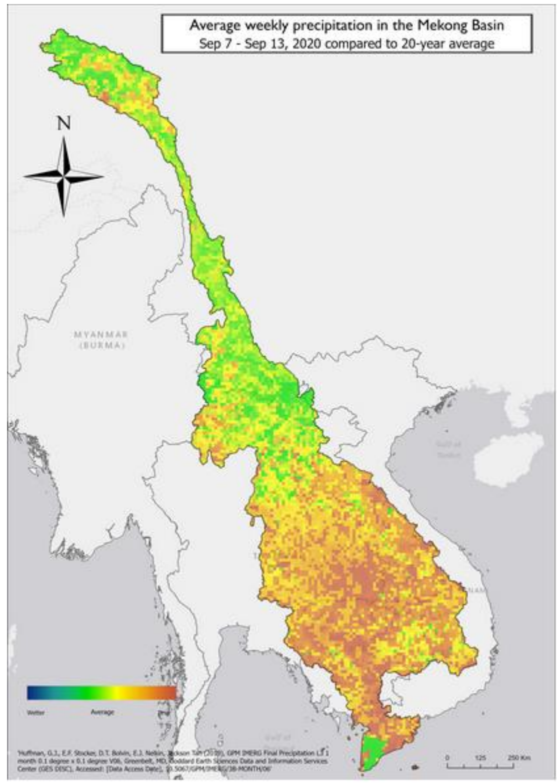
The monthly precipitation anomaly data averages determined by the Stimson Center utilize data from the Global Precipitation Measurement (GPM) and data collected using Google Earth Engine, which is compared to the median value from 2000 to the present (Stimson Center, 2020).

For figures 31 and 32, the September 2018 and 2019 average precipitation for the Mekong River Basin was calculated monthly by the Mekong Dam Monitor. In subsequent years the Mekong Dam Monitor calculated it on a weekly basis. This led to an increased ability to observe the precipitation averages in finer, more granular detail. Note the increase in precipitation from the 2018 to 2019 monthly average. It directly correlates to the Surface Wetness Index observed across the entire month of September in 2019 (Stimson Center, 2020).

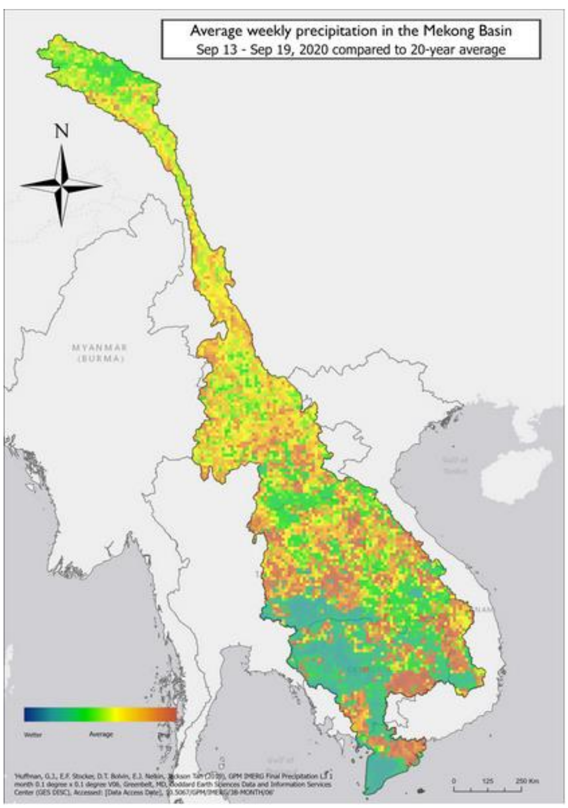
In figures 33-36, the drastic shortage of precipitation is clearly illustrated as a result of the La Nina effect. This hits particularly hard in the Lower Mekong River Basin and Lake Tonle Sap in particular. The observed shortages in precipitation reveal a much drier Surface Wetness Anomaly Index for the same period of time.

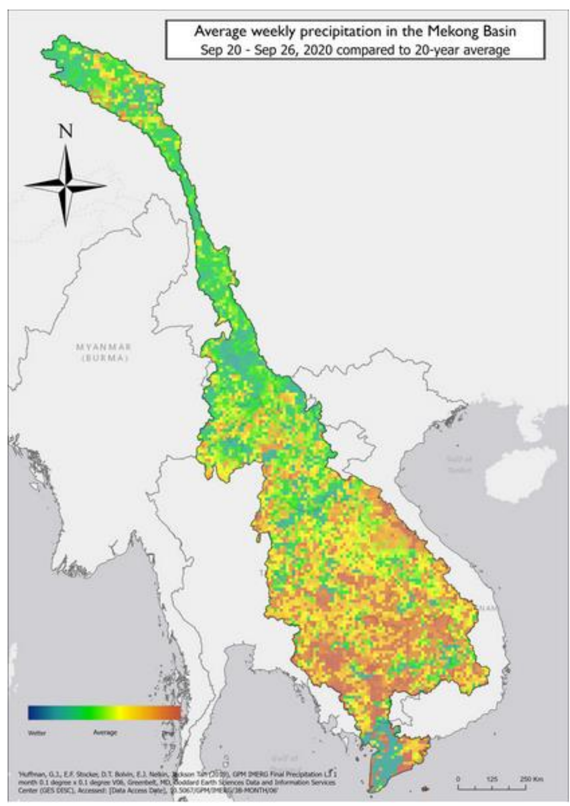
In 2021, the precipitation begins to return to its normal levels. Note the comprehensively more saturated environment indicated in the 2022 precipitation measurements.



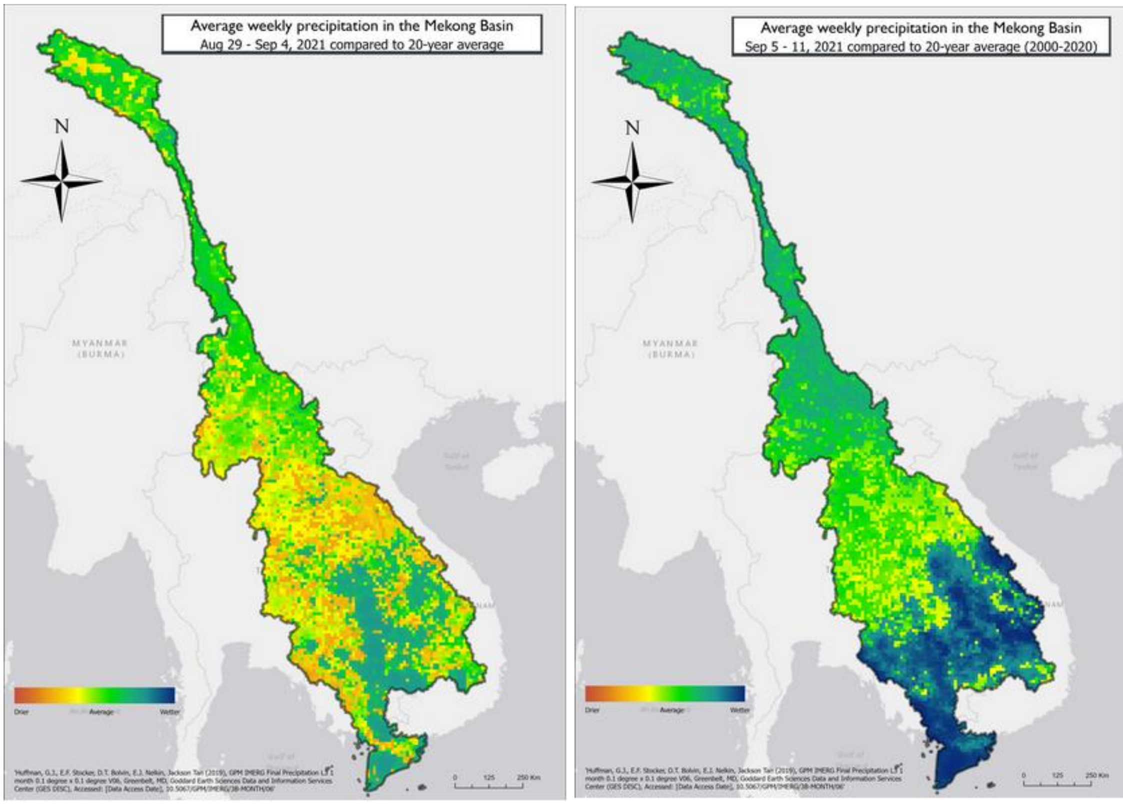


Figures 33 & 34 Average Monthly Precipitation First Half of September 2020 ([Mekong Dam Monitor](#))

