Multispectral and Statistical Analysis of Damming on the Lower Mekong River Basin

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I. Abstract:

The Mekong River Delta is threatened by salinization effects and normative water flow disruption due to damming by the Chinese and other nations. Other risk factors such as domestic over-use, low-elevation, and sea-level rise. The amount of water from rainfall and ground sources contribute to the normative water flow on the Delta from sources far to the north in the Upper Mekong River Basin in China and nearer by in the Lower Mekong River Basin which consists of Cambodia, Lao PDR, Thailand, and finally Vietnam. This natural function created a bountiful land of agricultural economic activity accounting for a significant portion of the rice production of the country of Vietnam. The Mekong River flows from China to the north down through Laos PDR, makes up much of the Thai-Lao PDR border, and then dives through Cambodia before it reaches the southern tip of Vietnam. In recent years the Mekong River has experienced historic low levels which has reduced water levels precipitously. Due to these low levels the effects of salinization have begun on the Delta. The present study utilizes multi-spectral LandSat 8 Imagery Collection 2 Level 2 data science products to formulate salinization discovery through Land Cover Use Change and hypothesis. This study also quantifies the effects of the role of salinization in essentially the agricultural economic loss of the southern tip of Vietnam.

II. Problem Background:

The Mekong River Delta is a low-lying area on the southern tip of Vietnam which is facing increased normative water flow disruption due to Chinese damming upriver (Yuka Kiguchi, 2016) (A. Basist, 2020) (Mekong River Commission, 2018). Although seasonal fluctuations along the river exist, structural water loss as a result of damming on the Mekong by the Chinese has exacerbated the problem in recent years (Mekong River Commission, 2018) (A. Basist, 2020). The cyclical process of wet and dry seasons persists in the Mekong River Basin due to normative weather patterns which are unaffected by damming. The rainfall, a product of fickle monsoon behavior, was measured using 119 riverine hydrological stations in the Lower Mekong River Basin (Mekong River Commission, 2020). Seasonal rainfall is responsible for a surge often twice the normal water levels along all segments of the Mekong averaging about five months in duration (Mekong River Commission, 2020). The effect of normative waterflow to the Mekong River Delta is crucial to replacing nutrients in sediment carried off throughout the year (Mekong River Commission, 2018). The lack of sedimentary flux being carried down river due to extant and planned damming will create a deleterious combination for the Delta which will contribute to its acidification and if left unchecked, the geomorphic progression to a salinized wasteland much like the Yellow River Delta in China (Zhuoran Wang, 2016) (Singh, 2020) (Stimson Center, 2021) (Gao Fan, 2011).

Although it is convenient to lay all blame at the feet of Chinese damming on the Mekong, a careful analysis reveals that late-arriving monsoons and their disproportionate impact on the Lower Mekong River Basin damming resulted in a daisy-chain of events which contributed to the disruption of the normative flow of water to the Lower Mekong River Basin and Delta in 2020 (Mekong River Commission, 2020). In effect, Chinese damming on the Mekong River during periods of decreased rainfall only exacerbated an already dry year in 2020 (Mekong River Commission, 2020). The Mekong River Delta experienced historic droughtlevels due to the combination of pre-existing damming and late monsoon activity brought about by a La Nina Effect (Mekong River Commission, 2020).

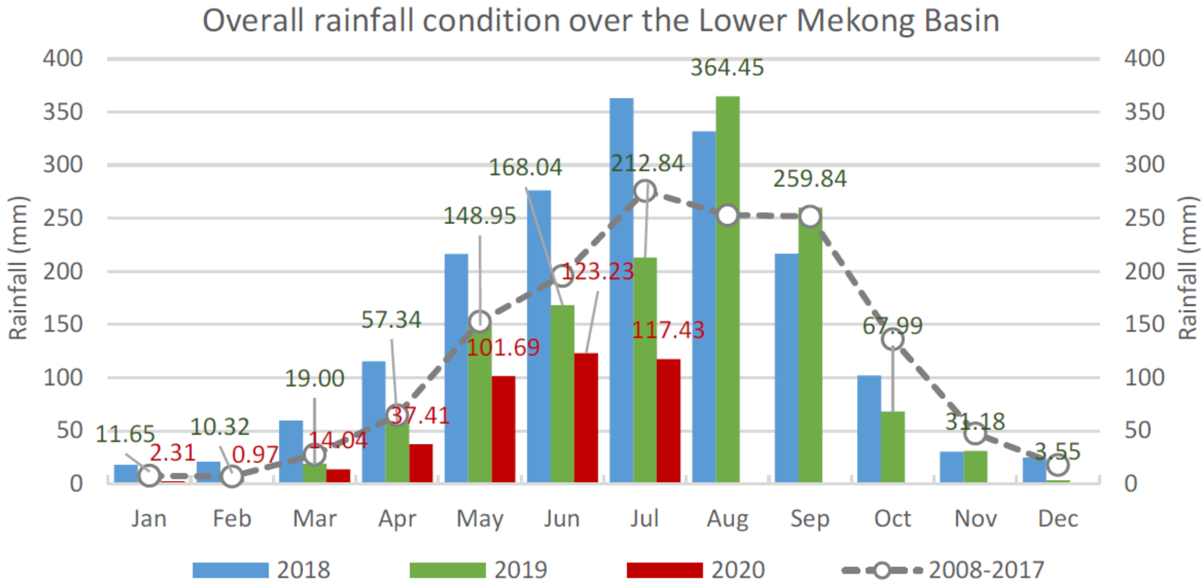


Figure 1. Overall monthly rainfall of 2018-2020 over the Lower Mekong River Basin, compared to the long-term condition of 2008-2017, generated and interpolated from 119 stations in the Lower Mekong Basin

One could be forgiven to conclude that the dams effecting the greatest impact are located directly on the Mekong River in China and not on tributaries of the Lower Mekong River Basin (Yuka Kiguchi, 2016) (Mekong River Commission, 2020). China's contribution of waters is only 16%; of mostly snowmelt from the Tibetan Plateau; not rainfall from La Nina (Yuka Kiguchi, 2016) (Mekong River Commission, 2018). China may have the largest dams on the Mekong River and may be unintentionally cementing its position as the worst offender of retaining water. However, it does withhold significant nutrient-rich sediment from downstream nations with no less than 10 dams in the lower stretch of the Upper Mekong Basin and further damming planned in Xizang (northern part of the Upper Mekong Basin) (The Mekong River Commission, 2018). Sedimentary concentration reduction from China to the rest of the Mekong River Basin is confirmed to be as high as 60-70% with total sedimentary reduction into the LMB at 55% in 2015 (The Mekong River Commission, 2018). The life-giving sediment that is retained in China has implications throughout the entire river and works against the geomorphology of the Mekong River Delta shoreline as erosion, exacerbated by climate change, impacts the coast (The Mekong River Commission, 2018). Approximately 500 hectares of land are lost annually in the Delta alone costing Vietnam $12.5 million USD annually (The Mekong River Commission, 2018).

The impounded water also creates a multidimensional threat in the form of seepage and evaporation (Mekong River Commission, 2020). Due to the mountainous topographical nature in Lao PDR, seepage is a very serious issue which will only be exacerbated by an increased number of dams (Mekong River Commission, 2020).

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

Table 1. Proposed Reservoir Development in the Four Countries (Mekong River Commission, 2020) (including mainstream reservoirs)*

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)

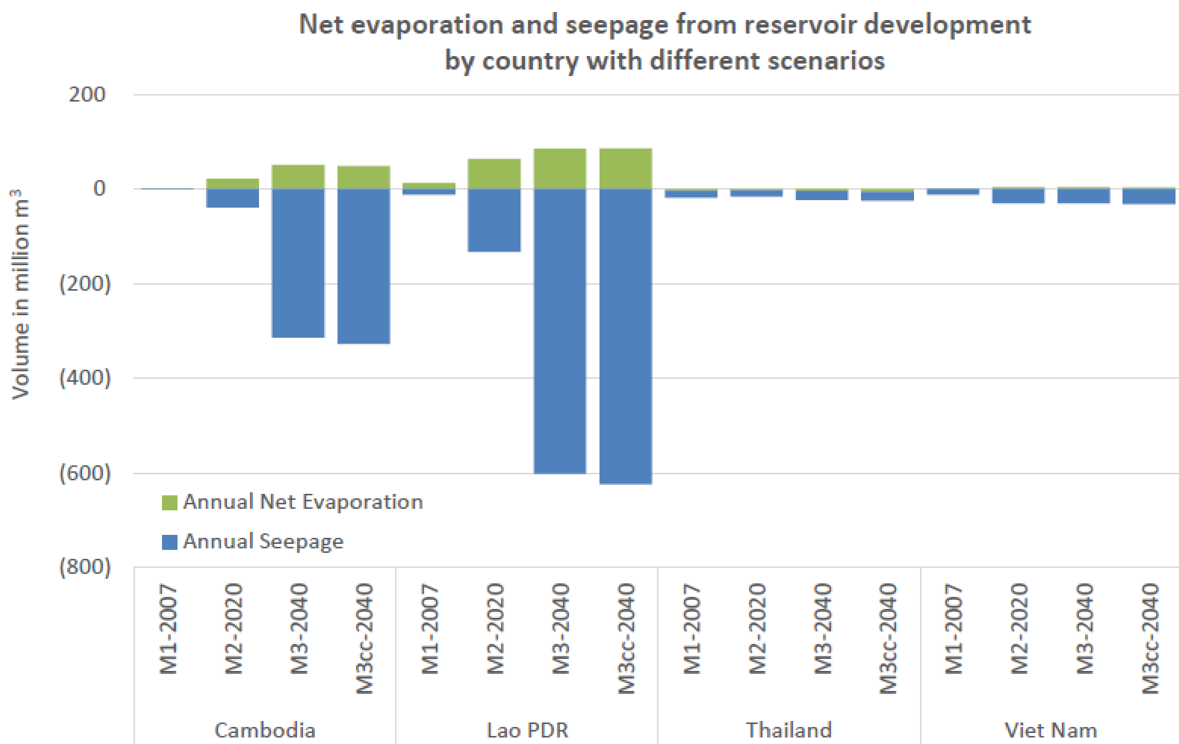


Figure 2. Annual Net Evaporation (sum of evaporation and rainfall and seepage from reservoir by country with different scenarios) (Mekong River Commission, 2020)

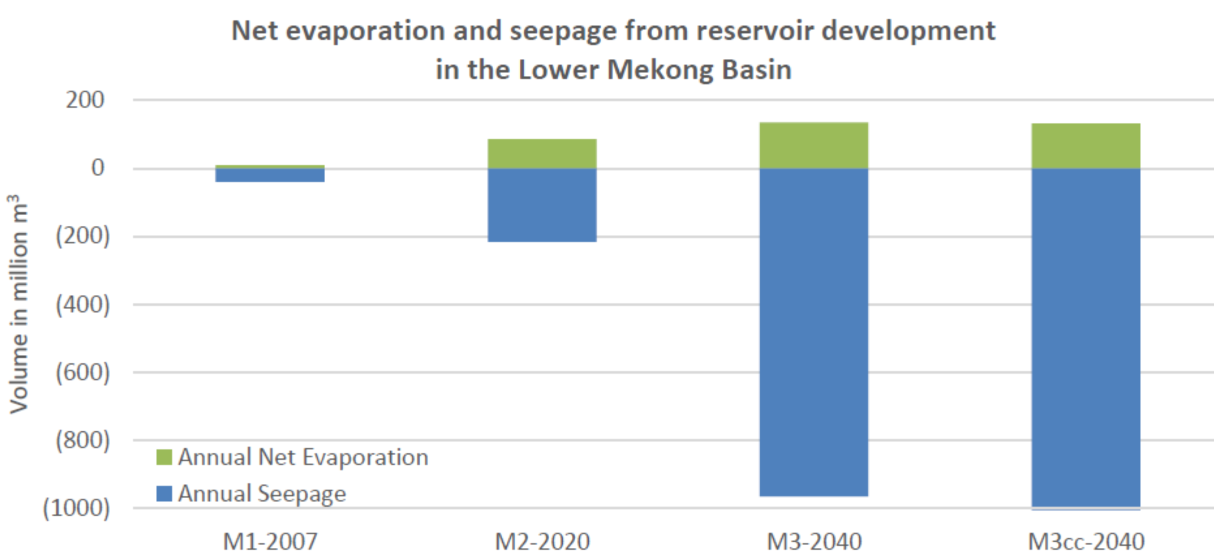


Figure 3. Annual net evaporation (sum of evaporation and rainfall) and seepage from reservoir development in the Lower Mekong Basin. (Mekong River Commission, 2020)

Potentially interested customers to resolving these issues are currently in a relevant, organizational body called the Mekong River Commission since 1995 (Mekong River Commission, 2021). The member states of the Mekong River Commission are located in the Lower Mekong Basin and deal with the challenges of damming or face debilitating economic consequences. One of the most at-risk members of the Mekong River Commission is the one furthest downstream; Vietnam (The Mekong River Commission, 2018). The Mekong River Delta represents 51% of national rice production, 58% of protein supply from rice sectors, 25% of total fisheries, 8% of hydropower, and 22% of tourism in Vietnam alone (The Mekong River Commission, 2018).

A very serious question facing the nations of the Mekong River Commission and in particular, Vietnam is; what are the consequences of damming on normative waterflow?

The consequences of Chinese damming are immediately having a deleterious effect on the Lower Mekong Basin (A. Basist, 2020) (Mekong River Commission, 2018) (The Mekong River Commission, 2018). The agricultural economic impact will drastically change the way of life currently enjoyed by all Vietnamese, especially those residing in the Mekong River Delta (The Mekong River Commission, 2018). Unfortunately, 2020 may have been the straw that broke the camel's back with severe saltwater intrusion into the Mekong River Delta due to lower water levels upstream (se, 2021). With intrusion up to 70km inland from the South China Sea, it will likely increase the salinity rate of four grams per liter which is four times the amount most crops and fruit trees can tolerate salinity (se, 2021). The reason for the increased salinization from 2020 may have something to do with the Jinghong Hydropower reservoir in China reducing water discharge by approximately 50% between January 5th and 24th (se, 2021). China has historically utilized the Dry Season as an opportunity to release impounded water but is increasingly disruptive of this flow. Moreover, the water which China releases is predominantly glacier melt from the Himalayas; a source of water, very little affected, by the poor Monsoon season brought about by La Nina, Fig 4. This base load water represents a necessary amount for the dry season, Fig 4.