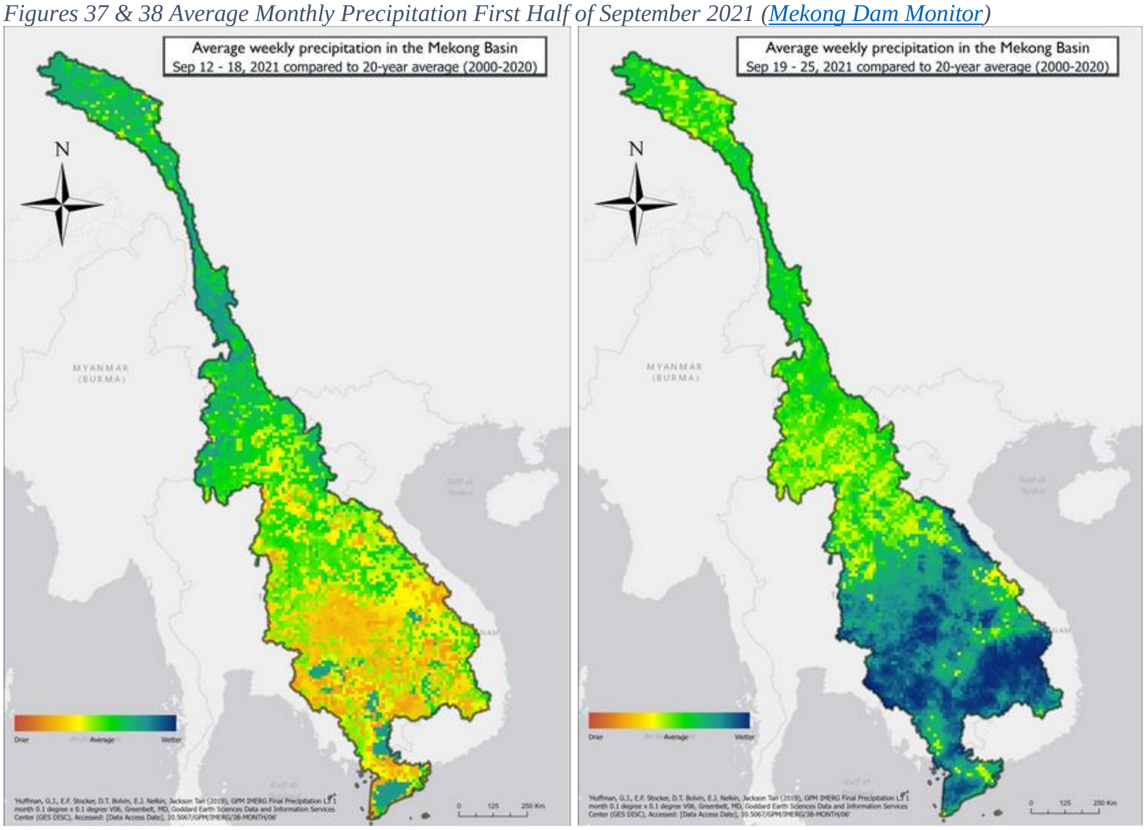




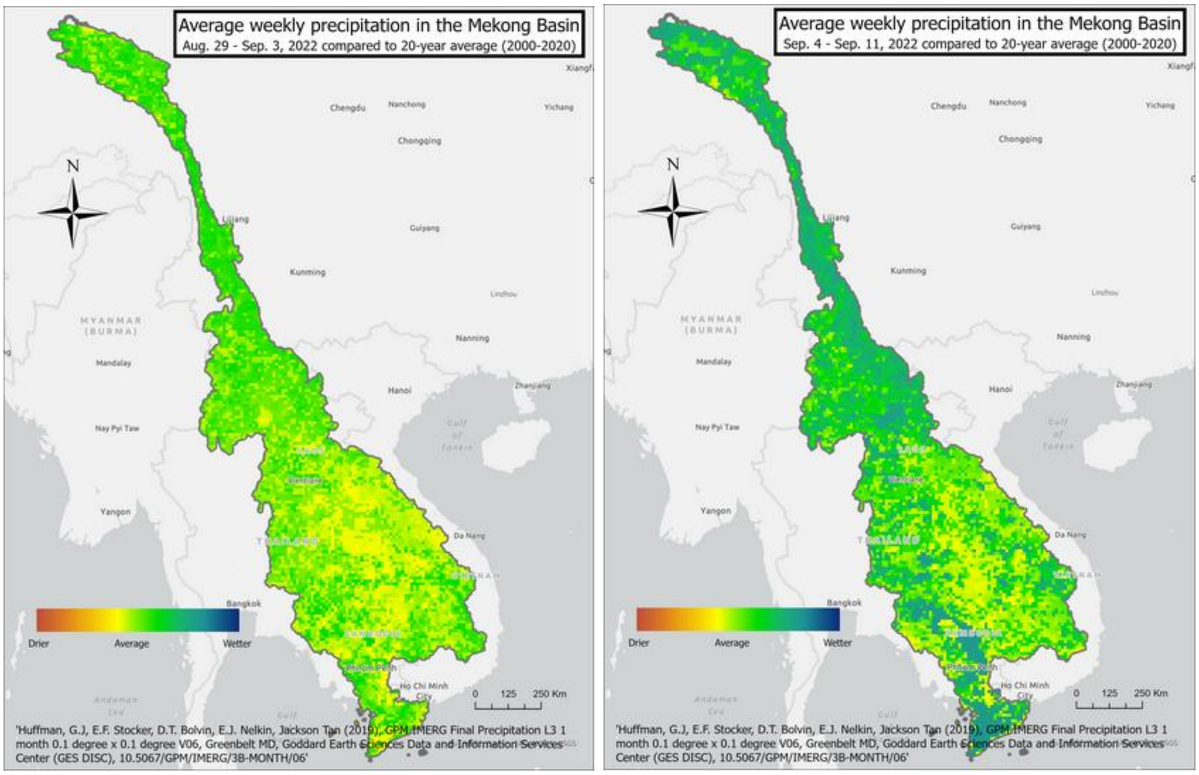
Figures 35 & 36 Average Monthly Precipitation Second Half of September 2020 ([Mekong Dam Monitor](#))



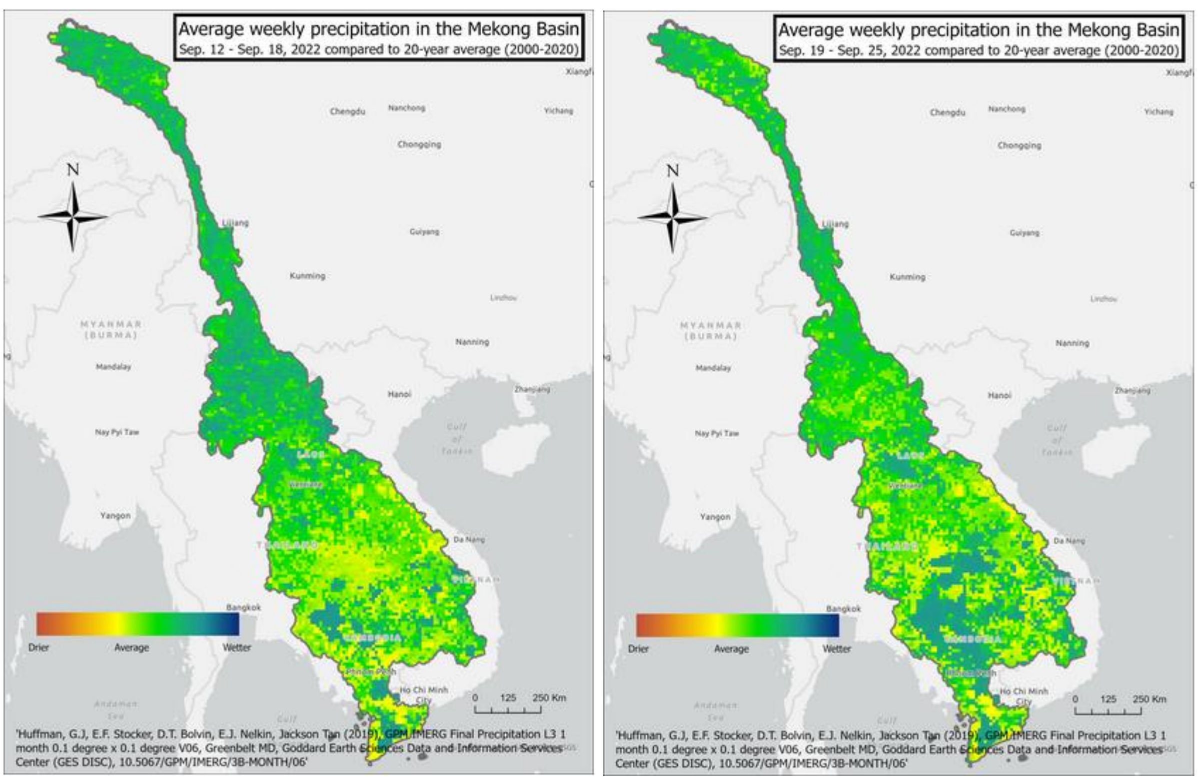
Figures 37 & 38 Average Monthly Precipitation First Half of September 2021 ([Mekong Dam Monitor]())



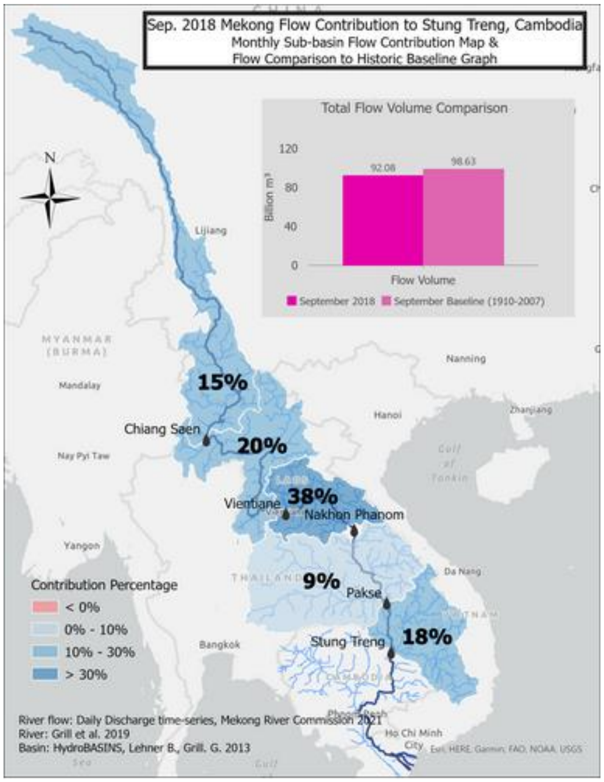
Figures 39 & 40 Average Monthly Precipitation Second Half of September 2021 ([Mekong Dam Monitor]())

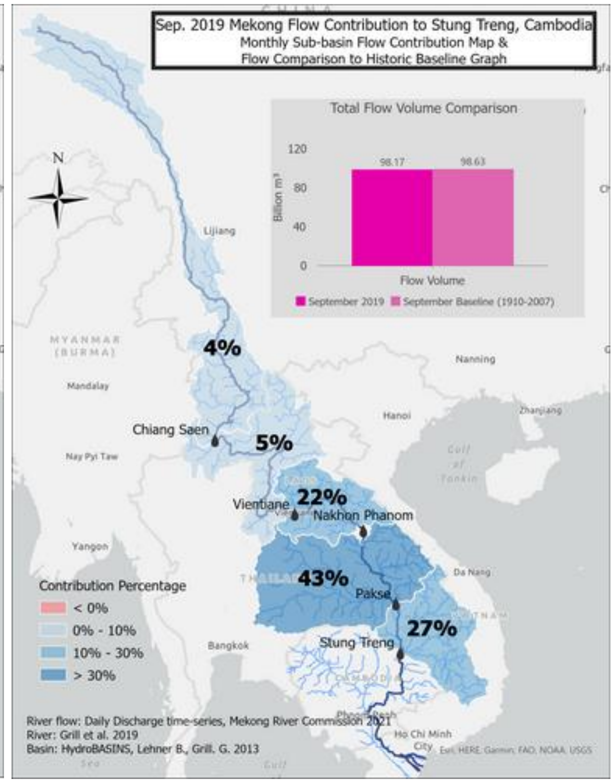


Figures 41 & 42 Average Monthly Precipitation First Half of September 2022 ([Mekong Dam Monitor](#))

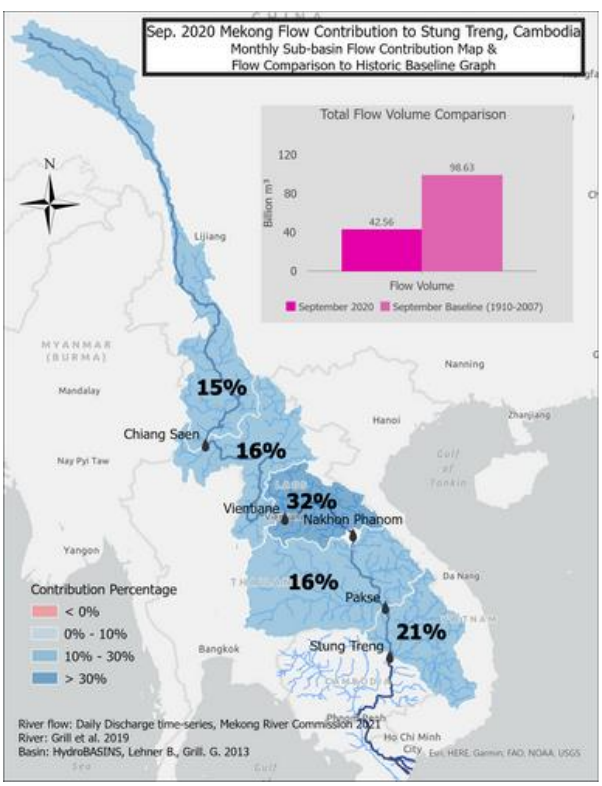


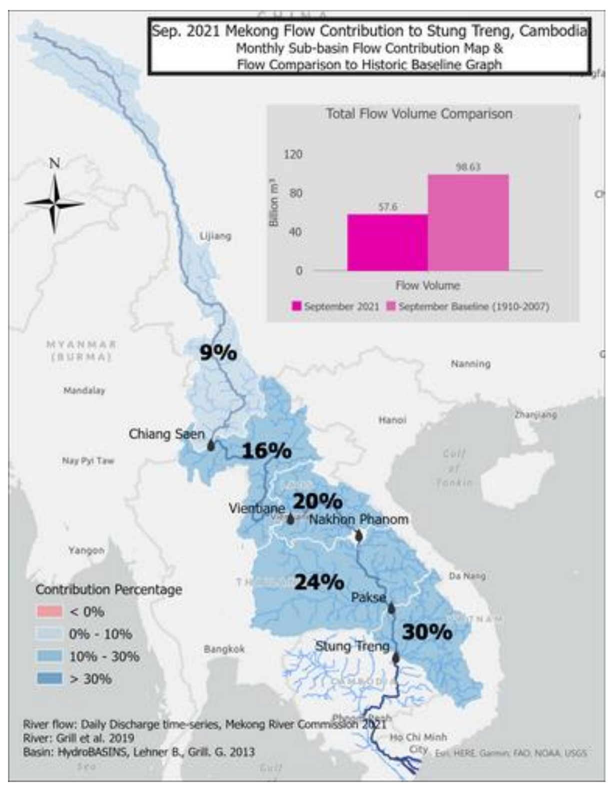
Figures 43 & 44 Average Monthly Precipitation Second Half of September 2022 ([Mekong Dam Monitor](#))





Figures 45 & 46 Mekong Flow Contribution to Stung Treng, Cambodia, September 2018 & 2019 (Mekong Dam Monitor)





Figures 47 & 48 Mekong Flow Contribution to Stung Treng, Cambodia, September 2020 & 2021 (Mekong Dam Monitor)

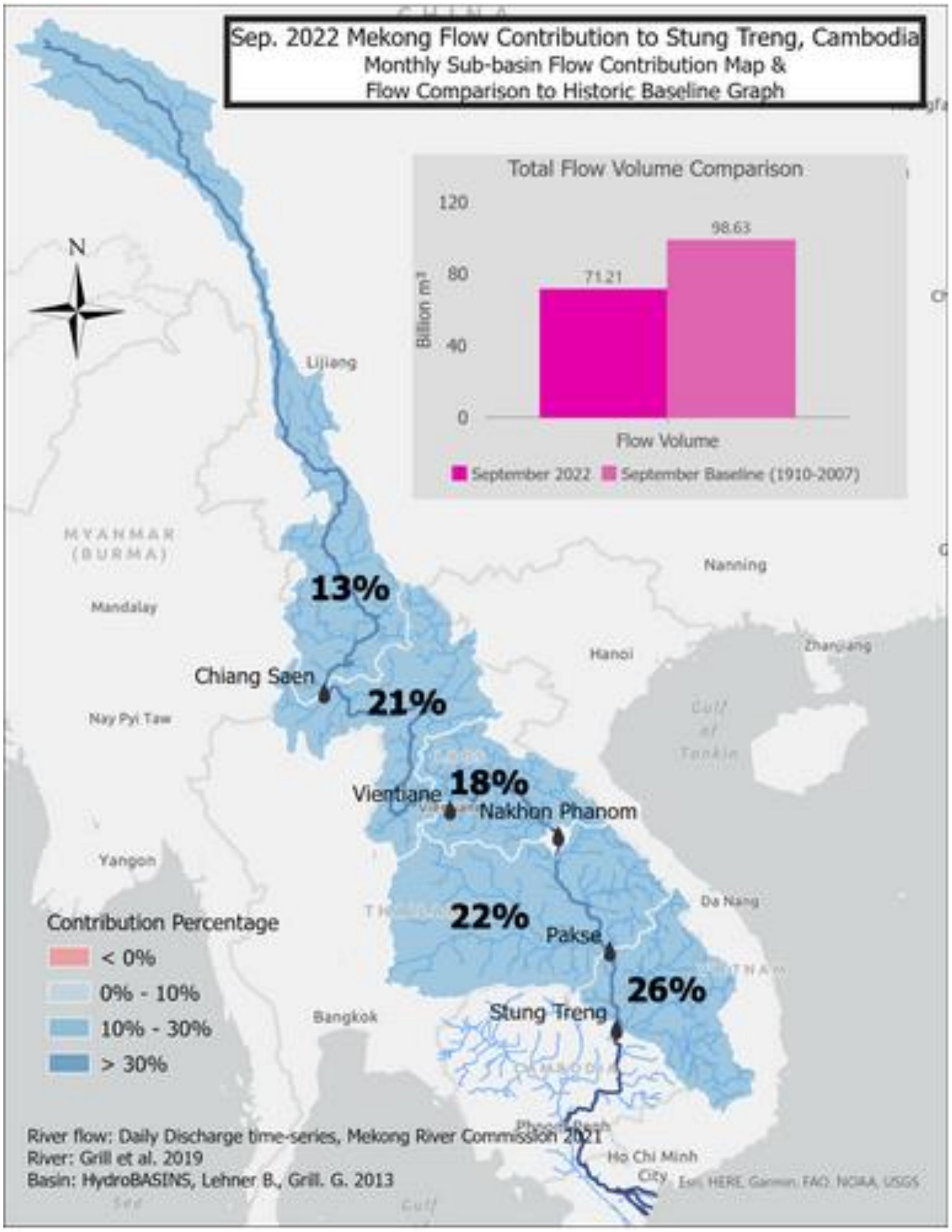
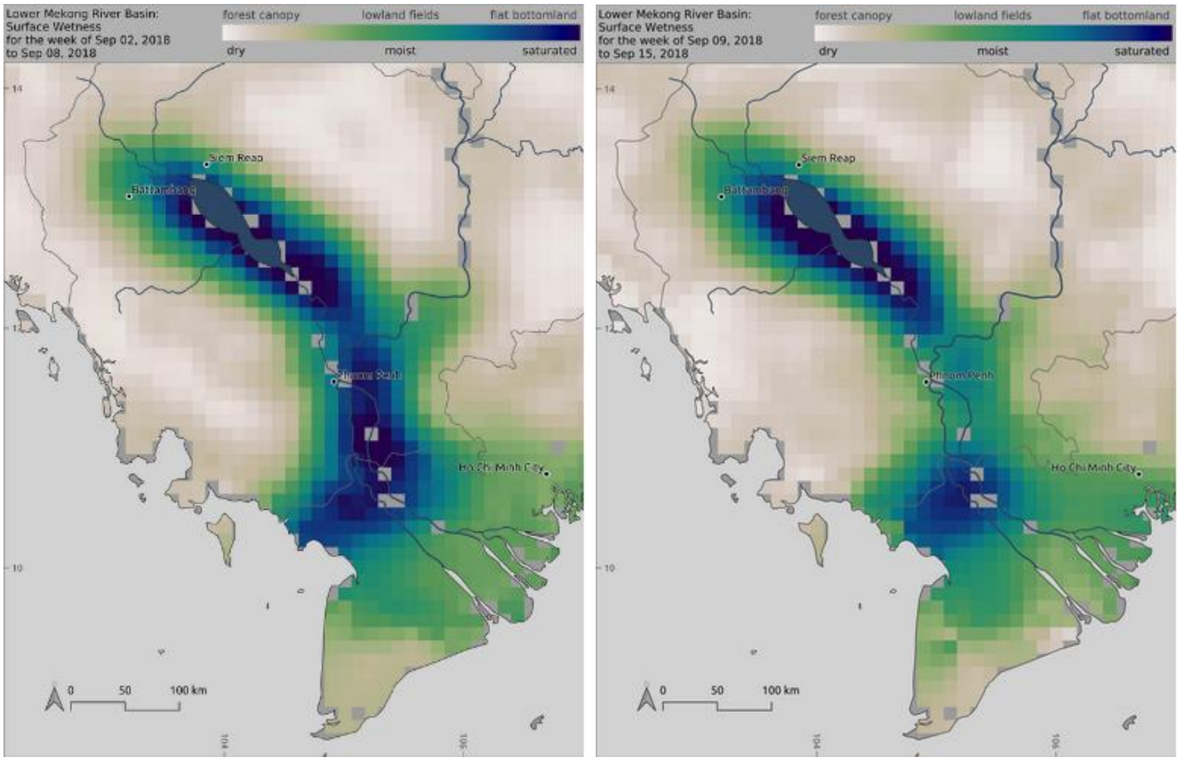
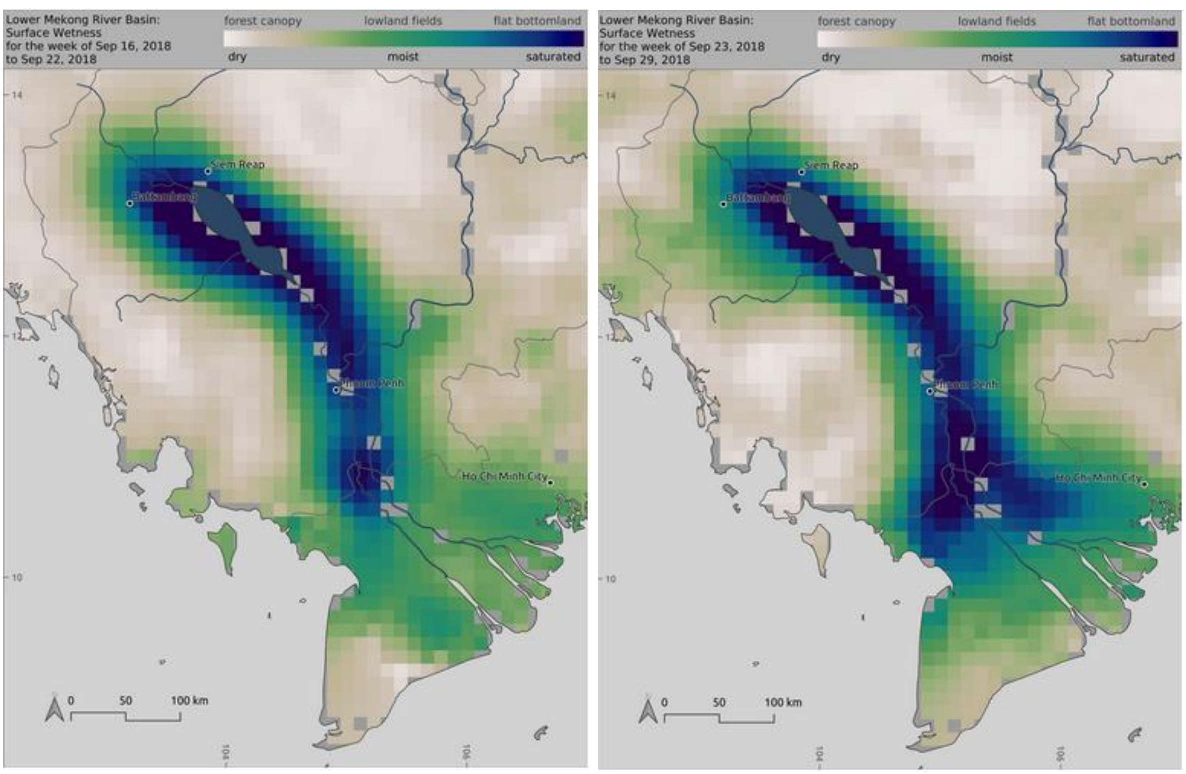