Figure 4. Mekong River Basin Seasons (Mekong River Commission, 2021)

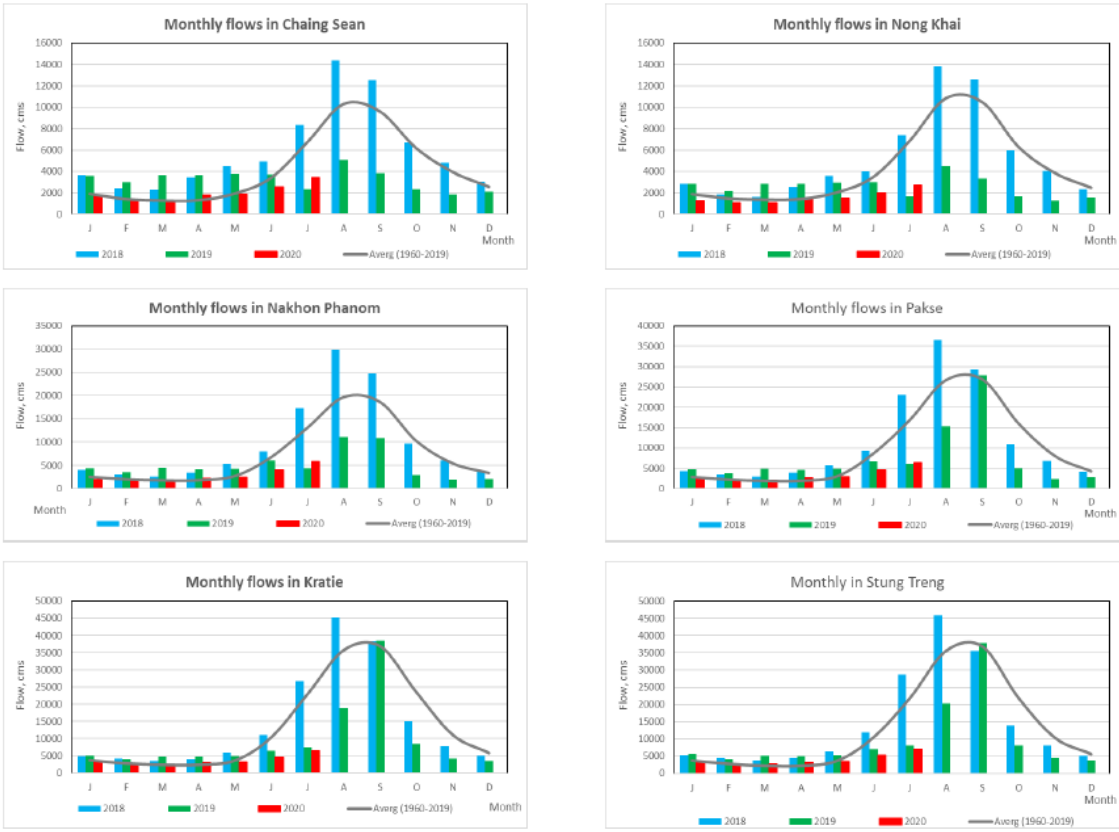


Figure 5. The 2018, 2019, and 2020 monthly flow calculated at selected sites on the Mekong mainstream from Chiang Saen to Stung Treng compared to the long-term averages (Mekong River Commission, 2020)

The Delta is the biggest producer of Vietnam’s rice, fruit, and seafood (se, 2021). The destruction of this extremely productive agricultural economic activity will trigger massive food insecurity and shake the social foundations of Vietnam. Although Vietnam is doing well overall economically, any nation facing the economic shock of losing its breadbasket and tourism powerhouse will cause widespread stagnation at the very least (Stimson Center, 2021). As the social fabric of Vietnam becomes frayed, the political threads will begin to tear possibly into two factions; those politicians from regions benefitting from Chinese Belt and Road Initiative projects and those suffering from Chinese water politics upriver. Ultimately there is no amount of Belt and Road Initiative projects that will outweigh the economic impact of losing the Mekong River Delta.

Not all of Vietnam is suffering from Chinese involvement. In Hanoi, investment in the Cat Linh-Ha Dong metro line has been under construction since October 2011 (Hiep, 2018). And Hanoi is not the only one to receive the attentions of China. China has its eye on the Haiphong Port Facility near Hanoi and is looking to capitalize on its favorable geographic location economically (Freitas, 2017) (Chan, 2017). Ultimately, the Chinese Belt and Road Initiative projects in the North of Vietnam in Hanoi and the agricultural destruction of South Vietnam’s breadbasket may create a politically unstable situation between North and South. While one side is enriched by Chinese investment; one side is destroyed by it.

As a result of economic degradation and social upheaval in Vietnam, its military readiness will be frayed as its limited capacity will be pulled more and more into internal security roles from external security roles. This loss in external military and geopolitical pressure will embolden Chinese ambitions in the South China Sea and almost certainly lead to annexation of offshore Vietnamese territory or the offer of annexation to Northern Vietnam.

Vietnamese infrastructure in the Mekong River Delta will be negatively impacted as water resources dry up and municipalities face potable water shortages. During the 2019-2020 dry season four grams per liter affected 1.68 million hectares of land; approximately 42.5% of the Delta's total area (se, 2021). 42,000 hectares of rice, 1,200 hectares of vegetables and other crops, and 8,700 hectares of aquaculture were damaged (se, 2021). 96,000 local households faced a shortage of clean water for daily use (se, 2021). The reduction in water from China is particularly impactful as this is base load Mekong River water and not monsoon rainfall. From 1993 to 2018 the Chinese built a total of 11 dams totaling 47.7 billion cubic meters impounded in the Upper Mekong Basin (A. Basist, 2020). This means that the base load of water being supplied from China during the dry season will be even less than it was during the 2019-2020 dry season (Mekong Water Monitor, 2021).

III. Maps & Descriptive Statistics:

In Figure 5 Chinese dams are detected releasing unnatural pulses of water during the dry season of the Mekong River due to hydropower generation management (A. Basist, 2020). The natural model of water flow shown in Figure 1 reveals that this is not a normative waterflow pattern (Mekong Water Monitor, 2021).

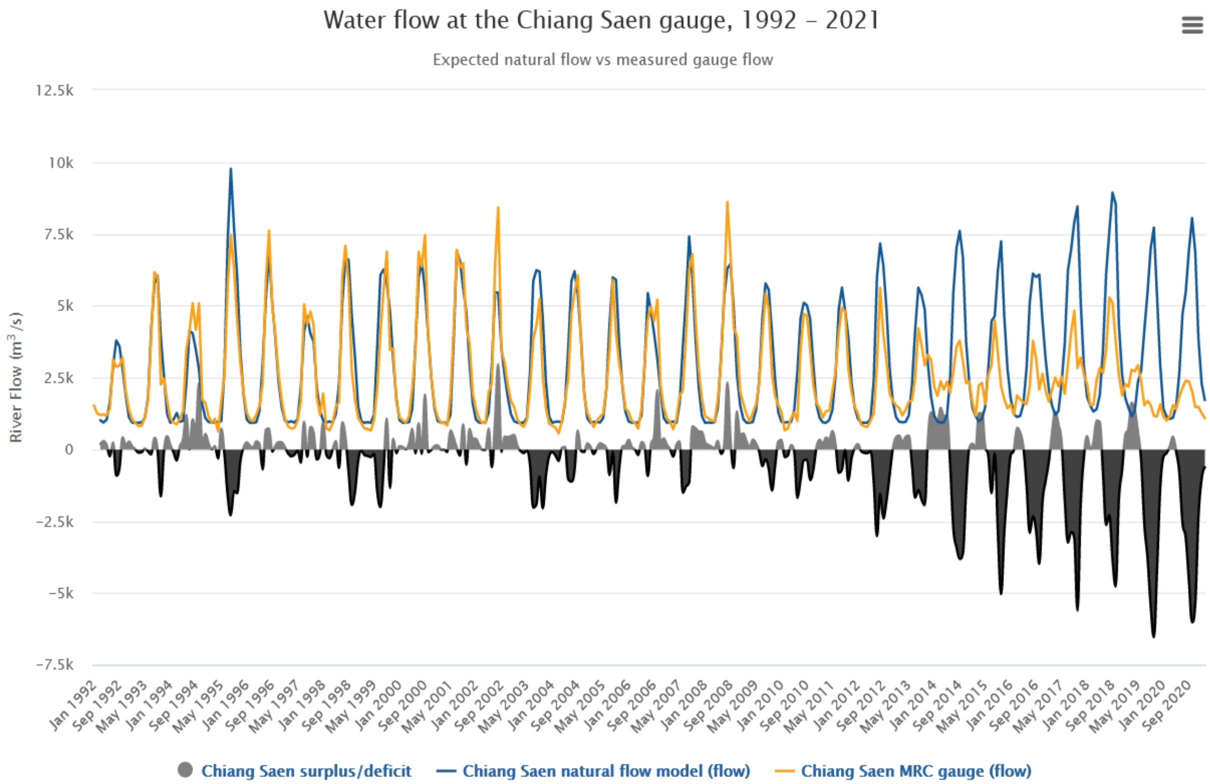


Figure 6 Water flow at the Chiang Saen Gauge, 1992-2021, courtesy of the Stimson Center & Mekong River Commission. *https://monitor.mekongwater.org/modeling-natural-river-flow/?v=1612886611078*

In Figure 3, the effects of increased Chinese damming may be detected by the increasingly differential surpluses and deficits detected at the Chiang Saen MRC gauge. These differences may be inferred as the electrical production of China's damming cascade on the Upper Mekong River Basin increases over time in Table 3. An enlarged portion of the Normative Water Flow from China's Upper Mekong River Basin to the Mekong River Commission's Lower Mekong River Basin may be observed in Figure 6. Note how closely the Gauge and Model follow each other while the Residual's deviation is markedly lower than in the 2010's. In Figure 7, the Mekong River flow Residual vacillates, while in Figure 8, it becomes decidedly erratic due to the massive, unnatural pulses brought about by significantly more massive water impoundment in Chinese dams. These pulses detected from the Residual measure are significant as it means that China possesses the ability to create Lower Mekong River Basin saturation equal to or greater than natural, seasonal flooding; thus, significantly disrupting dry/wet season normative water flow. It also offers a massively devastating weapon at their disposal.

Dams listed *by date of construction*	Reservoir size *in cubic meters*	Electrical production *by date turbine commissioned*
Manwan	920,000,000	1993
Dachaoshan	940,000,000	2002
Jinghong	249,000,000	2008
Xiaowan	15,130,000,000	2009
Nuozhadu	27,490,000,000	2012
Gongguoqiao	120,000,000	2012
Miaowei	660,000,000	2017
Huangdeng	1,613,000,000	2017
Dahuaqiao	293,000,000	2018
Lidi	75,000,000	2018
Wunonglong	284,000,000	2018

Table 3 Dams, Reservoirs, and Electrical Production on the Upper Mekong (A. Basist, 2020). https://wixlabs-pdf-dev.appspot.com/assets/pdfjs/web/viewer.html?file=%2Fpdfproxy%3Finstance%3DA1DlEzu4vPqdjSlScweawxi_rUultGOOnv9d6Wf4f5U.eyJpbnN0YW5jZUlkIjoiZmRhZTY5YzktYzBmZS00YWM0LTk1OGYtMjE2OGJlYWEwZWQ1IiwiYXBwRGVmSWQiOiIxM2VlMTBhMy1lY2I5LTdlZmYtNDI5OC1kMmY5ZjM0YWNmMGQiLCJtZXRhU2l0ZUlkIjoiM2U2Y2NmMjQtNTc0ZC00NmVjLTg4NzYtZjE3MWUzODhiMGQ4Iiwic2lnbkRhdGUiOiIyMDIxLTAyLTIwVDA4OjI5OjI4LjQ0OVoiLCJkZW1vTW9kZSI6ZmFsc2UsImFpZCI6ImY2YWYxYTM1LTg1OTAtNDRlMS1hMjNiLTQyOGE3NTQ5MGI4NiIsImJpVG9rZW4iOiJjM2MyYTZlZC05N2IzLTBjMjgtMWRmOS1kMDE5NWQyMmJlMGQiLCJzaXRlT3duZXJJZCI6IjllNmZjNDhmLWI3ZmQtNDc3Ni1hYzM5LWMxN2JmYzkxNzg5YiJ9%26compId%3Dcomp-k93y5xfn%26url%3Dhttps%3A%2F%2Fdocs.wixstatic.com%2Fugd%2F9e6fc4_fdbb62922f6f45a69d48dc81f814acd0.pdf#page=1&links=true&originalFileName=Monitoring%20water%20quantity%20April%2011%2C%202020&locale=en&allowDownload=true&allowPrinting=true

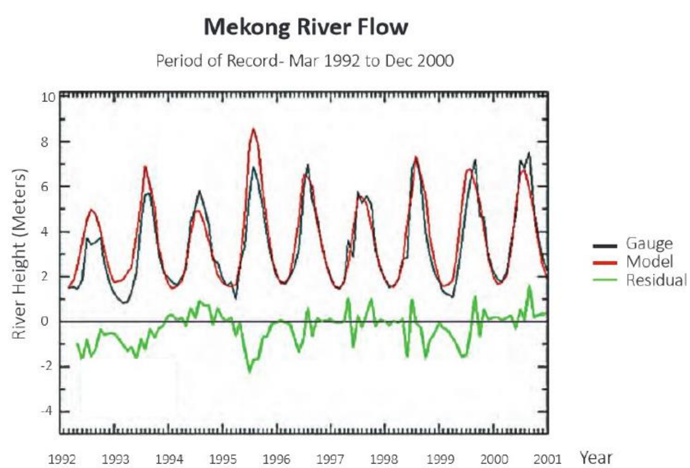


Figure 7. Mekong River Flow (Normative Water Flow) (A. Basist, 2020) https://wixlabs-pdf-dev.appspot.com/assets/pdfjs/web/viewer.html?file=%2Fpdfproxy%3Finstance%3DA1DlEzu4vPqdjSlScweawxi_rUultGOOnv9d6Wf4f5U.eyJpbnN0YW5jZUlkIjoiZmRhZTY5YzktYzBmZS00YWM0LTk1OGYtMjE2OGJlYWEwZWQ1IiwiYXBwRGVmSWQiOiIxM2VlMTBhMy1lY2I5LTdlZmYtNDI5OC1kMmY5ZjM0YWNmMGQiLCJtZXRhU2l0ZUlkIjoiM2U2Y2NmMjQtNTc0ZC00NmVjLTg4NzYtZjE3MWUzODhiMGQ4Iiwic2lnbkRhdGUiOiIyMDIxLTAyLTIwVDA4OjI5OjI4LjQ0OVoiLCJkZW1vTW9kZSI6ZmFsc2UsImFpZCI6ImY2YWYxYTM1LTg1OTAtNDRlMS1hMjNiLTQyOGE3NTQ5MGI4NiIsImJpVG9rZW4iOiJjM2MyYTZlZC05N2IzLTBjMjgtMWRmOS1kMDE5NWQyMmJlMGQiLCJzaXRlT3duZXJJZCI6IjllNmZjNDhmLWI3ZmQtNDc3Ni1hYzM5LWMxN2JmYzkxNzg5YiJ9%26compId%3Dcomp-k93y5xfn%26url%3Dhttps%3A%2F%2Fdocs.wixstatic.com%2Fugd%2F9e6fc4_fdbb62922f6f45a69d48dc81f814acd0.pdf#page=1&links=true&originalFileName=Monitoring%20water%20quantity%20April%2011%2C%202020&locale=en&allowDownload=true&allowPrinting=true

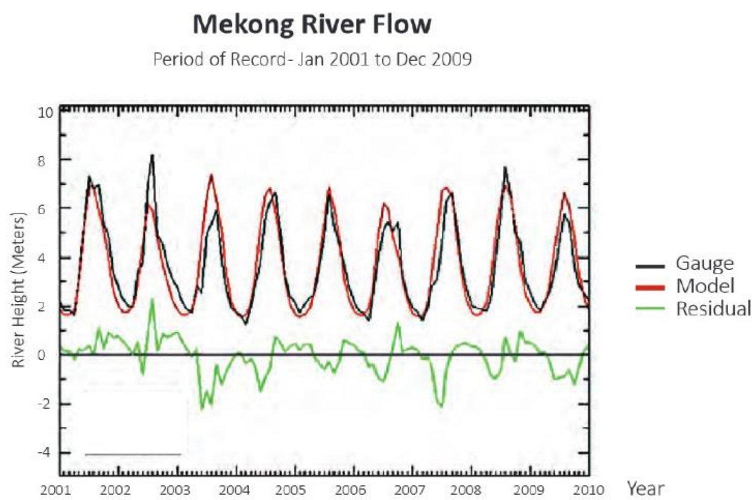


Figure 8. Slightly Abnormal Water Flow (A. Basist, 2020) https://wixlabs-pdf-dev.appspot.com/assets/pdfjs/web/viewer.html?file=%2Fpdfproxy%3Finstance%3DA1DlEzu4vPqdjSlScweawxi_rUultGOOnv9d6Wf4f5U.eyJpbnN0YW5jZUlkIjoiZmRhZTY5YzktYzBmZS00YWM0LTk1OGYtMjE2OGJlYWEwZWQ1IiwiYXBwRGVmSWQiOiIxM2VlMTBhMy1lY2I5LTdlZmYtNDI5OC1kMmY5ZjM0YWNmMGQiLCJtZXRhU2l0ZUlkIjoiM2U2Y2NmMjQtNTc0ZC00NmVjLTg4NzYtZjE3MWUzODhiMGQ4Iiwic2lnbkRhdGUiOiIyMDIxLTAyLTIwVDA4OjI5OjI4LjQ0OVoiLCJkZW1vTW9kZSI6ZmFsc2UsImFpZCI6ImY2YWYxYTM1LTg1OTAtNDRlMS1hMjNiLTQyOGE3NTQ5MGI4NiIsImJpVG9rZW4iOiJjM2MyYTZlZC05N2IzLTBjMjgtMWRmOS1kMDE5NWQyMmJlMGQiLCJzaXRlT3duZXJJZCI6IjllNmZjNDhmLWI3ZmQtNDc3Ni1hYzM5LWMxN2JmYzkxNzg5YiJ9%26compId%3Dcomp-k93y5xfn%26url%3Dhttps%3A%2F%2Fdocs.wixstatic.com%2Fugd%2F9e6fc4_fdbb62922f6f45a69d48dc81f814acd0.pdf#page=1&links=true&originalFileName=Monitoring%20water%20quantity%20April%2011%2C%202020&locale=en&allowDownload=true&allowPrinting=true