Figure 49 Mekong Flow Contribution to Stung Treng, Cambodia, September 2022 (Mekong Dam Monitor)

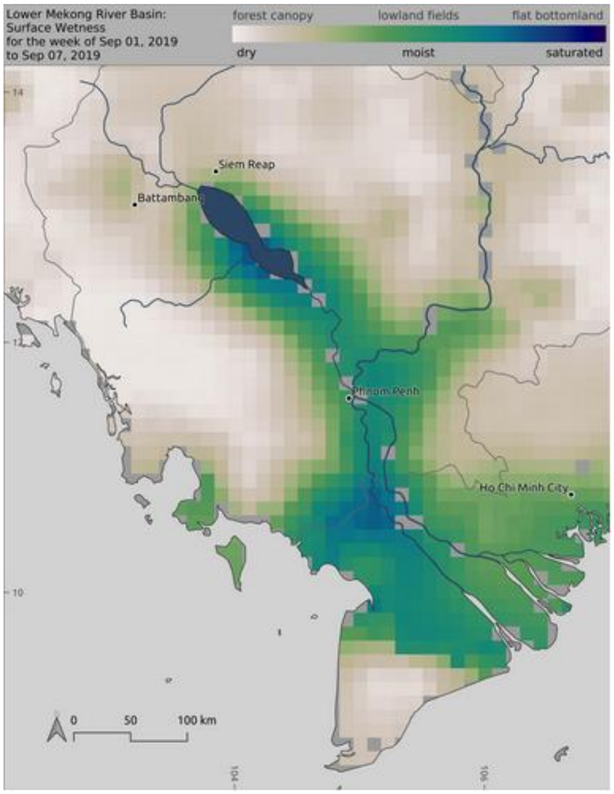
The Stimson Center's Mekong Dam Monitor provides flow analysis of the entire Mekong River Basin to support the geospatial analysis of the ecosystem's environment. In figures 45 and 46 we observe a more normative flow in September 2018, to a less normative flow in 2019. The precipitation glut observed in the surface wetness and average precipitation calculations further corroborate the disproportionate amount of wetness in Lao PDR. Analyzing the 2020 data reveal that there was a very uncharacteristic shortage of flow volume detected in the whole of the Lower Mekong River Basin. In 2020 the surface wetness, precipitation, and flow contribution to the Strung Treng sub-basin, all indicated an adverse, uncharacteristic year, with Lake Tonle Sap bearing much of the brunt of the flow volume shortage.

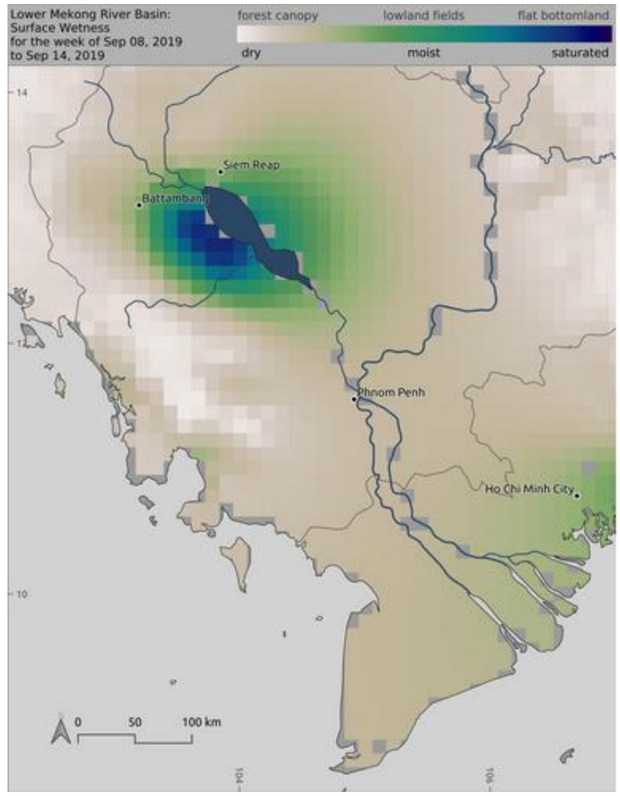


Figures 50 & 51 Lower Mekong Surface Wetness Map First Half of September 2018 ([Mekong Dam Monitor])

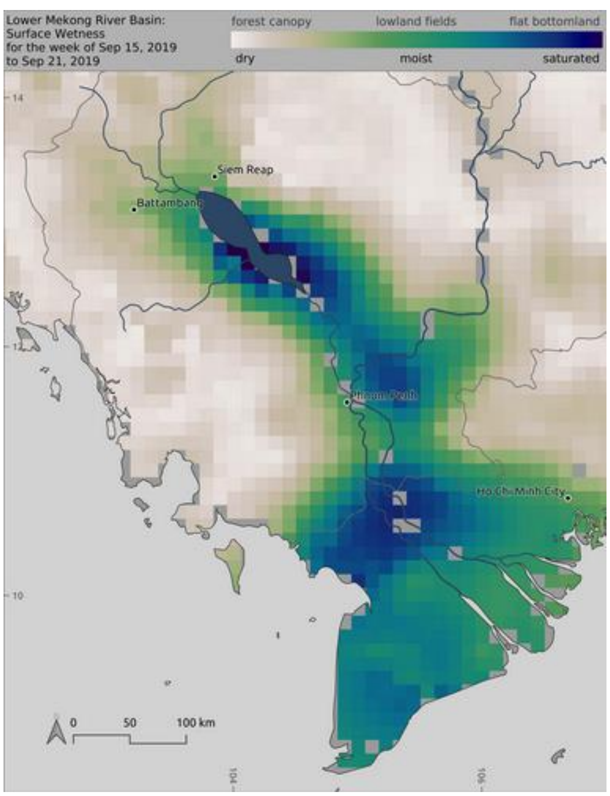


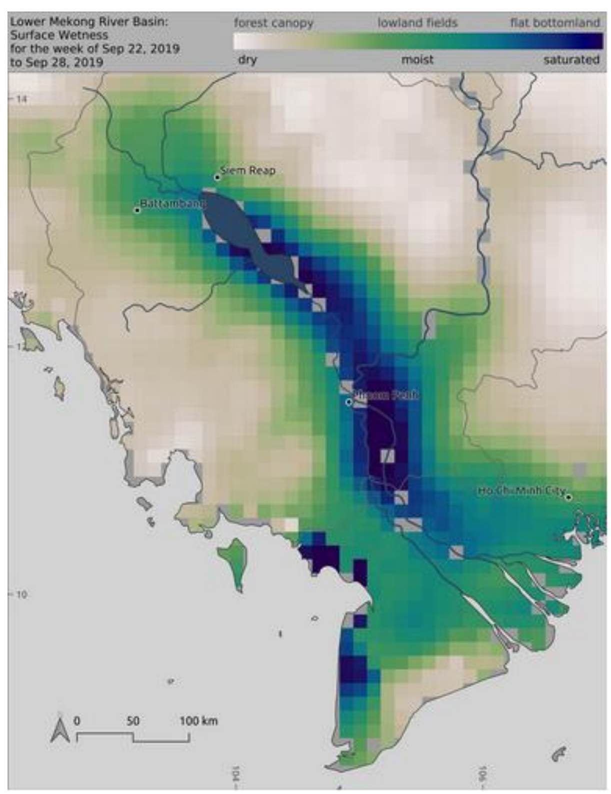
Figures 52 & 53 Lower Mekong Surface Wetness Map Second Half of September 2018 ([Mekong Dam Monitor])



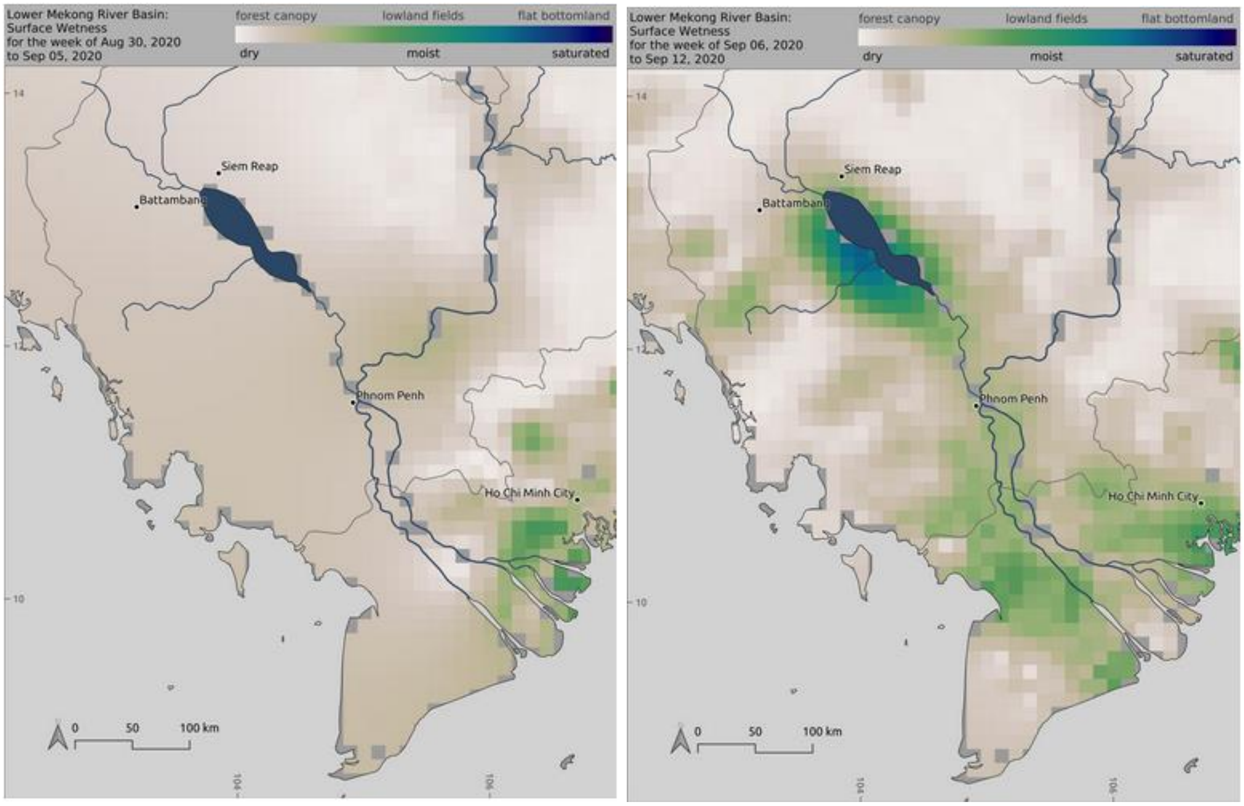


Figures 54 & 55 Lower Mekong Surface Wetness Map First Half of September 2019 ([Mekong Dam Monitor]())

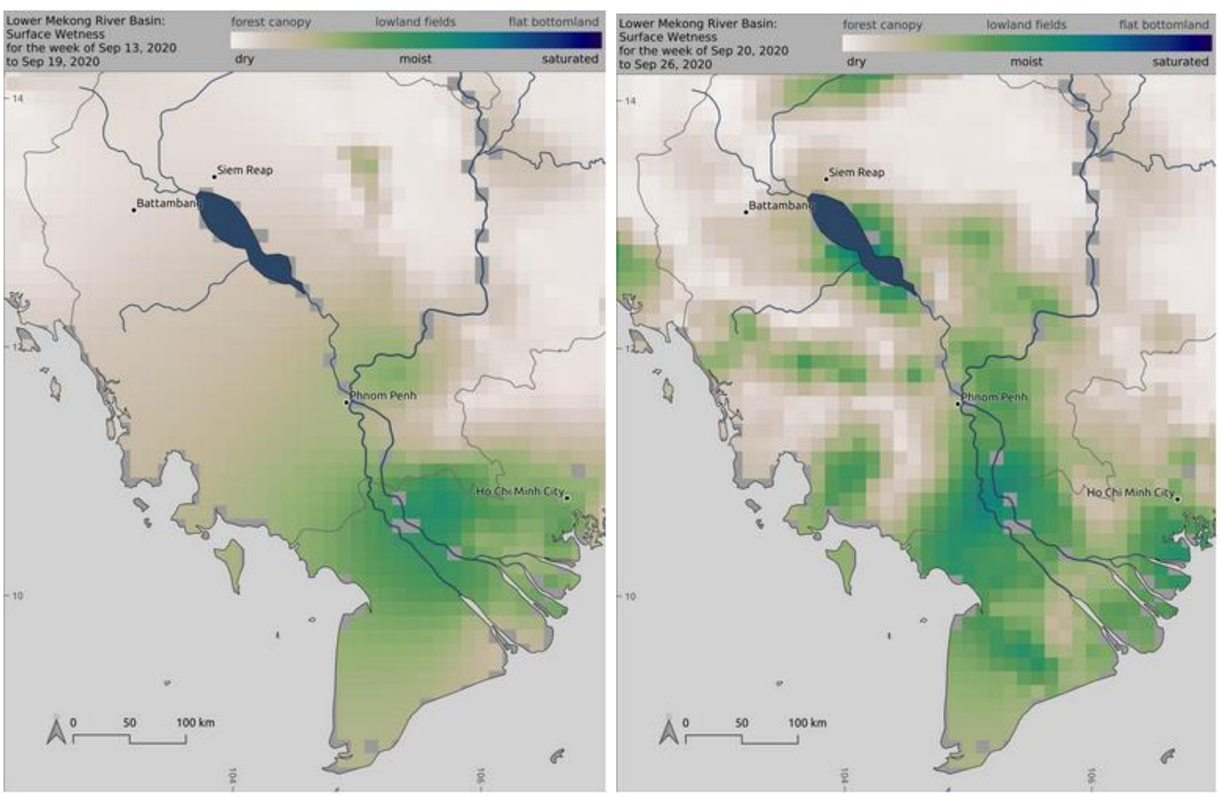




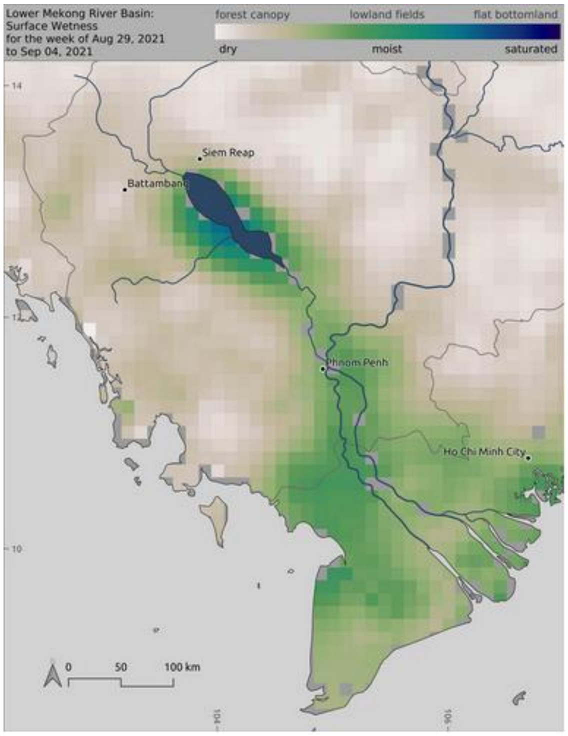
Figures 56 & 57 Lower Mekong Surface Wetness Map Second Half of September 2019 ([Mekong Dam Monitor]())



Figures 58 & 59 Lower Mekong Surface Wetness Map First Half of September 2020 (Mekong Dam Monitor)



Figures 60 & 61 Lower Mekong Surface Wetness Map Second Half of September 2020 (Mekong Dam Monitor)