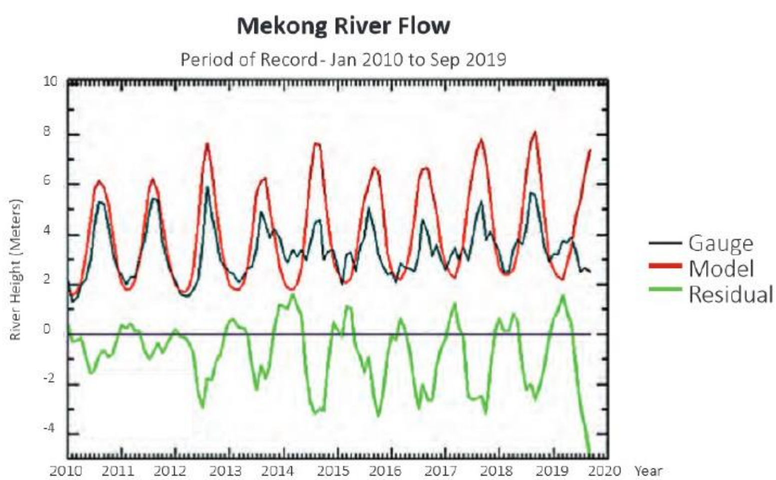


Figure 9. Abnormal Water Flow (A. Basist, 2020) https://wixlabs-pdf-dev.appspot.com/assets/pdfjs/web/viewer.html?file=%2Fpdfproxy%3Finstance%3DA1DlEzu4vPqdjSlScweawxi_rUultGOOnv9d6Wf4f5U.eyJpbnN0YW5jZUlkIjoiZmRhZTY5YzktYzBmZS00YWM0LTk1OGYtMjE2OGJlYWEwZWQ1IiwiYXBwRGVmSWQiOiIxM2VlMTBhMy1lY2I5LTdlZmYtNDI5OC1kMmY5ZjM0YWNmMGQiLCJtZXRhU2l0ZUlkIjoiM2U2Y2NmMjQtNTc0ZC00NmVjLTg4NzYtZjE3MWUzODhiMGQ4Iiwic2lnbkRhdGUiOiIyMDIxLTAyLTIwVDA4OjI5OjI4LjQ0OVoiLCJkZW1vTW9kZSI6ZmFsc2UsImFpZCI6ImY2YWYxYTM1LTg1OTAtNDRlMS1hMjNiLTQyOGE3NTQ5MGI4NiIsImJpVG9rZW4iOiJjM2MyYTZlZC05N2IzLTBjMjgtMWRmOS1kMDE5NWQyMmJlMGQiLCJzaXRlT3duZXJJZCI6IjllNmZjNDhmLWI3ZmQtNDc3Ni1hYzM5LWMxN2JmYzkxNzg5YiJ9%26compId%3Dcomp-k93y5xfn%26url%3Dhttps%3A%2F%2Fdocs.wixstatic.com%2Fugd%2F9e6fc4_fdbb62922f6f45a69d48dc81f814acd0.pdf#page=1&links=true&originalFileName=Monitoring%20water%20quantity%20April%2011%2C%202020&locale=en&allowDownload=true&allowPrinting=true

Acidification via salinization is recognized as an agriculturally destructive force which has been observed in the Yellow River Delta (Gao Fan, 2011) (Zhuoran Wang, 2016). In order to prevent a similar fate for the Mekong River Delta, it is necessary to first define the geospatial extent of the salinization. Although imperfect, remote sensing solutions exist for determining salinization and its effects on landcover (Olumuyiwa Idowu Ojo, 2018). Salinization destroys plants which remote sensing may detect utilizing the Landsat remote sensing satellites (Olumuyiwa Idowu Ojo, 2018). Color infrared, Healthy Vegetation, NDVI, and Natural View products are all possible with Landsat imagery (Olumuyiwa Idowu Ojo, 2018). For the purposes of this study Landsat 8 imagery will be utilized. Landsat 8 features increased collection of two new bands; coastal/aerosol band (band 1) and a cirrus band (band 9) for enhanced spectral analysis over previous missions as well as enhancing legacy Landsat bandwidth refinement (NASA, 2021). The Thermal Instrument (TIRS) also carries two additional Thermal Infrared bands (NASA, 2021). Figures 9, 10, and 12 represent multispectral false-color analysis of Landsat 8 imagery which is useful in detecting geospatial indicators of vegetation stress due to ongoing acidification of the Mekong River Delta brought about by salinization for the month of July 2015. This period of time is representative of relative health on the Delta and is not indicative of current levels of salinization on the Delta. It does provide a relative benchmark for the analysis of ongoing salinization efforts.

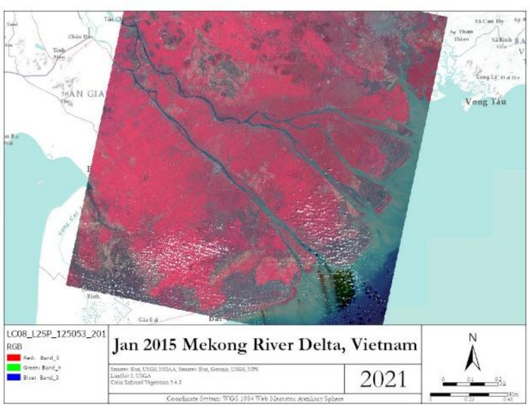


Figure 10 Color Infrared Map of the Mekong River Delta

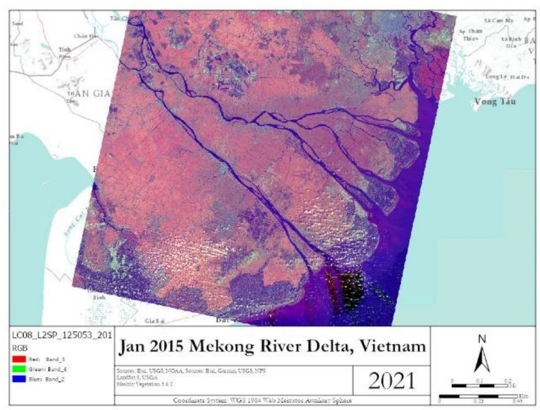
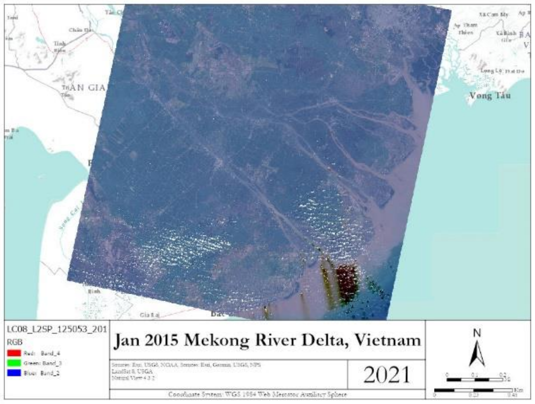


Figure 11 Healthy Vegetation Map of the Mekong River Delta



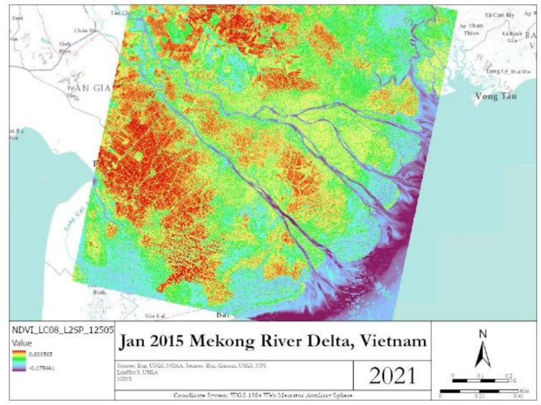


Figure 12 Natural View Map of the Mekong River Delta

Figure 13 NDVI Map of the Mekong River Delta

IV. Proposed Methodology and Problem Solving Process:

The Mekong River Basin is an extremely complex environment which provides challenges to succinct analysis utilizing remote sensing strategies exclusively. By applying the scientific process to the data, we may observe inherently advantageous elements of this unique geospatial expression. Chiefly, the Mekong River descends in a relatively linear path; that is, each nation making up the basin running from North to South (China, Myanmar, Lao PDR, Thailand, Cambodia, and Vietnam) represent roughly linear portions of the overall watershed. This means that it may be possible to roughly gauge the impact of linear damming along the basin. By determining a Damming Impact Value assessed by each basin's relation to its position up and downriver, a Flow Impact Value and Area Impact Value may capture the Damming Impact Value.

To solve for the Damming Impact Value, some data must be collected which represent a roughly linear basin's water flow and area (catchment).

	China	Myanmar (Burma)	Lao PDR	Thailand	Cambodia	Vietnam	Entire Region
Catchment area (km^2)	165,000	24,000	202,000	184,000	155,000	65,000	795,000
Catchment (% of entire watershed)	21	3	25	23	20	8	100
Volume (% of entire watershed)	16	2	35	18	18	11	100

Table 4 Comparison of the Six Countries in the Mekong River Catchment Area (MRC 2005:1)
http://www.mekongwatch.org/PDF/MekongDam_20160223_report.pdf

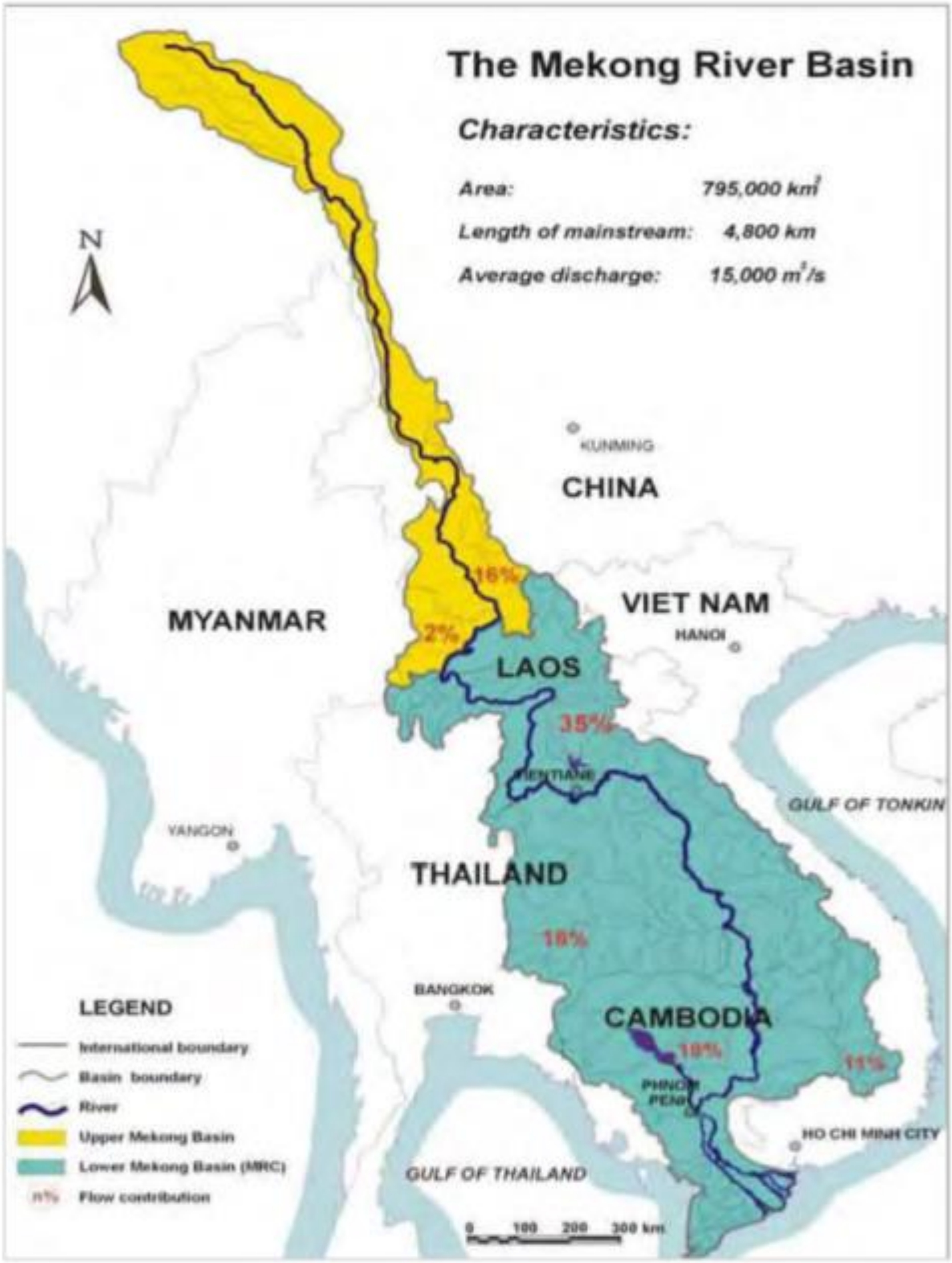


Figure 14. The Mekong River Basin (Mekong River Commission 1999)

To determine the impact of a roughly linear basin's damming, a Target Basin must be identified and quantified by using the following equations:

Damming Impact Value = Flow Impact Value x Area Impact Value

Flow Impact Value =

(Tgt Basin Flow % Of Total Watershed / Sum of Upriver Flow % + Tgt Basin Flow %)

X

(Tgt Basin Flow % Of Total Watershed / Sum of Downriver Flow % + Tgt Basin Flow %)

Area Impact Value =

(Tgt Basin Area % Of Total Watershed / Sum of Upriver Area % + Tgt Basin Area %)

X

(Tgt Basin Area % Of Total Watershed / Sum of Downriver Area % + Tgt Basin Area %)

Equation 1. Damming Impact Value

Damming Impact Values for the Mekong River Basin:

China:

Flow Impact Value = (16/16) x (16/100) = 0.16

Area Impact Value = (21/21) x (21/100) = 0.21

Damming Impact Value = 0.16 x 0.21 = 0.0336

Equation 2. China Damming Impact Value MRB

Myanmar:

Flow Impact Value = (2/18) x (2/84) = 0.003

Area Impact Value = (3/24) x (3/79) = 0.005

Damming Impact Value = 0.003 x 0.005 = 0.000015

Equation 3. Myanmar Damming Impact Value MRB

Lao PDR:

Flow Impact Value = (35/53) x (35/82) = 0.282

Area Impact Value = (25/49) x (25/76) = 0.168

Damming Impact Value = 0.282 x 0168 = 0.047

Equation 4. Lao PDR Damming Impact Value MRB

Thailand:

Flow Impact Value = (18/71) x (18/47) = 0.097

Area Impact Value = (23/72) x (23/51) = 0.144

Damming Impact Value = 0.097 x 0.144 = 0.014

Equation 5. Thailand Damming Impact Value MRB

Cambodia:

Flow Impact Value = (18/89) x (18/29) = 0.125

Area impact Value = (20/92) x (20/28) = 0.155

Damming Impact Value = 0.125 x 0.155 = 0.019

Equation 6. Cambodia Damming Impact Value MRB

Vietnam:

Flow Impact Value = (11/89) x (11/11) = 0.124

Area Impact Value = (8/100) x (8/8) = 0.08

Damming Impact Value = 0.124 x 0.08 = 0.01

Equation 7. Vietnam Damming Impact Value MRB

After solving for all Flow, Area, and Damming Impact Values, an examination of the data reveals interesting results. As expected, Lao PDR leads the way in Damming Impact Value (DIV) due to its larger Flow Impact Value (FIV) and Area Impact Value (AIV). Although both Thailand and Cambodia represent equal amounts of total basin flow, Cambodia has a slightly higher DIV thanks to its larger area and greater relationship to downriver flows.