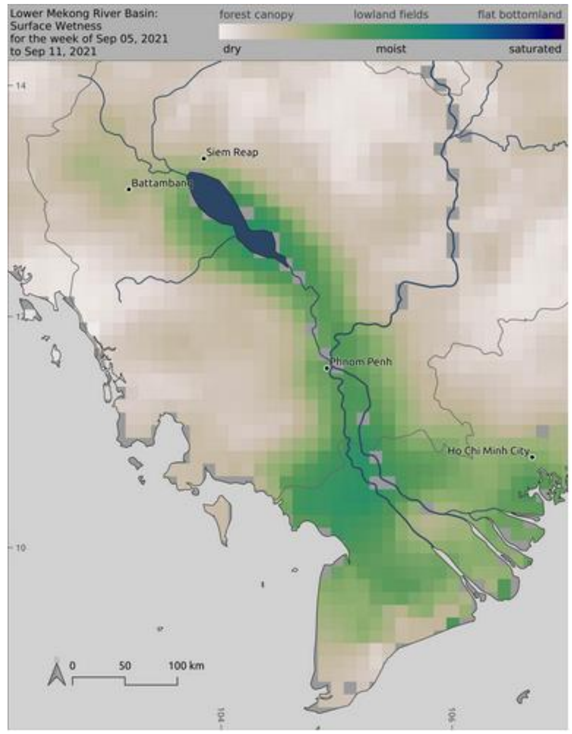
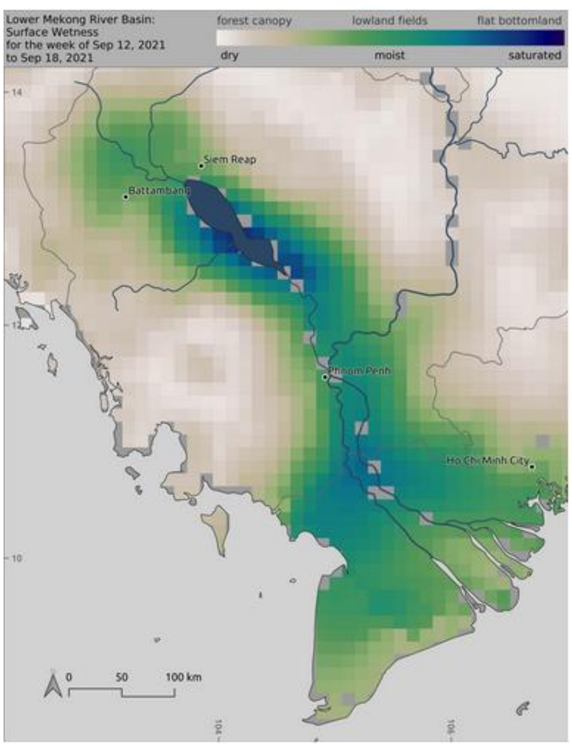
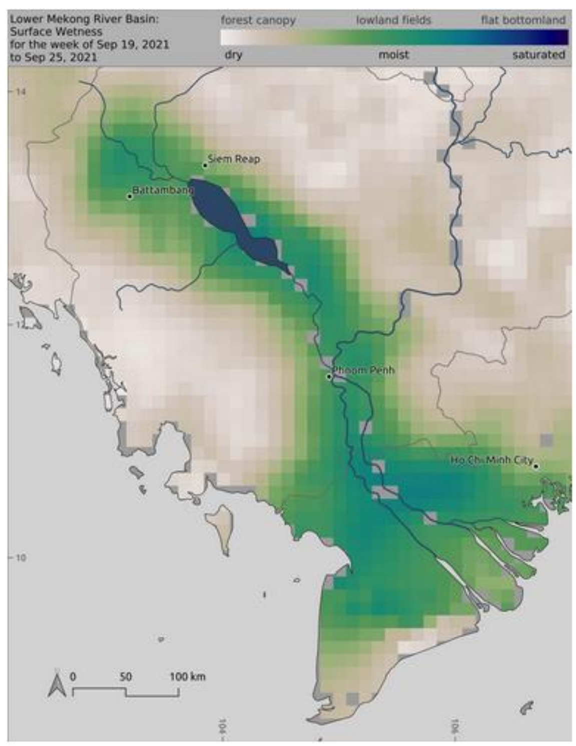
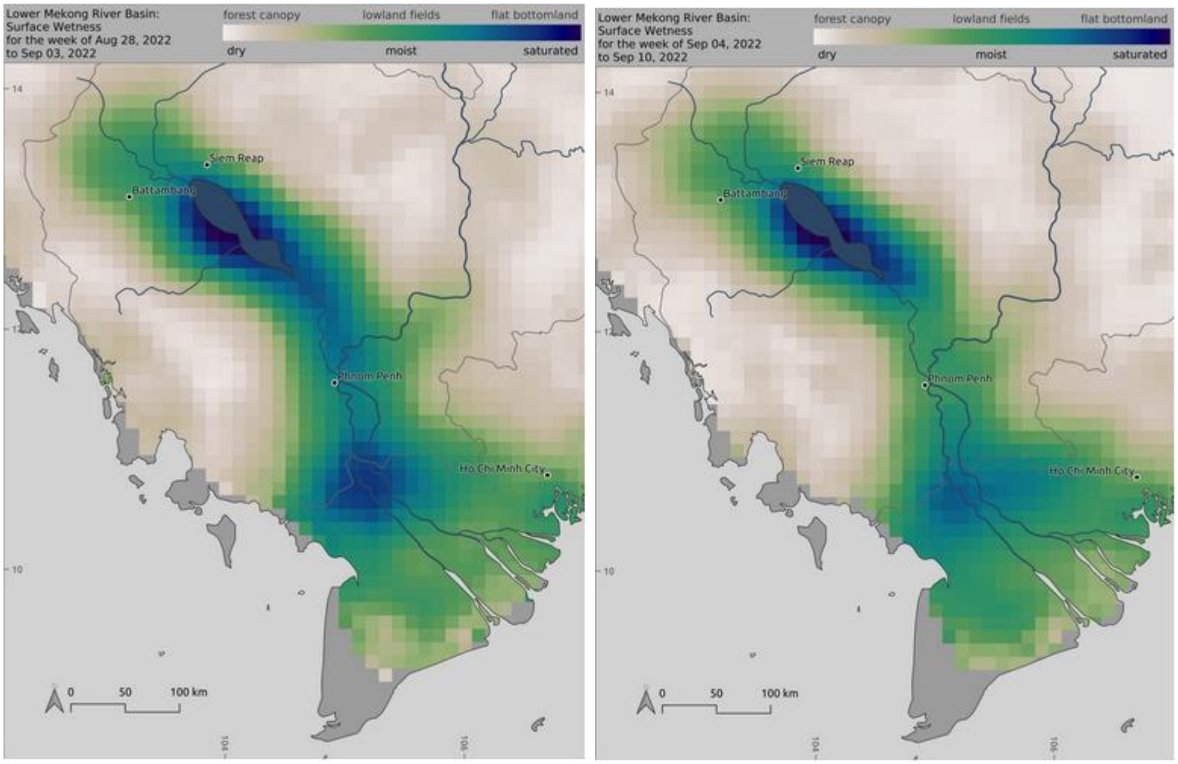


Figure 10 & 63 Lower Mekong Surface Wetness Map First Half of September 2021 ([Mekong Dam Monitor]())

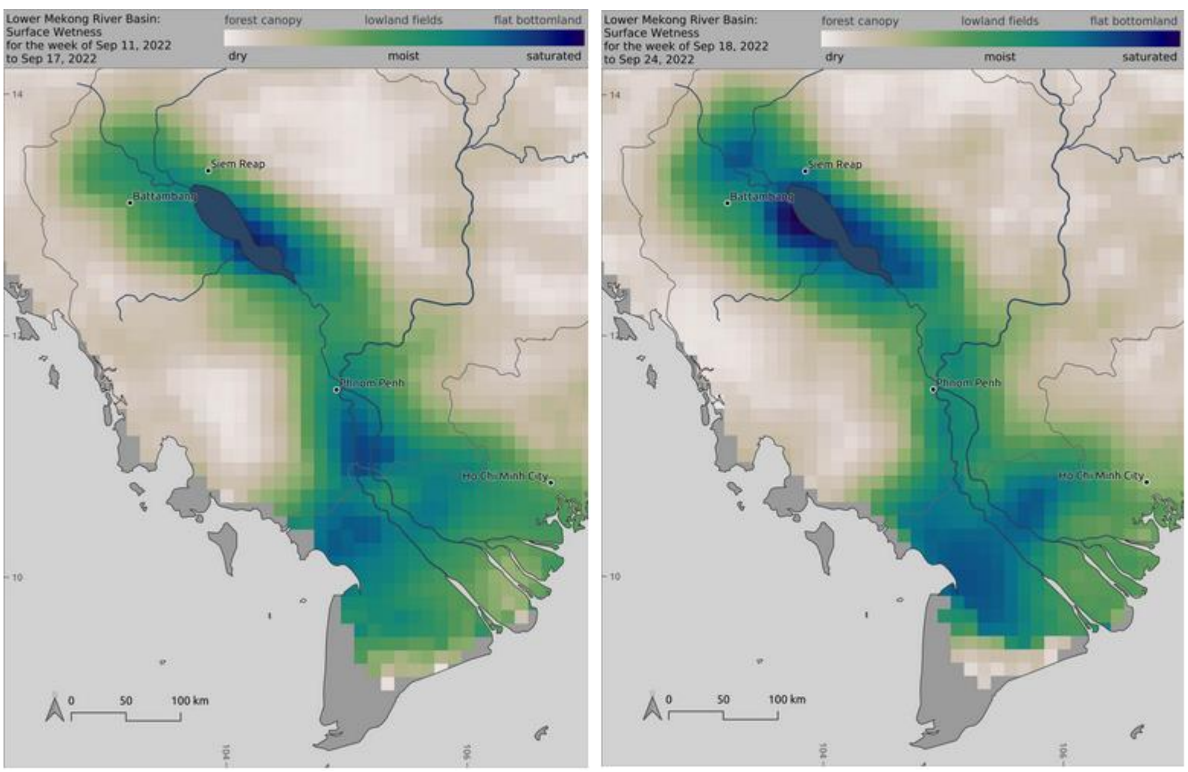




Figures 64 & 65 Lower Mekong Surface Wetness Map Second Half of September 2021 ([Mekong Dam Monitor]())



Figures 66 & 67 Lower Mekong Surface Wetness Map First Half of September 2022 (Mekong Dam Monitor)



Figures 68 & 69 Lower Mekong Surface Wetness Map Second Half of September 2022 (Mekong Dam Monitor)

The Lower Mekong Surface Wetness Map is a geospatial analysis product focused on the Stung Treng sub-basin. It captures the wetness-health of Lake Tonle Sap at a finer level of detail and allows for better analysis of the wetness tendencies of the sub-basin. In Figures 50-53 and 66-69, we can observe a much more normal wetness level for the sub-basin. While in Figures 58-61, September of 2020, we observe an astonishing drop in wetness. Based off of the precipitation analysis for this time period, we can say that there was a severe lack of rainfall at this time; contributing to the drought. Additionally, we can bring the data from the Tonle Sap Bottleneck River Level product to bear. It reveals a dip in the measure of water level, where a crest should appear; another indicator of health for Lake Tonle Sap.

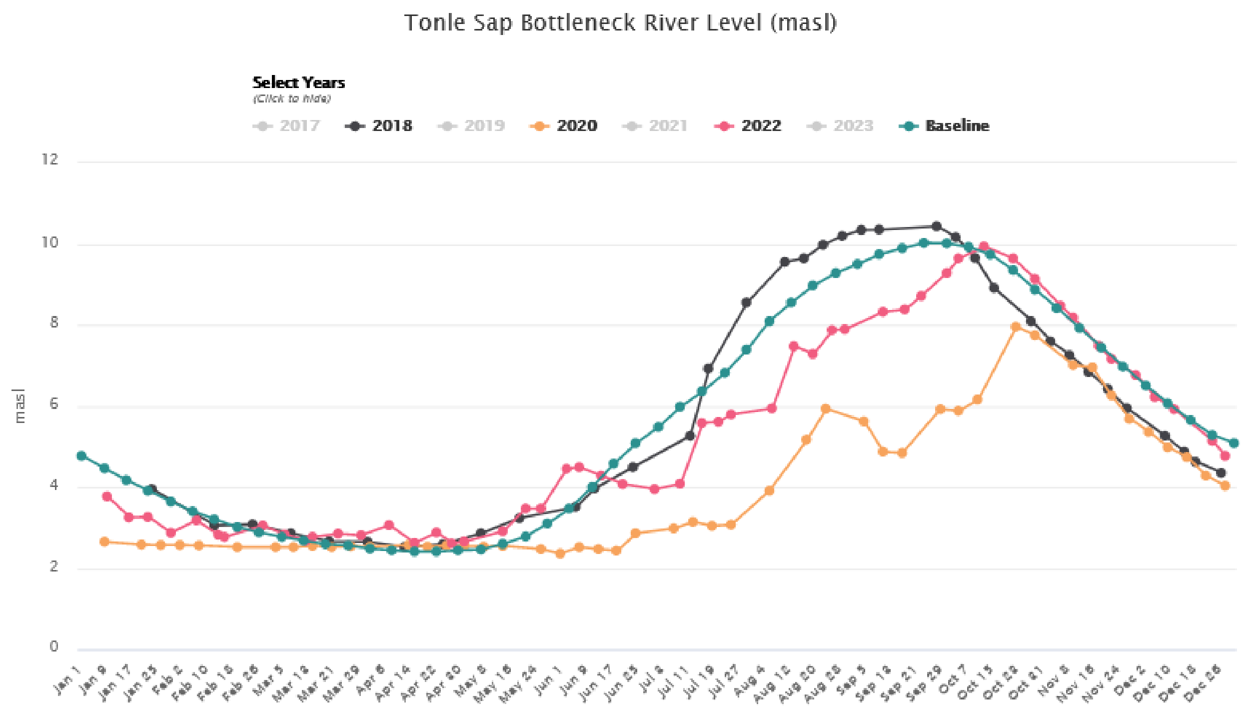
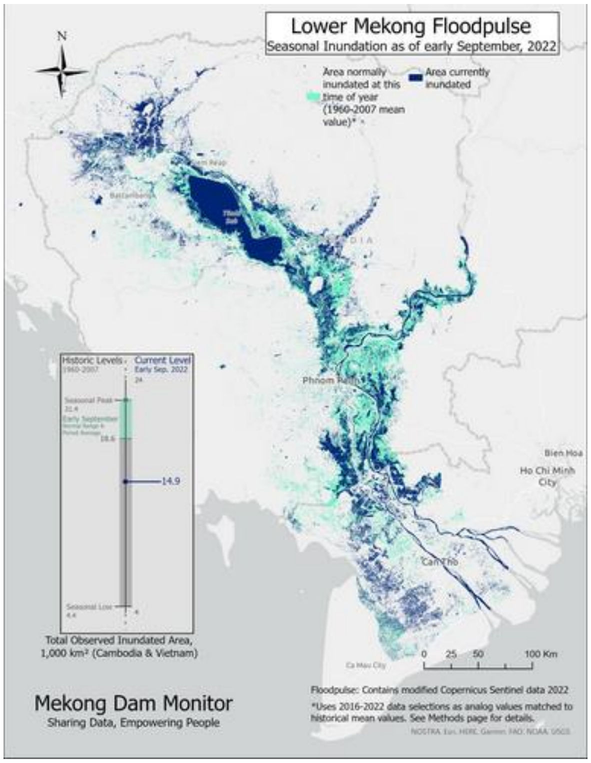
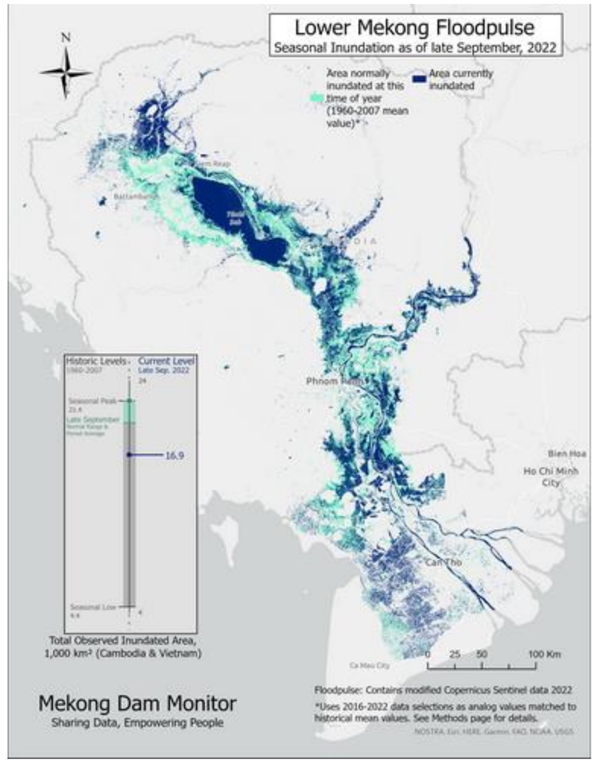


Figure 70 Tonle Sap Bottleneck River Level 2018, 2020, 2022 (Mekong River Monitor)

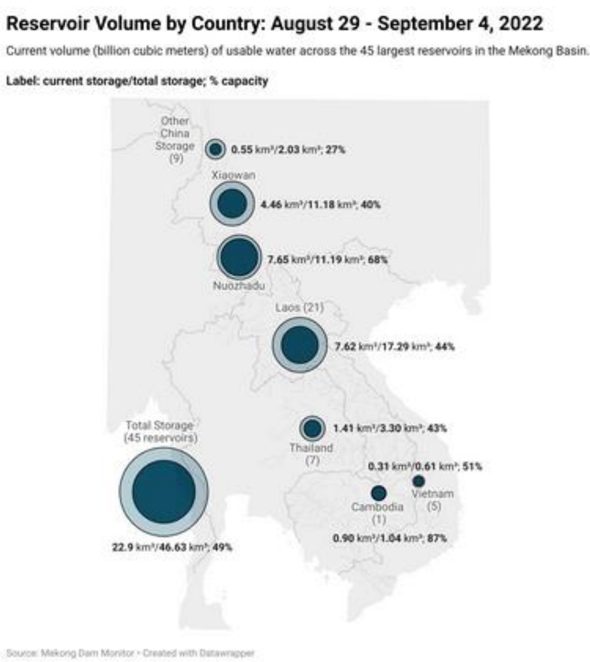
In 2020, the La Nina effect reduced the levels of precipitation normally observed. In Figure 70, the river level at the Tonle Sap Bottleneck is illustrated for 2018, 2020, and 2022. As observed in the previous precipitation, surface wetness, and flow level products, we can observe a commensurate dip for the years depicted.

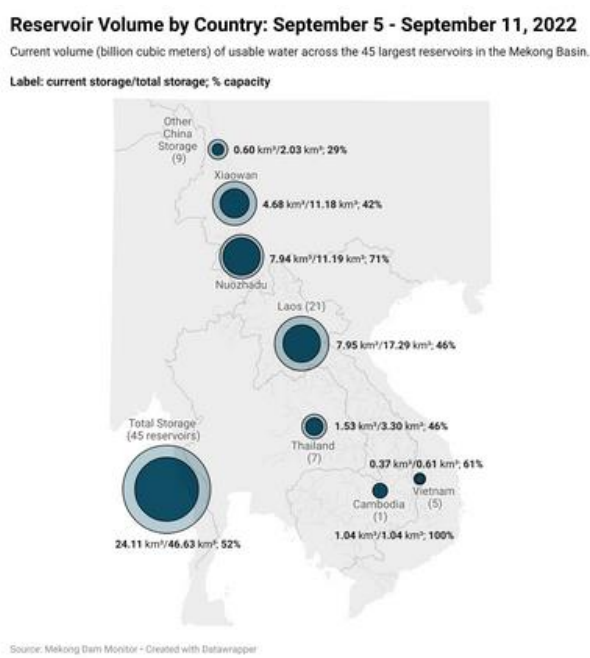
Two, new geospatial analysis products developed by the Stimson Center Dam Monitor, promise to assist in the monitoring of Lake Tonle Sap. The first is a measure of the Lower Mekong Floodpulse in the Stung Treng sub-basin. It graphically illustrates the levels of water with the mean surface extent from 1960-2007. This bi-monthly product is available from 2022 onward. The second product is a graphic depicting the Reservoir Volume by Country which reveals how much water Mekong River Commission and the People's Republic of China, are impounding. This is a very useful weekly product and is available from 2022 onward.



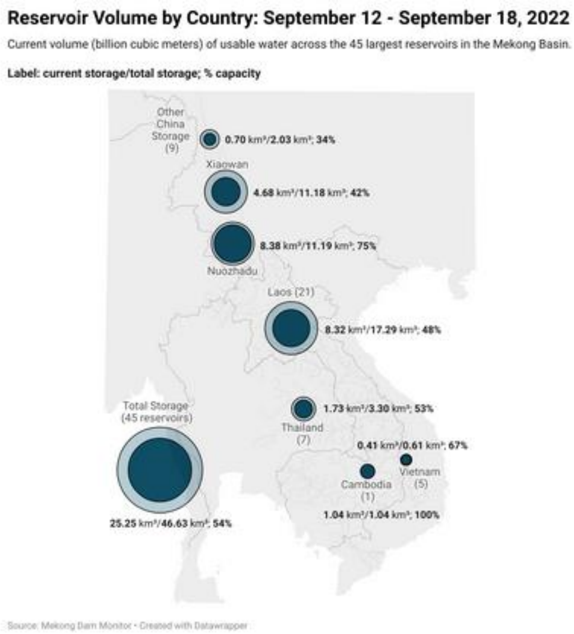


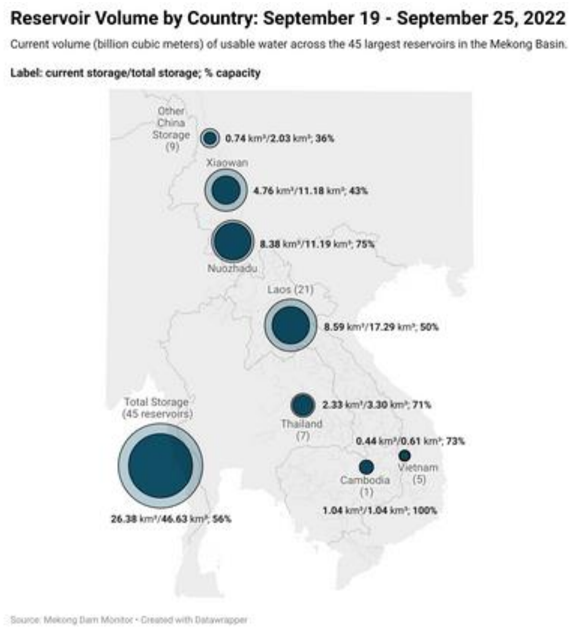
Figures 71 & 72 Lower Mekong Floodpulse First and Second Halves of September 2022 ([Mekong Dam Monitor](#))





Figures 73 & 74 Reservoir Volume by Country First Half of September 2022 ([Mekong Dam Monitor](#))





Figures 75 & 76 Reservoir Volume by Country Second Half of September 2022 ([Mekong Dam Monitor])

Reservoir volumes are calculated using arithmetically calculated elevation readings from Digital Elevation Models and full reservoir levels (Stimson Center, 2020). These are derived utilizing tables detailing reservoir volume at one-meter increments for all dams monitored on the Mekong which correspond to altimetry estimates of reservoir levels (Stimson Center, 2020). The volume readings estimate dead and active storage levels. Dead storage is calculated as water held behind the dam that will likely never flow downstream (Stimson Center, 2020). Active storage is water for hydropower production and may flow downstream via the dam (Stimson Center, 2020).