An examination of FIVs amongst the six nations reveal that the top and bottom nations (China and Vietnam) have the largest Upriver and Downriver relationships, respectively, as expected. The trend of downriver nations having larger downriver flow relationships is invariable except in the case of Lao PDR (0.427) which sits between Thailand (0.383) and Myanmar (0.024). The Lao PDR basin also maintains the second highest upriver flow relationship (0.660). This relationship may also be appreciated by considering the vertical relationship of dams in general; more opportunities for damming exist on the higher stretches of a river than lower stretches as rivers flow to the sea. In summary, the data reveal Lao PDR has the greatest FIV in the entire Mekong River Basin.

AIVs convey a similar conclusion in that Lao PDR comes out ahead of the rest of the Mekong River Basin nations. However, a complete examination of the data show that the AIVs are much tighter than the FIVs due to a more equitable distribution of land vice water flow. This relationship means that Lao PDR's FIV and AIV result in a DIV (0.047) greater than China's (0.0336). It also means that per square kilometer, Lao PDR's basin is the most impactful. These DIVs support previously presented data which attribute the greatest damage being attributed to Lao PDR (damming, seepage, and evaporation) and second greatest harm being attributed to China withholding base load flow.

The Mekong River Delta is a bellwether location on the watershed as it is the lowest and therefore most at-risk location. A Land Cover Use Change analysis of this area consisting of 22 distinct land cover categories from 2015-2020 utilizing remotely sensed Landsat 8 imagery was utilized in capturing the effects of topographical geomorphology in Figures 13-26. A side-by-side analysis of Jan-Dec 2015 with Jan-Dec 2020 is produced as well as a year long land cover use change over 2015 and 2020 (Figs 25 & 26). Through analyzing the data from the land cover use change it becomes less meaningful to assess the land cover use change so much as detecting geomorphological changes across the topography of the Mekong Delta due to seasonal flooding and other conditions. An Unsupervised ISO Cluster Classification of the Landsat 8 images was conducted according to the workflow in Figure 14.