IV: Proposed Methodologies and Problem Solving Process:

Lake Tonle Sap is a complex freshwater ecosystem. The ability to capture the freshwater health of Lake Tonle Sap may executed by utilizing Conservation International's Freshwater Health Index (FHI) (Conservation International, 2022) (Freshwater Health Index, 2022) (Justine Spore, 2021) (Joey Lindsay, 2021). Conservation International is in the process of applying the FHI around the world. Its purpose is to assess the safety status of the most important commodity in the world. This basin-by-basin approach details the presence or absence of leading indicators to freshwater health. The FHI is a remote sensing and geospatial analysis tool which national freshwater management teams can empower themselves with to make confident, informed decisions.

Conservation International has set an achievable goal of refining the FHI and catalyzing its widespread adoption to ensure at least one billion people in the world's most water-insecure basins benefit from FHI assessments (Conservation International, 2022). The FHI helps by transforming difficult to assimilate data into a quantifiable 0-100 health scale, tracks freshwater health over time, and evaluates potential environmental impact from sundry vectors (Freshwater Health Index, 2023).

The FHI evaluates basin health by assessing three separate components: Ecosystem Vitality, Ecosystem Services, Governance and Stakeholders (Freshwater Health Index, 2023).

Figure 77 Freshwater Health Index Components (Freshwater Health Index)

Basins are given a specific score for each of the three components, calculated on a 0-100 scale (Freshwater Health Index, 2023). Higher values indicating a more sustainable, healthy, freshwater ecosystem than lower values (Freshwater Health Index, 2023). This separation of values provides a more refined perspective of freshwater health for a given basin. The analysis performed is conducted completely with remotely sensed data.

Figure 78 Freshwater Health Index Component Scores (Freshwater Health Index)

Unfortunately, one of the drawbacks with this method is its reliance upon the Canadian Councel of Ministries of the Environment (CCME) calculation for the Water Quality Index (Freshwater Health Index, 2023) (Shweta Tyagi, 2023).

Attributes	
Scale of calculation:	Sub-basin/monitoring station, aggregate to basin
Range of Output:	100-95 indicates excellent water quality; 80-94 indicates good water quality; 79-65 indicates fair; 64-45; <45 indicates poor water quality
Reference:	Canadian Water Quality Index (CCME 2001)
Type/Class of Input required:	Total Suspended Solids (TSS), Total Nitrogen (TN), Total Phosphorus (TP), Dissolved Oxygen (DO) time series and concentrations of other pollutants of interest.
Suggested source of 'minimum' data to enable calculation:	Data requires local input from observation or models for minimum 4 pollutants with at least 4 data points each.

Figure 79 Freshwater Health Index Component Scores (Freshwater Health Index)

While useful in calculating the water quality in similar latitudes, the latitudinal differences between Cambodia and Canada may make it difficult to reconcile the results. An additional strategy must be considered to provide additional water quality insight.

$$WQI = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}$$

Figure 80 Canadian Water Quality Index Formula ([Water Quality Assessment](#))

Canadian Council of Ministers of the Environment (CCME) WQI		
1. Represent measurements of a variety of variables in a single number. 2. Flexibility in the selection of input parameters and objectives. 3. Adaptability to different legal requirements and different water uses. 4. Statistical simplification of complex multivariate data. 5. Clear and intelligible diagnostic for managers and the general public. 6. Suitable tool for water quality evaluation in a specific location 7. Easy to calculate 8. Tolerance to missing data 9. Suitable for analysis of data coming from automated sampling. 10. Combine various measurements in a variety of different measurement units in a single metric.	1. Loss of information on single variables. 2. Loss of information about the objectives specific to each location and particular water use. 3. Sensitivity of the results to the formulation of the index. 4. Loss of information on interactions between variables. 5. Lack of portability of the index to different ecosystem types. 6. Easy to manipulate (biased). 7. The same importance is given to all variables. 8. No combination with other indicators or biological data 9. Only partial diagnostic of the water quality. 10. F_1 not working appropriately when too few variables are considered or when too much covariance exists among them.	[51,52]

Figure 81 CCME Demerits ([Water Quality Assessment](#))

An alternative measure; the Soil and Water Assessment Tool (SWAT), may be utilized to conduct a certain measure of water quality. The SWAT is a public domain model developed jointly between the USDA Agricultural Research Service and Texas A&M AgriLife Research (Environmental Protection Agency, 2023). The SWAT is a scalable model which simulates the quality and quantity of surface and ground water and predicts the environmental impact of land use, land management, and climate change (Environmental Protection Agency, 2023).

The FHI and SWAT analyses require in situ data which is acquired from multiple online sources available for free to the public. A recent analysis of Lake Tonle Sap utilized Shuttle Radar Topography Mission (SRTM) data to construct a digital elevation model for the SWAT (Joey Lindsay, Tonle Sap: Agriculture III - Evaluating Changes in Ecosystem Vitality and Freshwater Health in the Tonlé Sap Basin using Remotely Sensed Data, 2023). The Gravity Recovery and Climate Experiment (GRACE) was also utilized to provide groundwater storage information for the FHI, while Landsat 5TM, 7ETM+, and 8 OLI were used to derive the Normalized Difference in Vegetation Index to track vegetation changes from 2000 to 2020 (Joey Lindsay, Tonle Sap: Agriculture III - Evaluating Changes in Ecosystem Vitality and Freshwater Health in the Tonlé Sap Basin using Remotely Sensed Data, 2023). The NDVI is a valuable geoprocess performed on multi-spectral remotely sensed imagery to detect healthy vegetation.

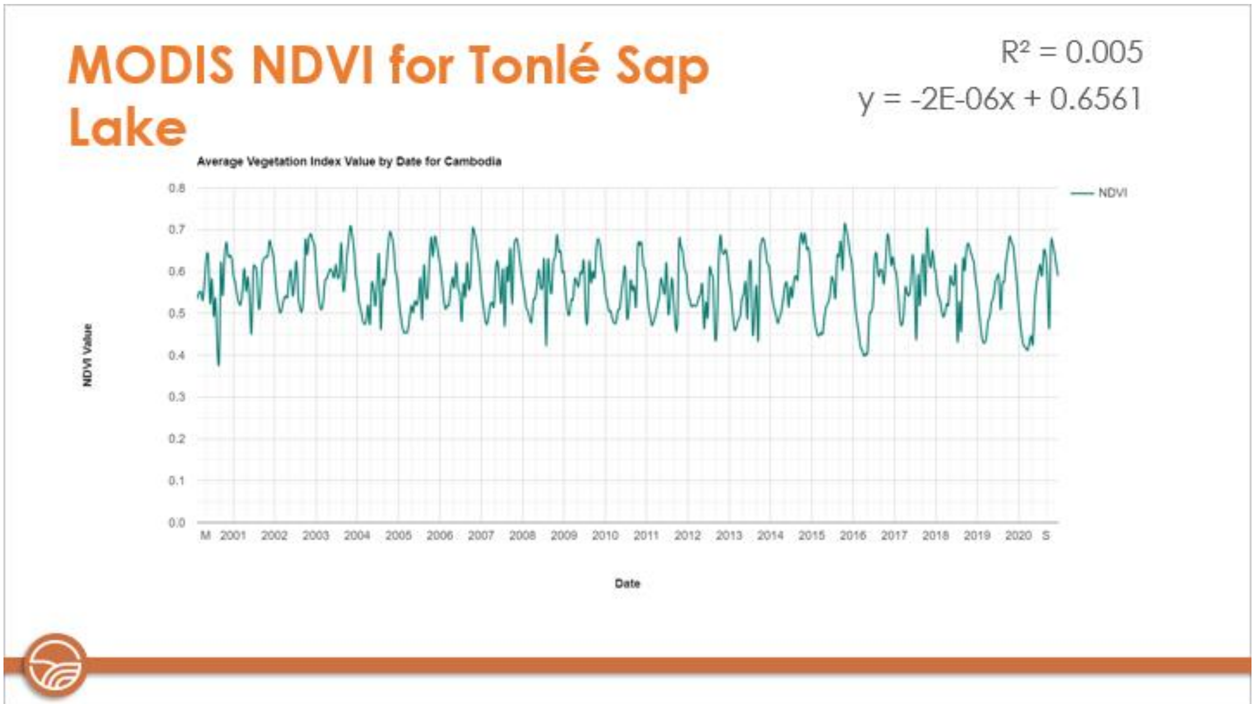


Figure 82 MODIS NDVI for Tonle Sap Lake (NASA)

In Figure 82 we can see that there is a greater total variance between the crest and trough each year. This is indicative of an increased worsening of vegetative health around Lake Tonle Sap. The smoother slopes, where smaller crests and troughs have decreased, are indicative of an increased aridness almost certainly due to climate change affecting the precipitation in the basin. Healthier precipitation patterns for Lake Tonle Sap would see an increase in the smaller crests and troughs a precipitation comes into the basin. Note how smooth the slopes are from the end of 2018 to the beginning of 2021.

V: Assumptions:

Limited assumptions are available for the above methodologies:

1. The remotely sensed data acquired is free of error
2. Processing methodologies are executed free of error
3. Findings are peer-reviewed

Remotely sensed data available from NASA, the USGS, the ESA, and other online resources are more frequently utilized in Google Earth Engine to provide enhanced, cloud-based analysis. This process is conducted remotely in the cloud. However, the analyst possesses much oversight through process management and a large community to assist in quality assurance. The quality assurance extends beyond the actual data itself and much peer-reviewed coding is available to ensure that the findings and even experiments themselves have met the professional rigor usually found in lengthier, more time-consuming environments.

Further assumptions for Lake Tonle Sap include:

1. Lake Tonle Sap is becoming more arid, thus decreasing the fishing yields
2. Climate change will continue to be the chief culprit in Lake Tonle Sap's distress
3. Increased damming activity will continue in the basin; thus decreasing Lake Tonle Sap's ability to heal itself

VI: Findings:

While remote sensing methodologies alone are effective in determining Lake Tonle Sap's environmental health in a myriad of indicators such as water quality, erosion, vegetation distress, etc. It must be coupled with geospatial analysis of the rest of the basin in order to ensure that member nations of the Mekong River Commission can act in a cohesive fashion to ensure that it can be kept healthy. By utilizing the Mekong Dam Monitor's Reservoir Volume product with the remote sensing methodologies outlined above, it may be possible to predict emergent threat thresholds to Lake Tonle Sap.

In order to achieve a comprehensive, basin-wide effort, a multilateral coordination system must be agreed upon to open up the active storage waters to send downriver whenever remotely sensed signatures detect a spectrum of concerning values. In fact, if the process of flood pulsing is properly accounted for, it may be possible for the Mekong River Commission members to simulate precipitation adversely affected by climate change; thus lowering the impact of an every changing world outside their control.

Barriers exist but only through a concerted effort between harmonious partners can an effective solution be implemented.

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