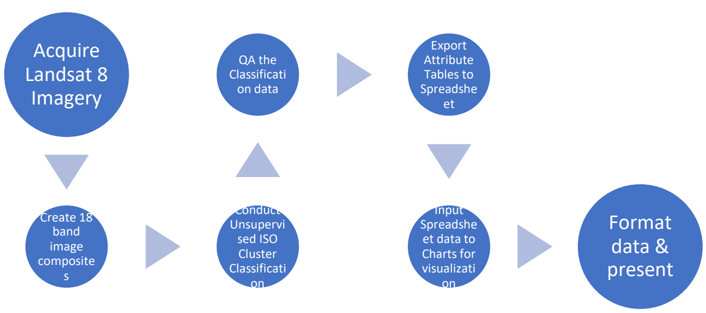


Figure 15. Imagery Classification Workflow

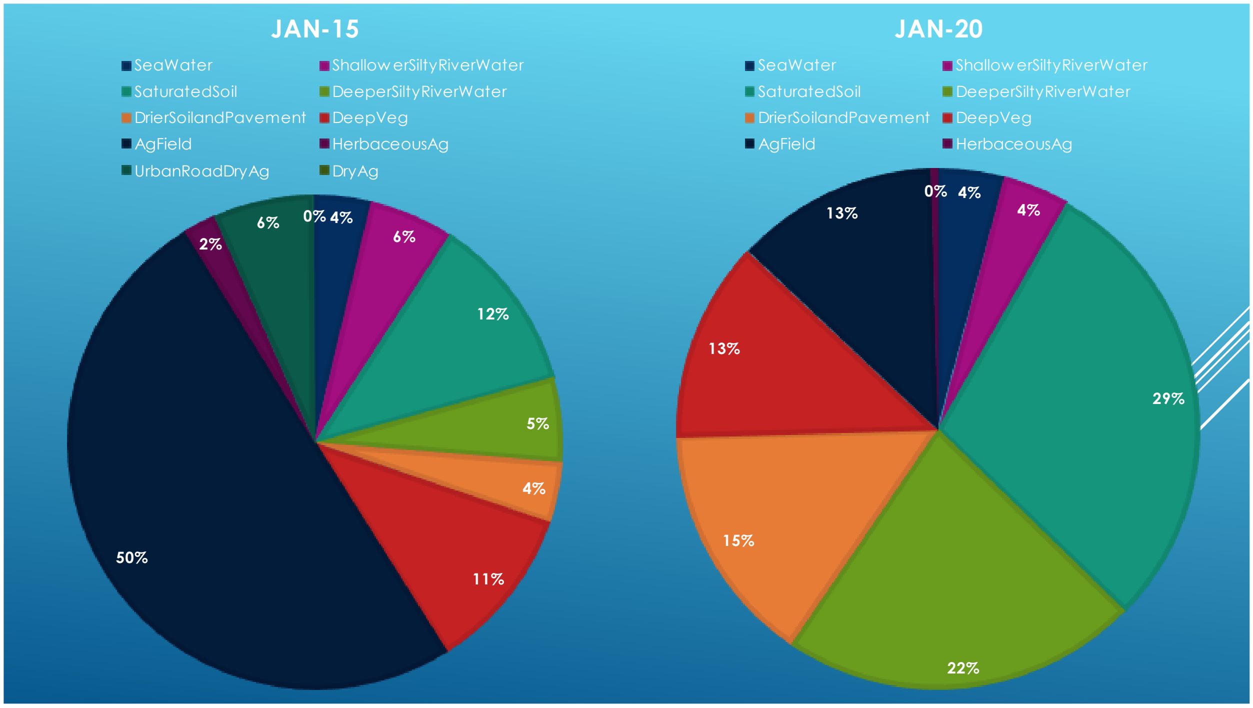


Figure 16. January 2015 & 2020 Land Cover Comparison of the Mekong River Delta

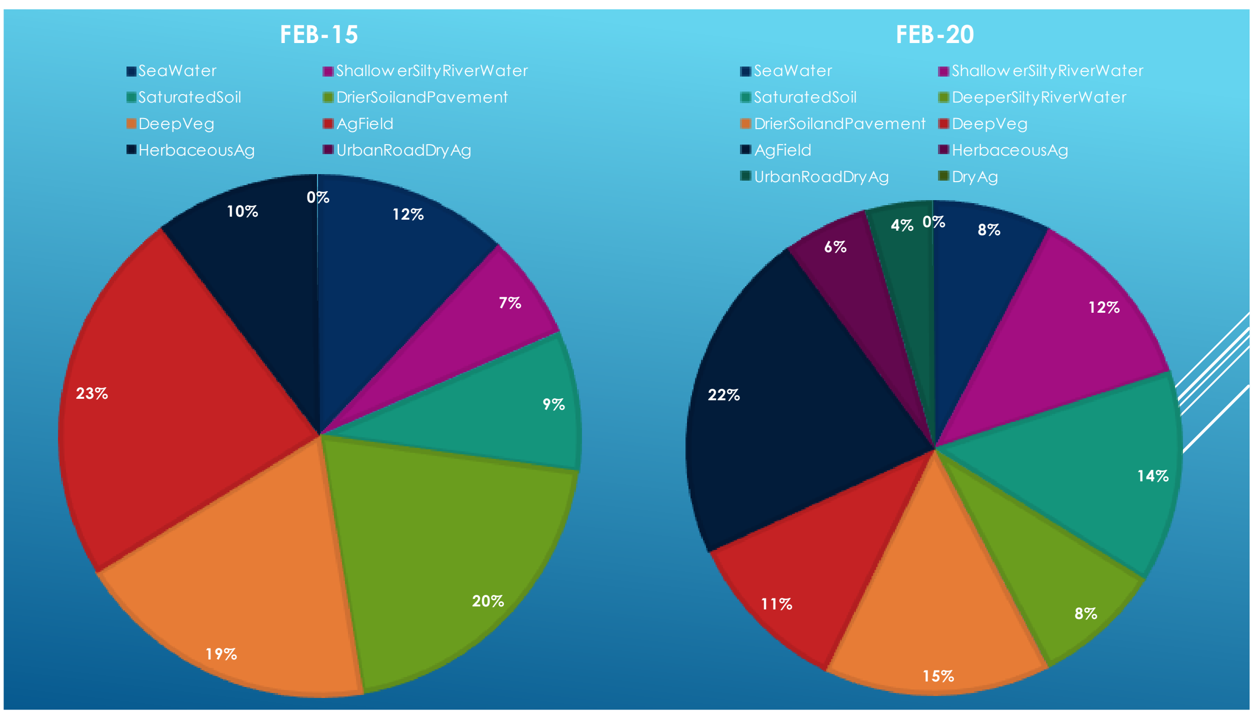


Figure 17. February 2015 & 2020 Land Cover Comparison of the Mekong River Delta

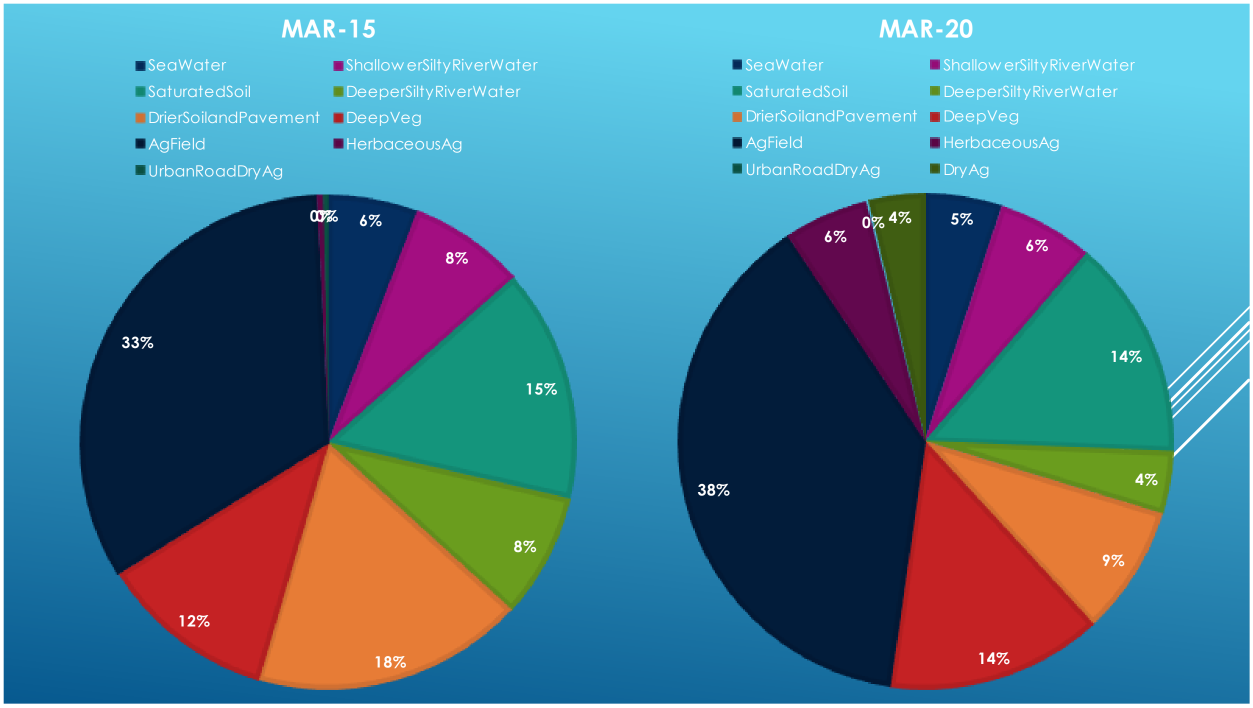


Figure 18. March 2015 & 2020 Land Cover Comparison of the Mekong River Delta

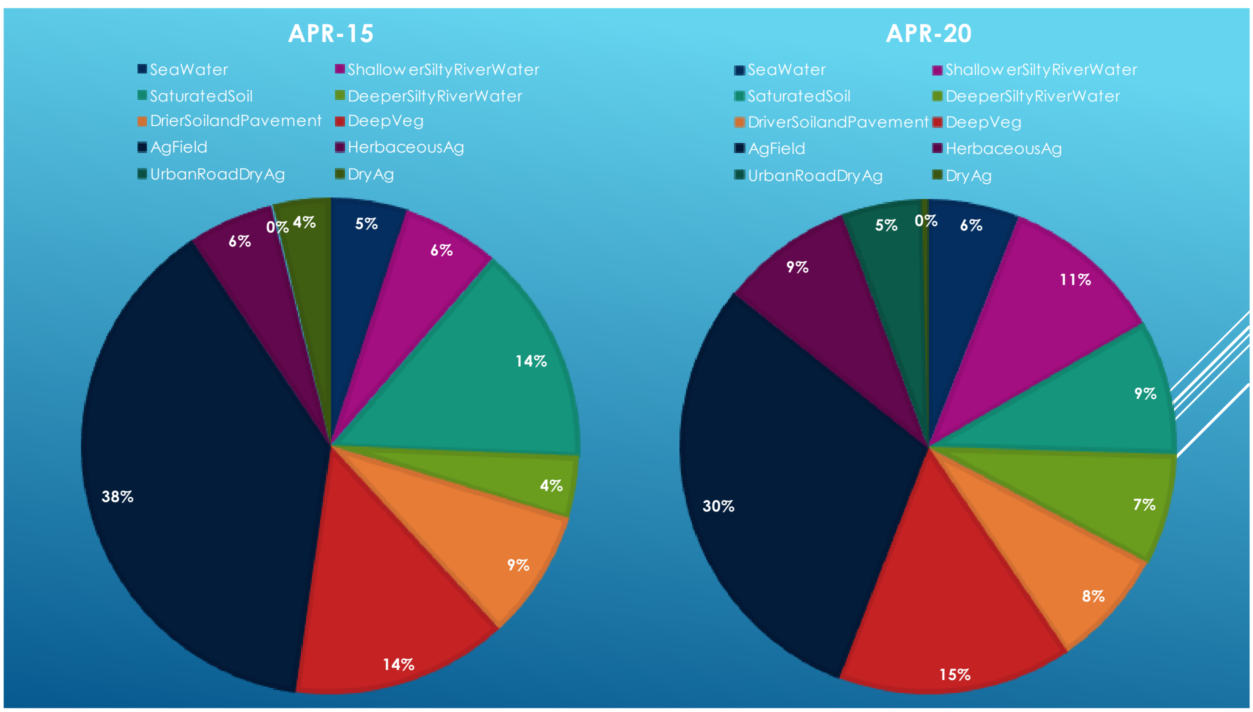


Figure 19. April 2015 & 2020 Land Cover Comparison of the Mekong River Delta

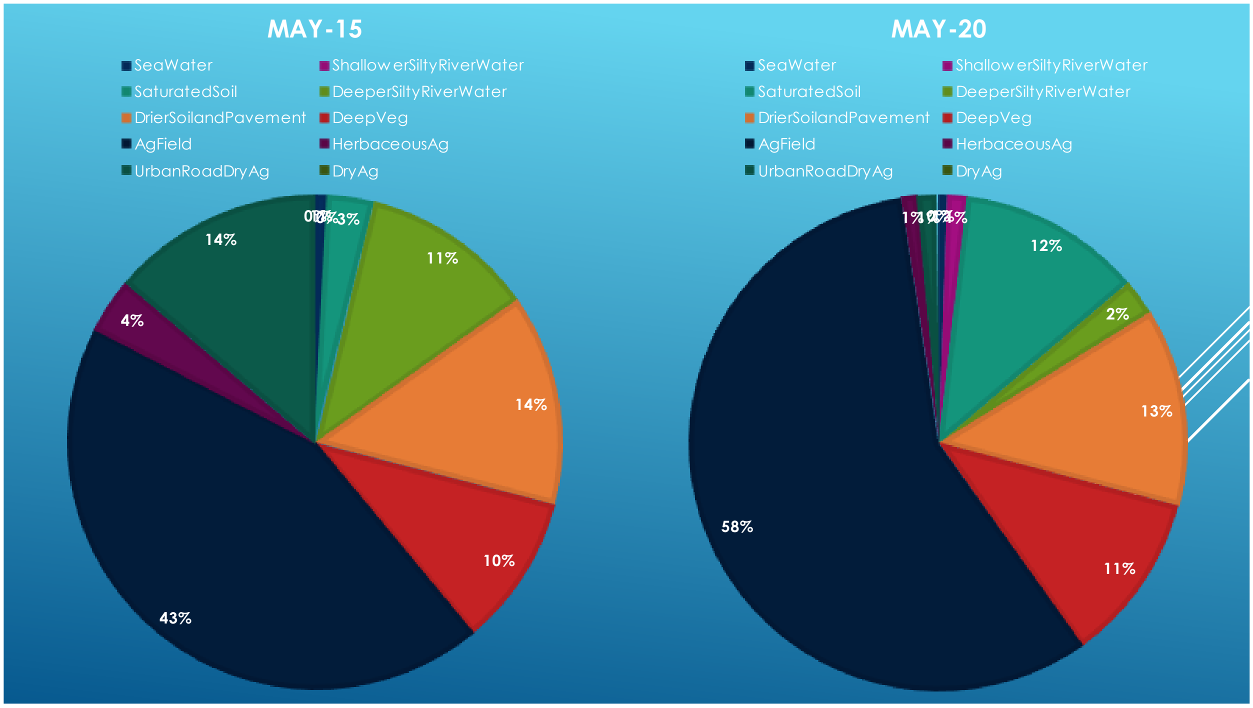


Figure 20. May 2015 & 2020 Land Cover Comparison of the Mekong River Delta

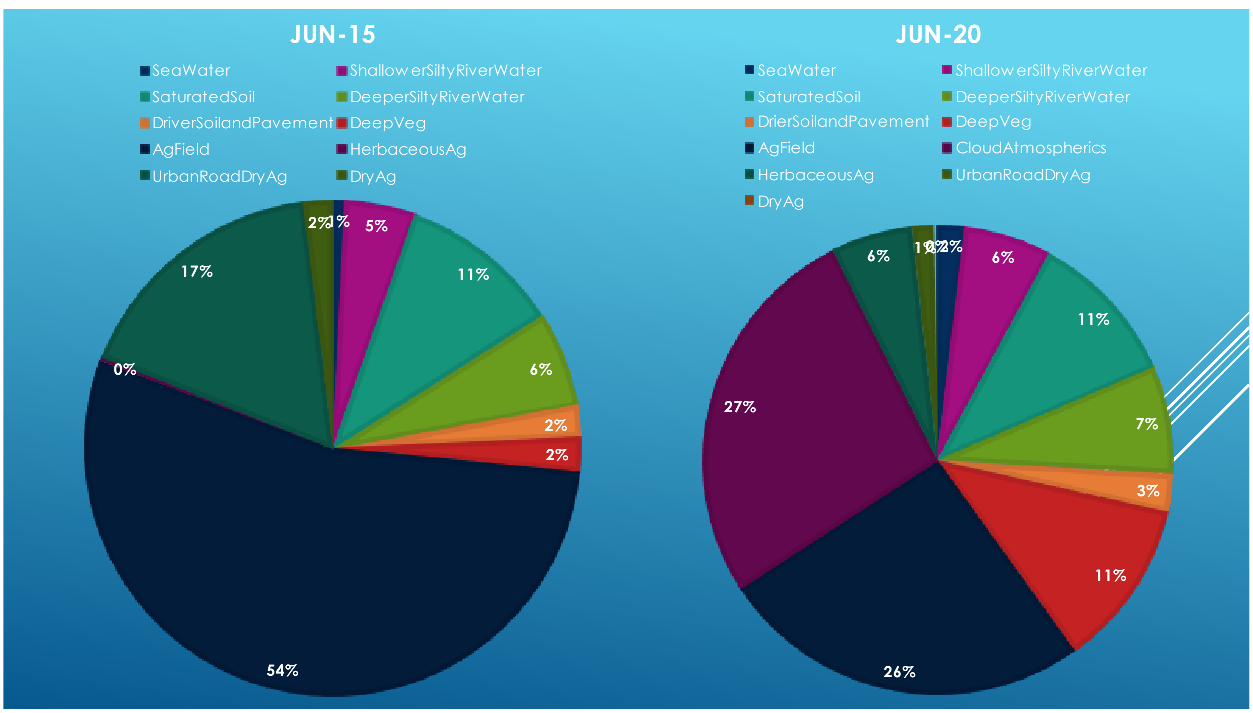


Figure 21. June 2015 & 2020 Land Cover Comparison of the Mekong River Delta

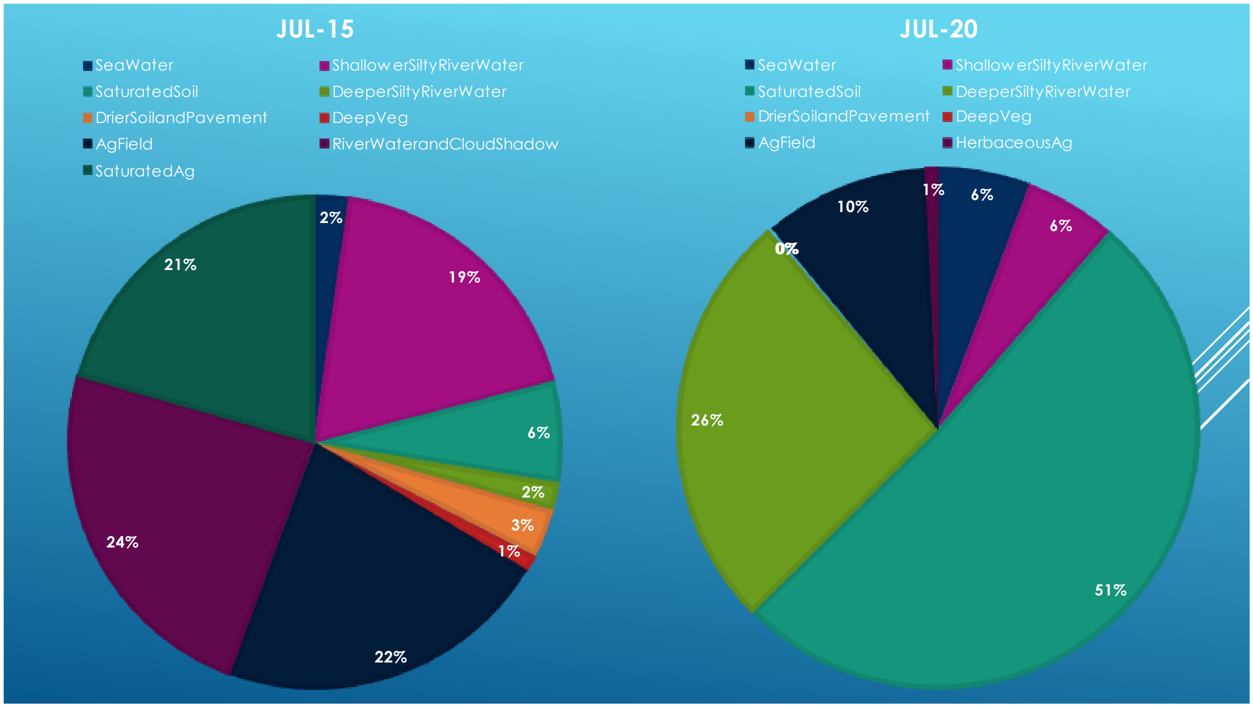


Figure 22. July 2015 & 2020 Land Cover Comparison of the Mekong River Delta

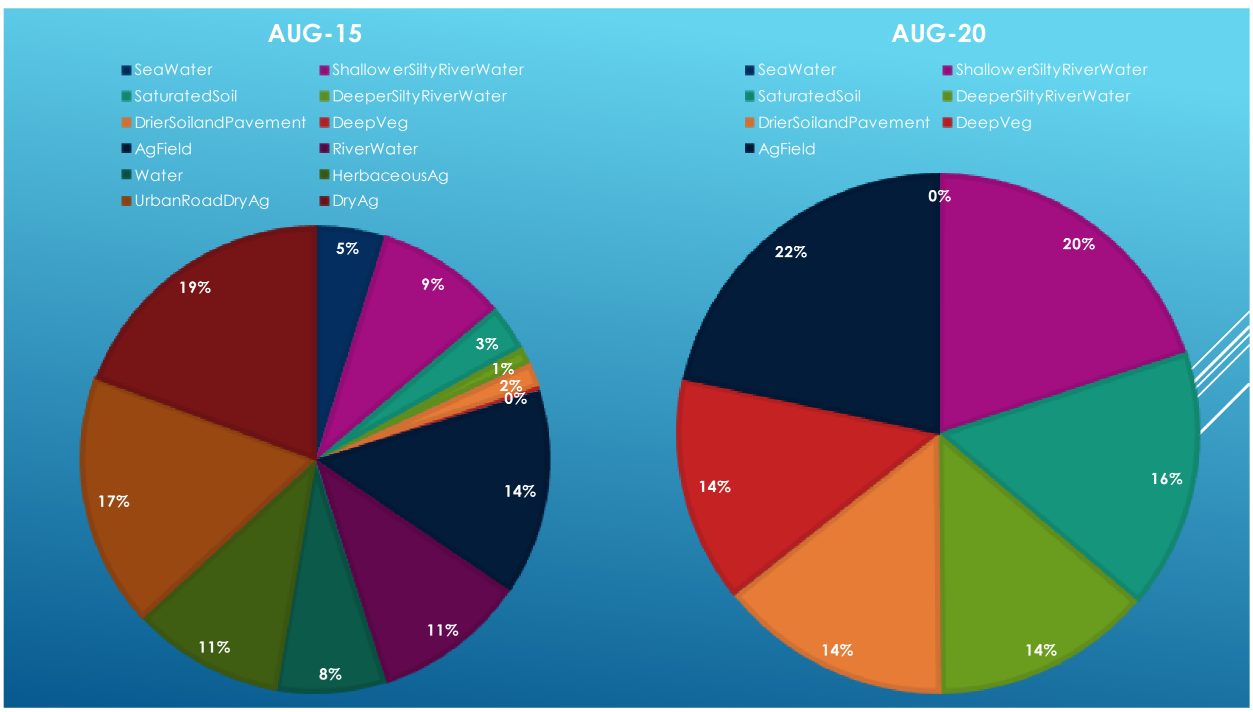


Figure 23. August 2015 & 2020 Land Cover Comparison of the Mekong River Delta

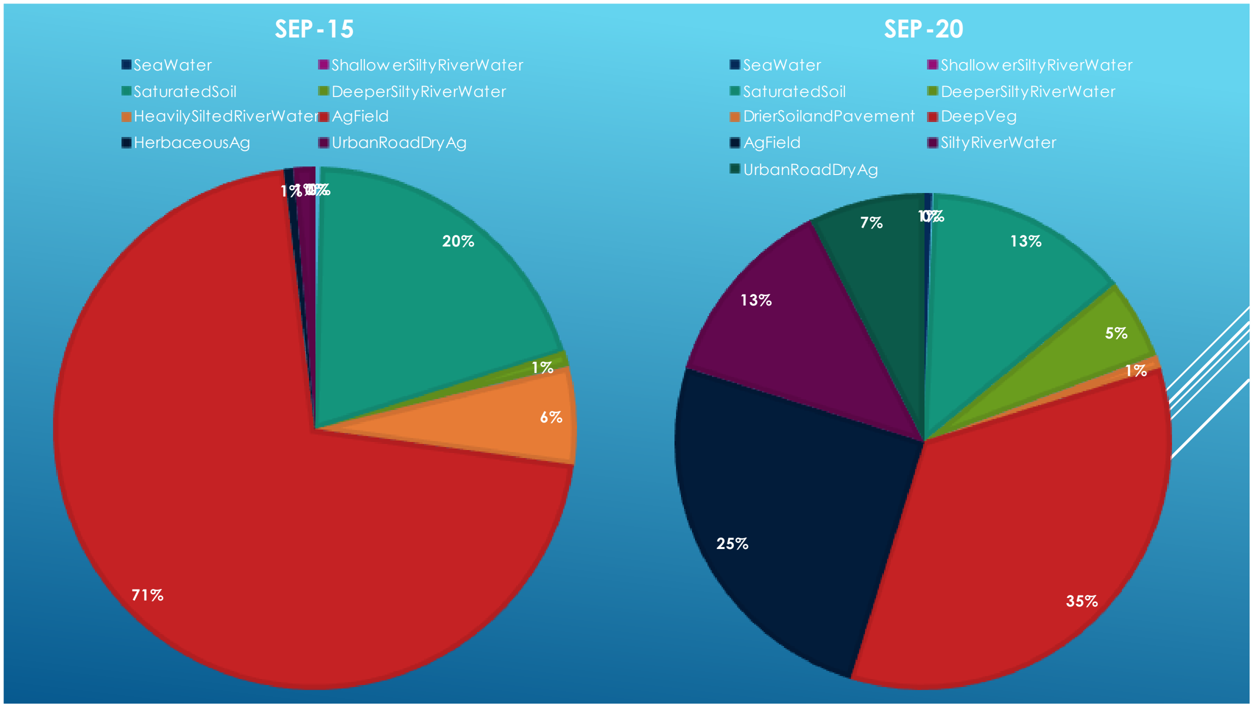


Figure 24. September 2015 & 2020 Land Cover Comparison of the Mekong River Delta

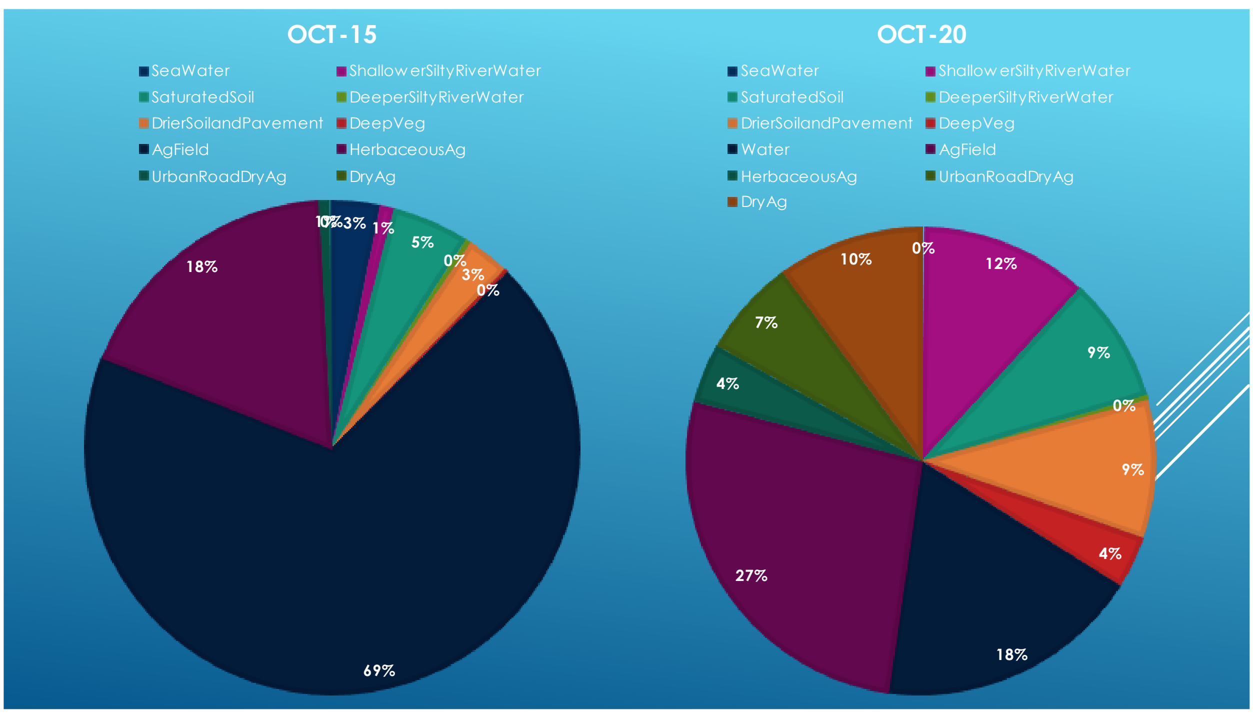


Figure 25. October 2015 & 2020 Land Cover Comparison of the Mekong River Delta

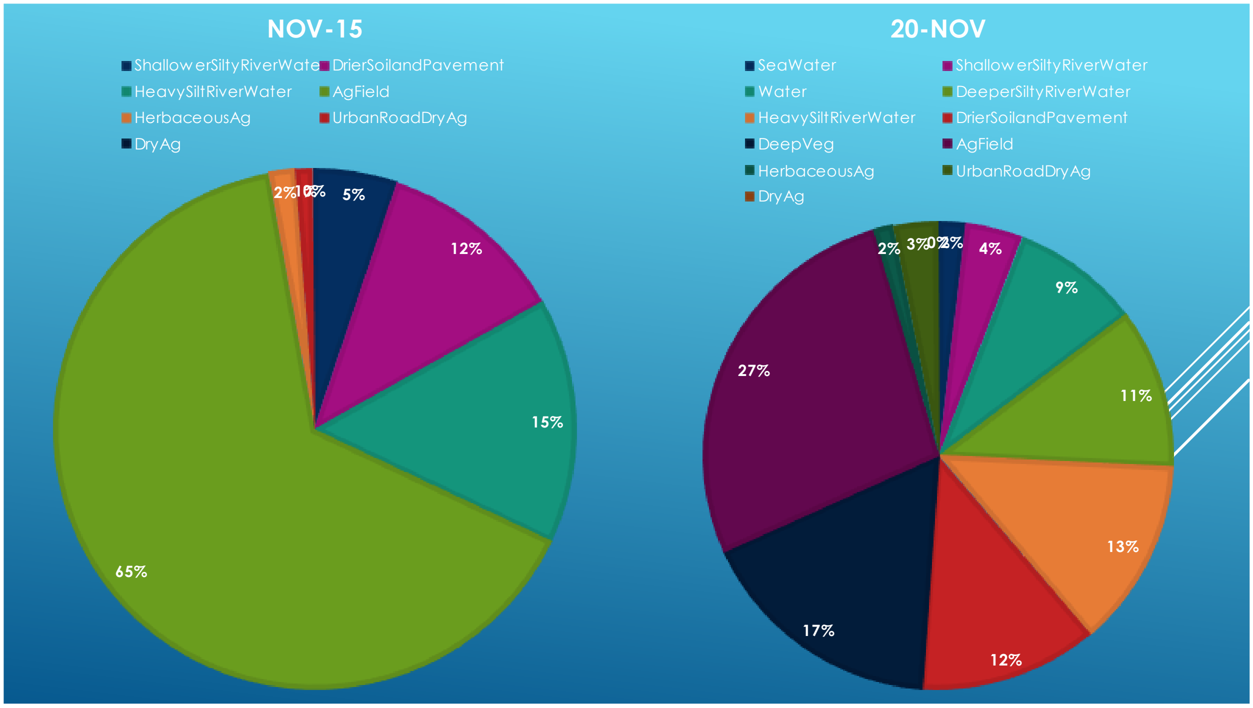


Figure 26. November 2015 & 2020 Land Cover Comparison of the Mekong River Delta

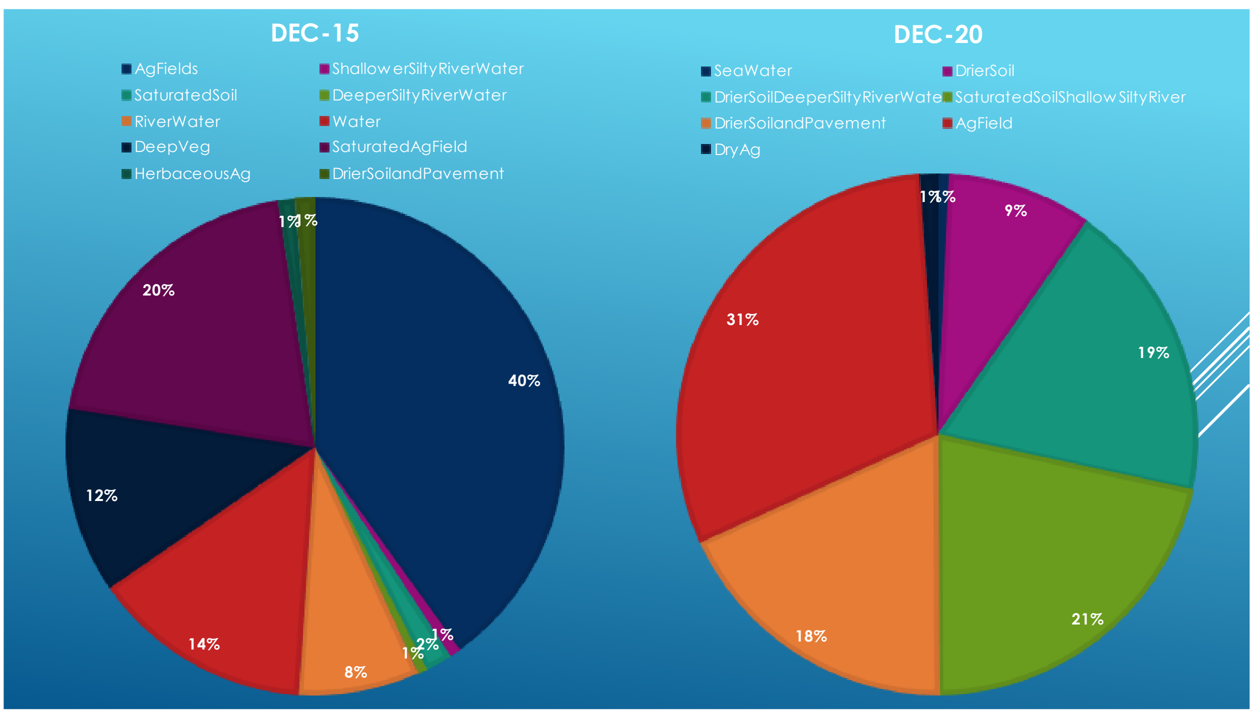


Figure 27. December 2015 & 2020 Land Cover Comparison of the Mekong River Delta

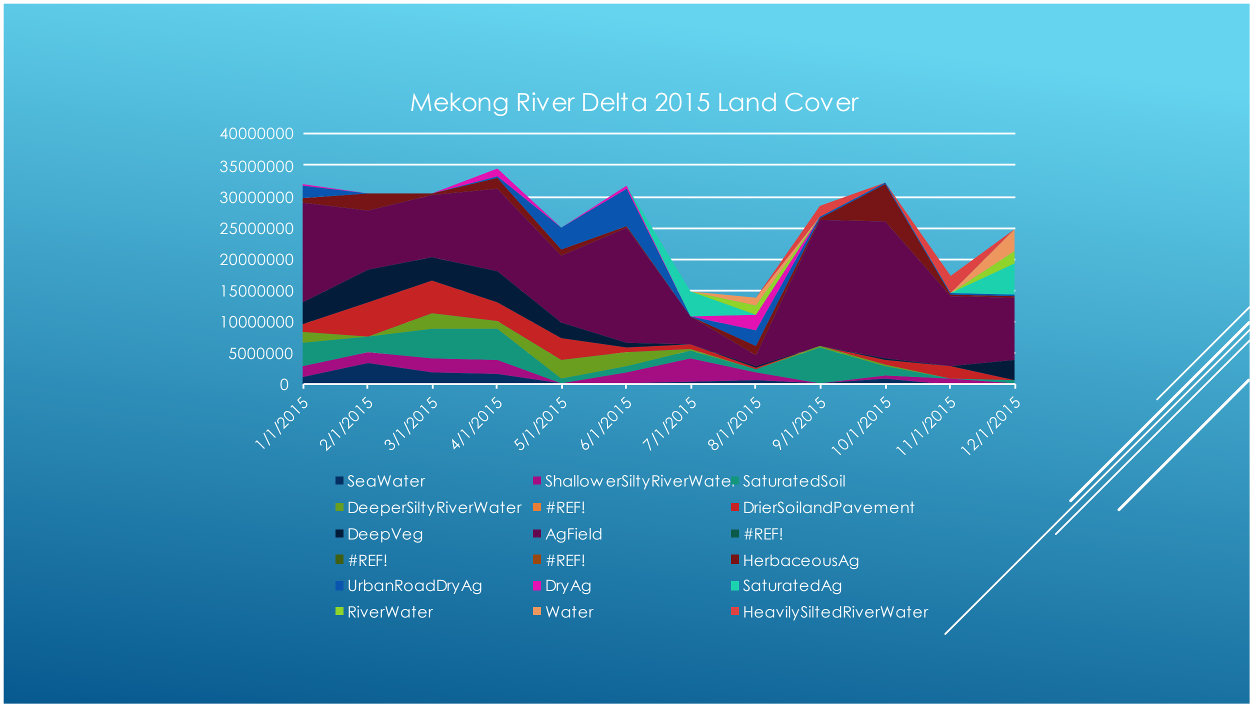


Figure 28. Mekong River Delta 2015 Land Cover Change

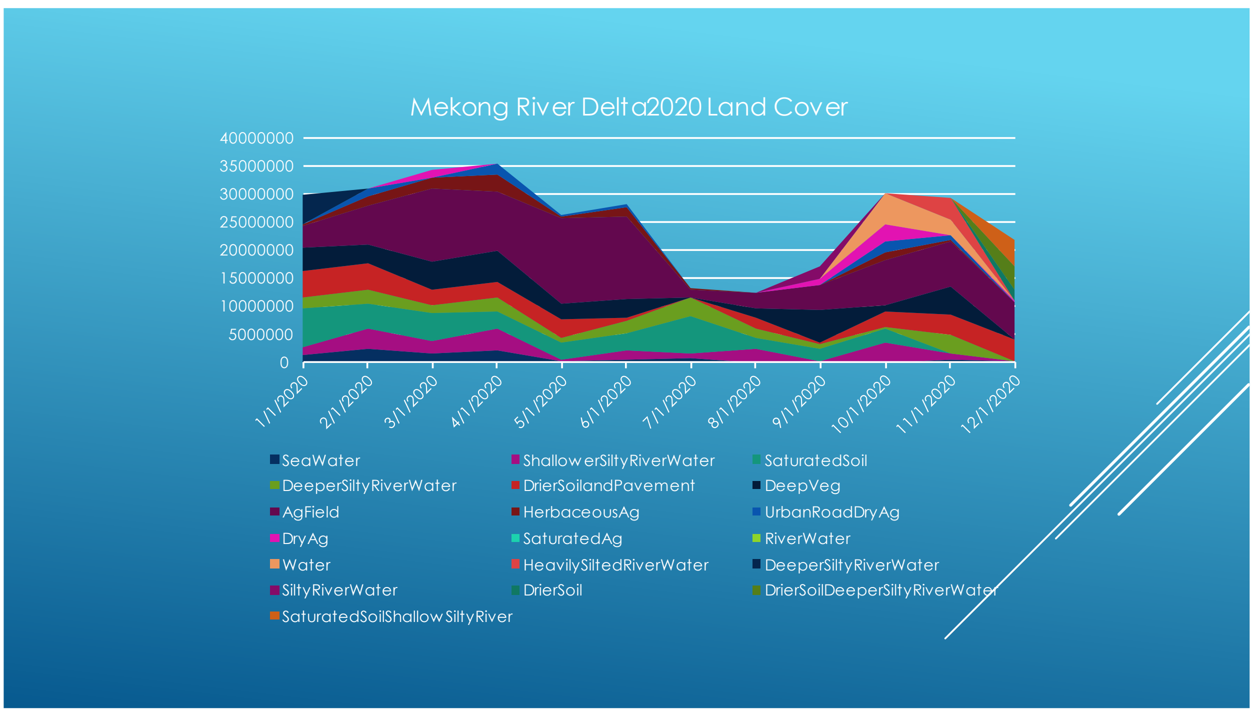


Figure 29. Mekong River Delta 2020 Land Cover Change

V. List and Discuss Hypotheses:

Three hypothesis are being utilized to recognize challenges for normative Mekong waterflow.

1. Normative Mekong River Delta water levels are low due to decreased rainfall.

Rainfall was markedly decreased in 2020 due to La Nina (Mekong River Commission, 2021). In Figure 6, a comparison of water levels is made between the years 2018 to 2020 with an average water line refined from 1960-2017 (Mekong River Commission, 2020). The average and preceding years indicate a marked decrease in water levels across all monitoring stations in the Lower Mekong River Basin. Taken with the data in Figure 1 one would be forgiven for concluding that damming on the Upper Mekong River Basin is solely responsible for the lower water levels in the Lower Mekong River Basin.

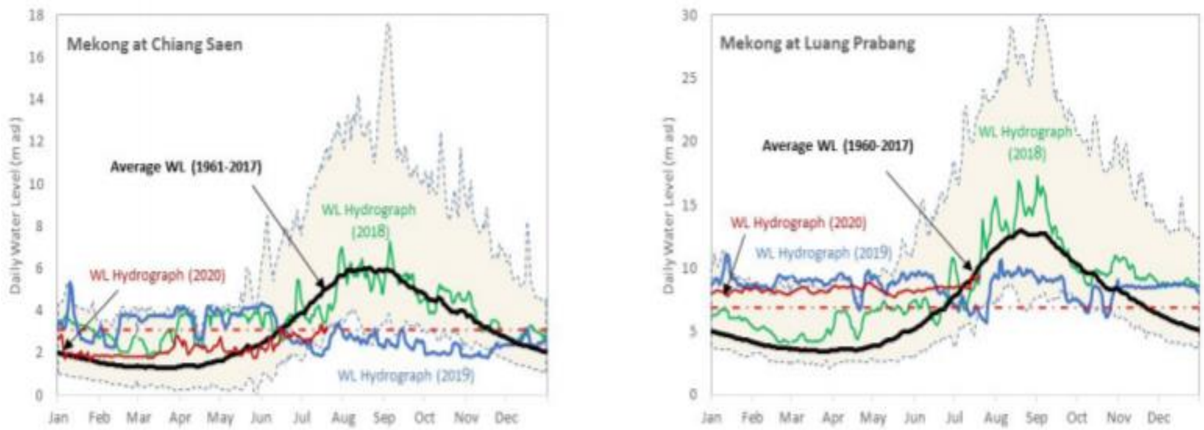
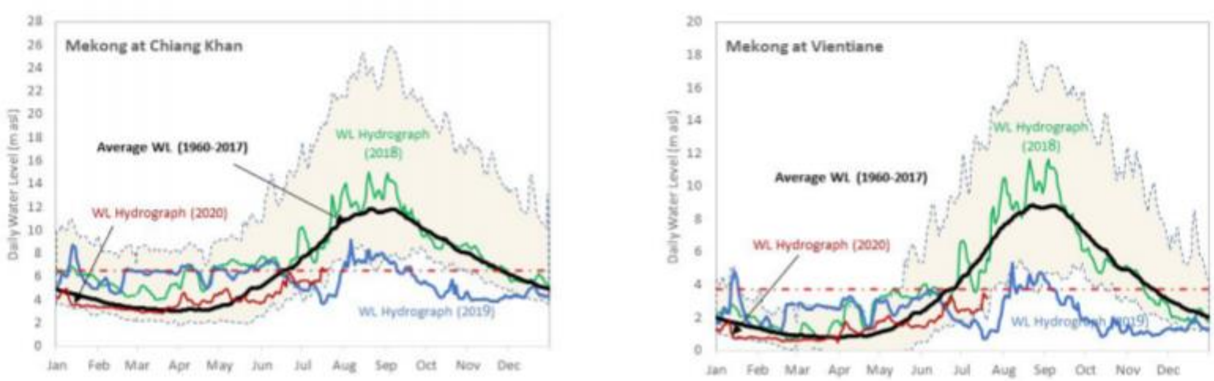


Figure 30. Mekong at Chiang Saen (Mekong River Commission)



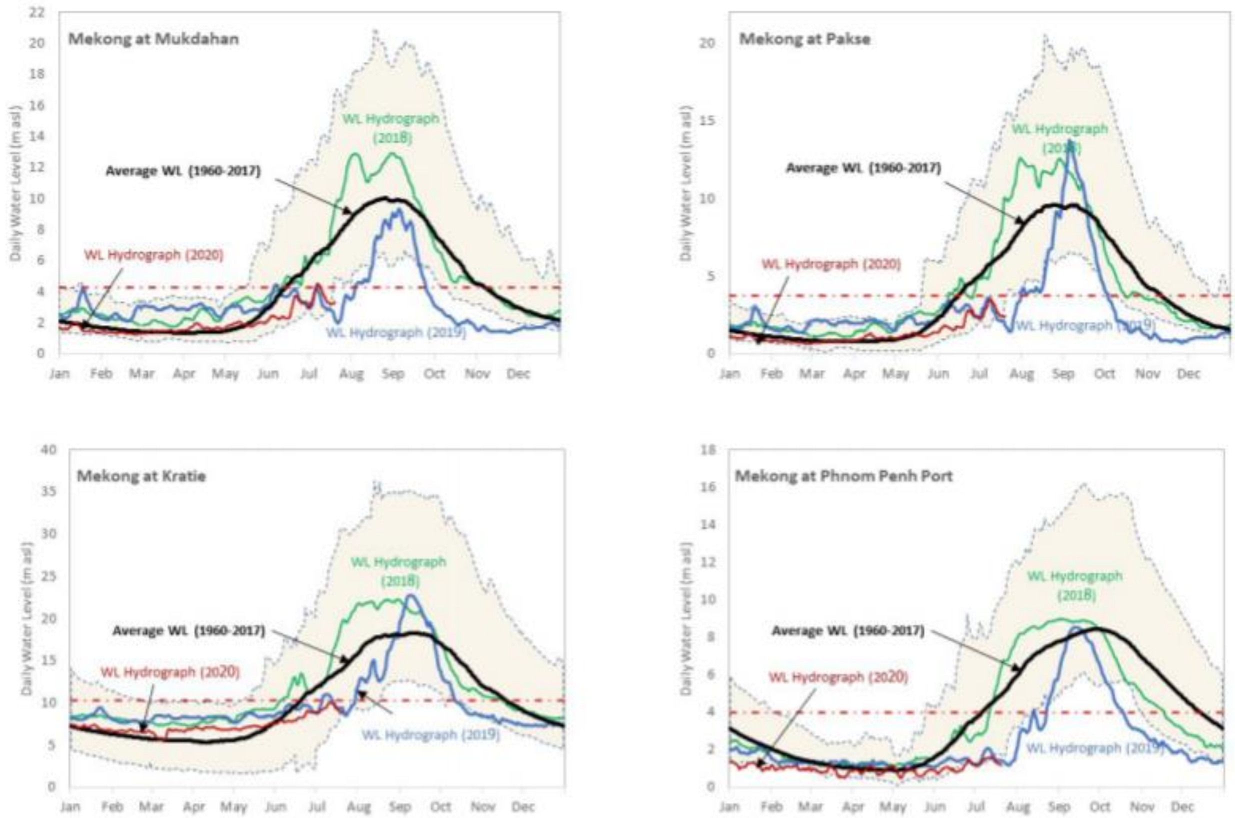


Figure 31 The 2018, 2019, and 2020 daily water level hydrographs observed at selected sites on the Mekong mainstream from Chiang Saen to Phnom Penh Port Compared to the Long-Term Averages.
https://www.mrcmekong.org/assets/Publications/Situation-report-Jan-Jul-2020.pdf

However, normative water flow in the Mekong River Basin includes precipitation from monsoon activity. In Figures 7, 8, 9, 10, 11, and 12 precipitation levels from the third week of October from 2015 to 2020 reveal a decrease (Mekong Water Monitor, 2021). Precipitation in October 2018 and 2019 reveal that this week was below norms in terms of precipitation. However, in Figure 6 we see water levels along parts of the Mekong increase in relation to its latitudinal distribution; northern segments of the river experienced lower water levels than southern segments (Mekong Water Monitor, 2021) (A. Basist, 2020) (Mekong River Commission, 2020). The further south in the Lower Mekong Basin one travels; the less opportunity for dams are present due to reduced topographical verticality. Consider the DIV of Cambodia vs Thailand. Both are 18% FIV but Cambodia's DIV is worse; the further down a roughly linear watershed a dam is constructed, the flatter and less vertical the topography. This is due to the fact that rivers flow to the sea.

With data revealing that normative water flow from the Upper Mekong Basin was disrupted by billions of cubic meters of impounded water; clearly Hypothesis 1 is partly accurate.

2. Normative Mekong River Delta water levels are low due to other damming activities on the Mekong besides the Chinese.

The Mekong River watershed is divided between six nations; China, Myanmar (Burma), Lao PDR, Thailand, Cambodia, and Vietnam (Yuka Kiguchi, 2016). Table 5 provides a comparison of the six nations' contributions to the river. It reveals that although the Chinese impoundment of water is the greatest, it only represents 16% of the total volume of the watershed (Yuka Kiguchi, 2016). This leaves 84% of the total Mekong River watershed to continue on to the Delta but is subject to damming from the remaining riparian nations. On the Mekong River the most dams lie in the nation with the greatest catchment and volume of the entire watershed; Lao PDR has 65 hydropower dams operational (Mekong Water Monitor, 2021). With a further 270 planned and under construction the cumulative and projected effects of this cannot be understated (Mekong Water Monitor, 2021).

With a total of 25332 MW of hydropower planned, under construction, or installed on the Lower Mekong Basin, Lao PDR represents the biggest impounder of water where it has the most impact on basin wetness index (Mekong Water Monitor, 2021).

	China	Myanmar (Burma)	Lao PDR	Thailand	Cambodia	Vietnam	Entire Region
Catchment area (km^2)	165,000	24,000	202,000	184,000	155,000	65,000	795,000
Catchment (% of entire watershed)	21	3	25	23	20	8	100
Volume (% of entire watershed)	16	2	35	18	18	11	100

Table 5 Comparison of the Six Countries in the Mekong River Catchment Area (MRC 2005:1)
http://www.mekongwatch.org/PDF/MekongDam_20160223_report.pdf

Although considerable, Chinese water flow contributions only make up 16% of the total Mekong basin flow (Mekong Water Monitor, 2021). Lao PDR is responsible for 35% of total basin flow and is currently withholding the most (A. Basist, 2020) (Mekong River Commission, 2021) (Mekong Water Monitor, 2021).

Data indicates there is merit in Hypothesis 2.

3. Normative Mekong water levels are low due to Chinese damming.

Given the data in Table 5 China only accounts for 16% of the total watershed which is not an insignificant amount (Mekong Water Monitor, 2021). The issue with normative water flow in the Mekong River Basin is a sophisticated system of interrelated networks of tributaries, canals, lakes, and streams; all converging at the Delta. Chinese damming in the Upper Mekong Basin, is extensive and significant, representing the majority of installed hydropower generation at around 15900 MW (Mekong Water Monitor, 2021) (General Institue of Hydropower & Water Resource Planning and Design, 2009). Chinese damming is less impactful though as it is in the Upper

Mekong Basin and contributes demonstrably less to the total volume of the entire watershed as illustrated in Table 5.

Lao PDR represents a greater contribution to the watershed in every meaningful category. In addition to being in a more impactful location they have far and away built the most dams in the area (Mekong Water Monitor, 2021) (Mekong River Commission, 2021) (Mekong River Commission, 2021). Moreover, due to their damming efforts they are the biggest offenders of seepage and evaporation (Mekong River Commission, 2020).

In consideration of these facts Hypothesis 3 is partially correct as well.

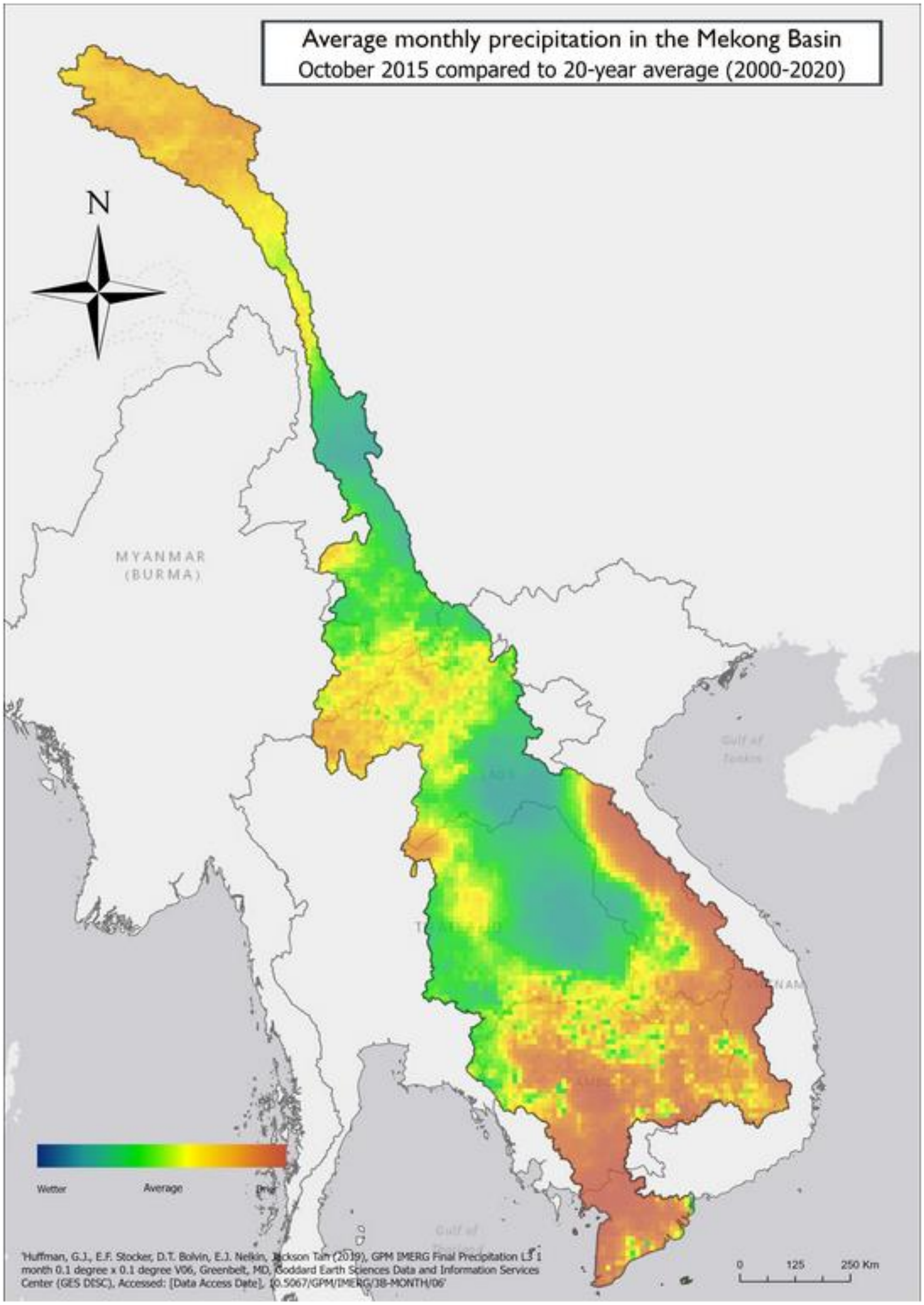


Figure 32 Third Week of October 2015. https://monitor.mekongwater.org/wetness-precipitation-temperature-anomalies/?v=1612886611078

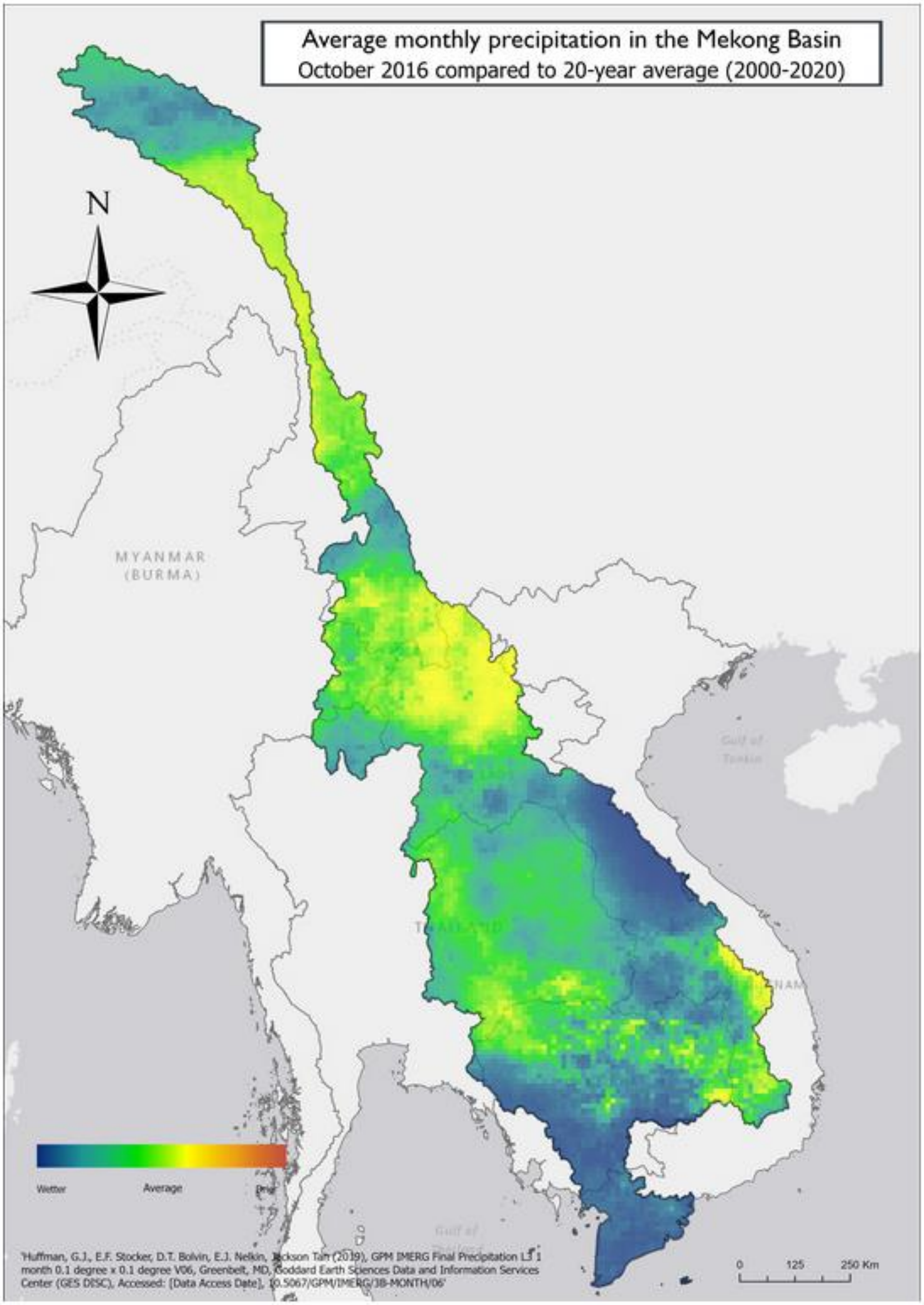


Figure 33 Third Week of October 2016. https://monitor.mekongwater.org/wetness-precipitation-temperature-anomalies/?v=1612886611078

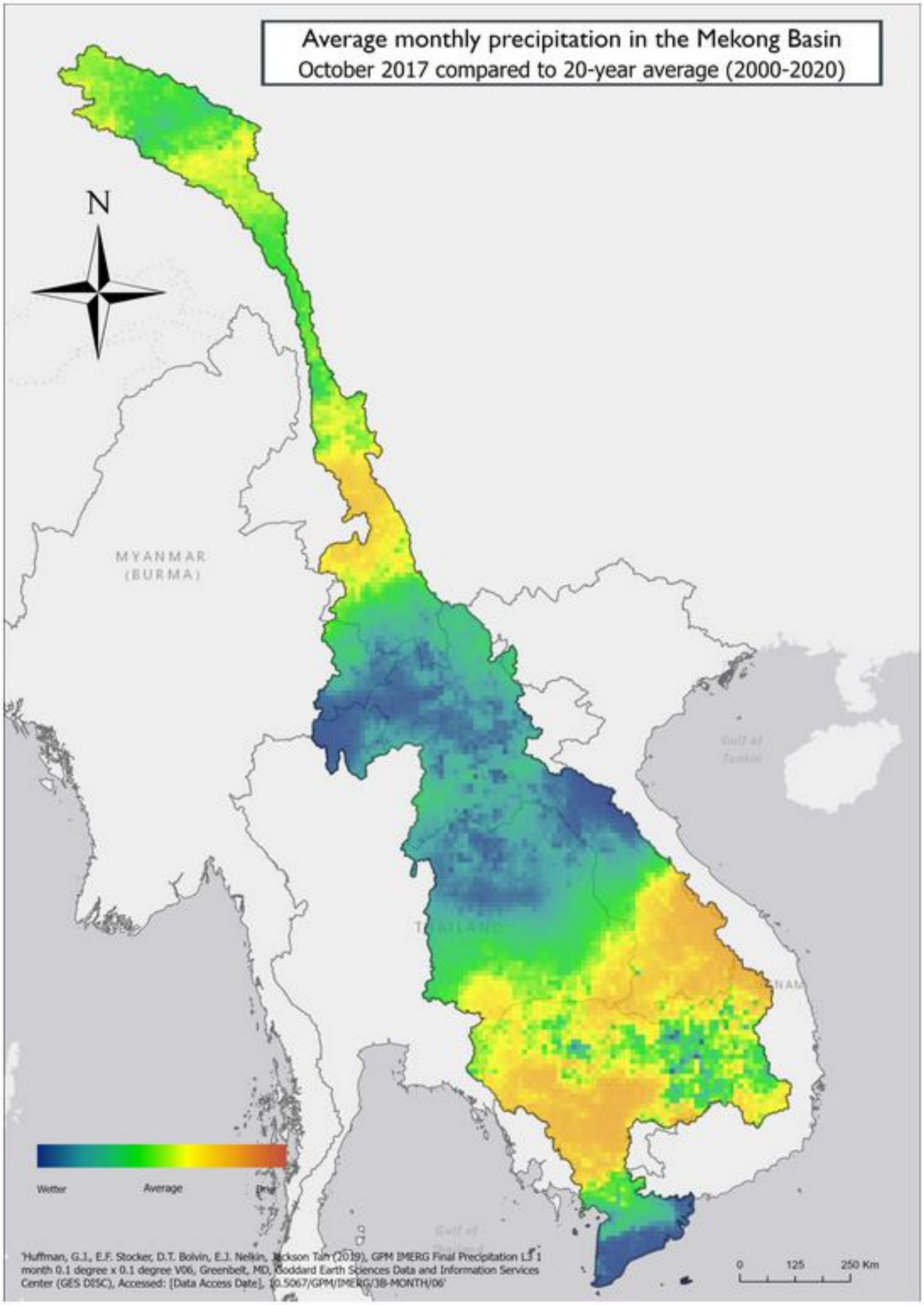


Figure 34 Third Week of October 2017. [*https://monitor.mekongwater.org/wetness-precipitation-temperature-anomalies/?v=1612886611078*](https://monitor.mekongwater.org/wetness-precipitation-temperature-anomalies/?v=1612886611078)

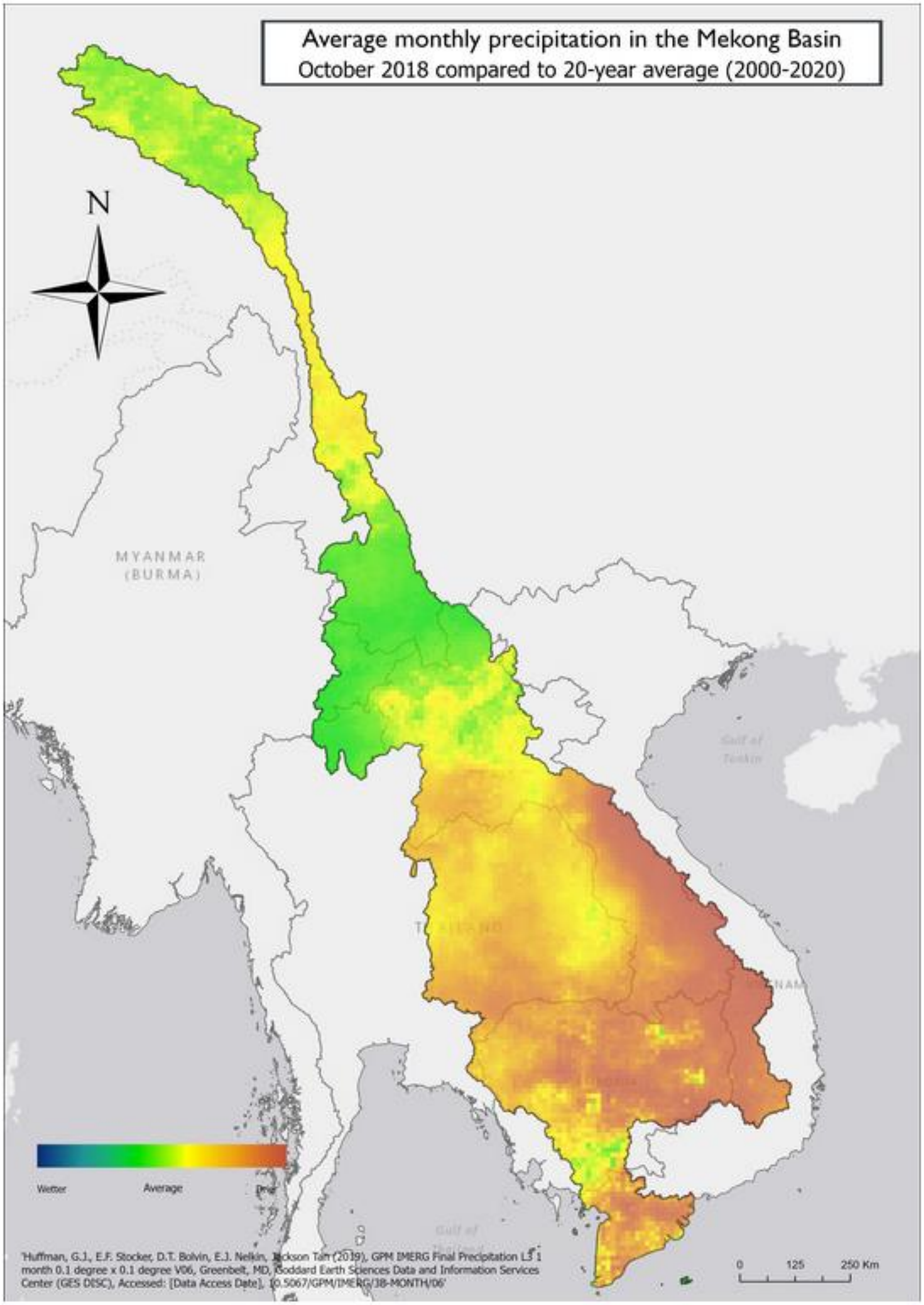


Figure 35 Third Week of October 2018. [*https://monitor.mekongwater.org/wetness-precipitation-temperature-anomalies/?v=1612886611078*](https://monitor.mekongwater.org/wetness-precipitation-temperature-anomalies/?v=1612886611078)

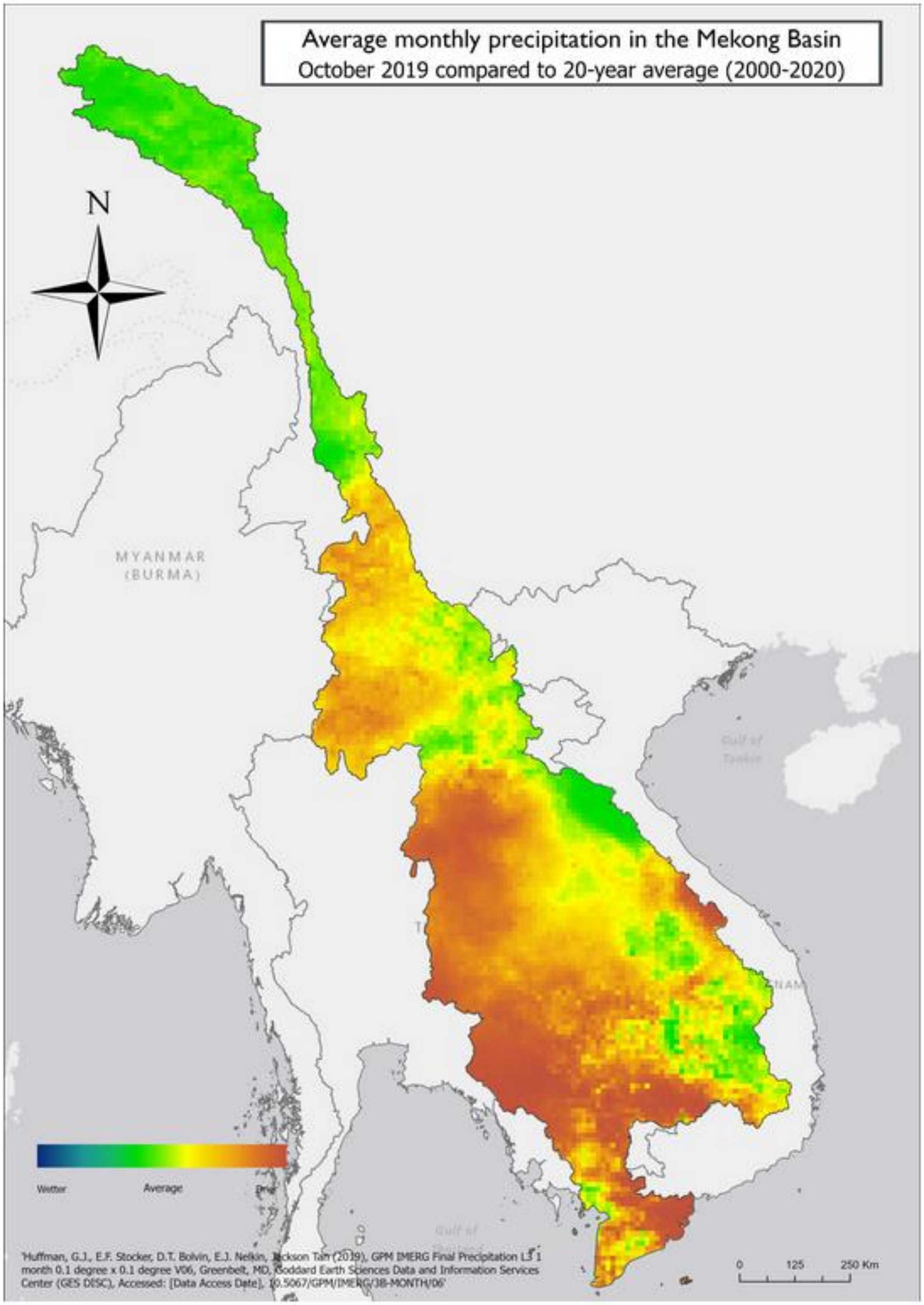


Figure 36 Third Week of October 2019. https://monitor.mekongwater.org/wetness-precipitation-temperature-anomalies/?v=1612886611078

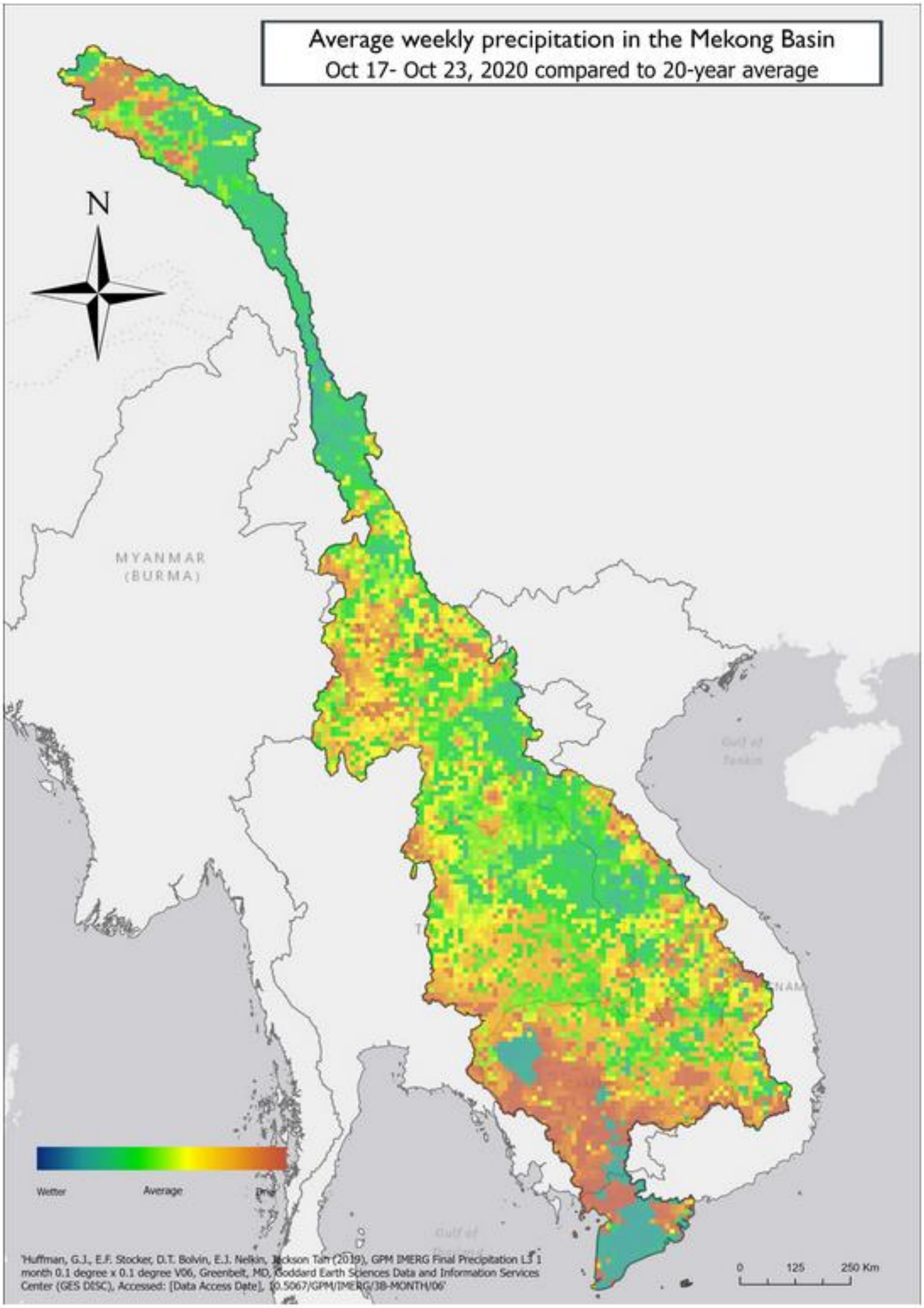


Figure 37 Third Week of October 2020. https://monitor.mekongwater.org/wetness-precipitation-temperature-anomalies/?v=1612886611078

V. List and Discuss Assumptions:

In order to guide the analysis into a constructive channel for this study some assumptions were made. These assumptions were based off of common scientific, geopolitical, and historical data.

1. Salinization is ongoing. Reporting from multiple media sources indicate that salinization in the Mekong River Delta is present and spreading. Last year alone 96000 households alone face a shortage of clean water every day on the Delta (se, 2021).
2. The normative waterflow disruption creates a lack of freshwater pressure on the Mekong River Delta, thus creating salinization (se, 2021).
3. Salinization will occur when normative water flows are interrupted (Mekong River Commission, 2021) (Singh, 2020) (Islam, Uddin, & Hossain, 2020) (Gao Fan, 2011).
4. Salinization is deleterious to agricultural activity (Olumuyiwa Idowu Ojo, 2018).
5. Salinization is negatively impacting political, military, economic, social, infrastructure, and information.

VII. List and Discuss Limitations:

1. Remotely sensed data accumulation will be limited to a portion of the Mekong River Delta. This is to prevent mission creep up the river and enable focused analysis on multispectral imagery. All tables and figures are sourced from authoritative institutions with essentially benign geopolitical goals.
2. Remotely sensed data accumulation will be limited to a period of 12 months in 2015 to 12 months in 2020 to show Land Cover Use Change. The reason for these timeframe limitations is due to computational and temporal challenges.
3. Analysis will include but not be limited to PMESII fallout of the Mekong River Delta and its consequences in the nation of Vietnam. The purpose of this limitation is to focus on the research question and amplify the analytical insight provided.

VIII. Conclusions:

The data analysis reveal that the Mekong River Delta land cover has changed significantly due to lower water levels on the Mekong River. These lower levels were brought about by two factors; first, base load river level decreases for years due to increased Chinese damming and second, lower levels of precipitation due to La Nina in 2020. The La Nina effects being exacerbated by the Lao PDR destructive damming practices which allow for wasting great quantities of water through evaporation and seepage.

The DIV of both Lao PDR and China are the first and second highest, respectively.

This directly threatens the livelihood of the Vietnamese living on the Delta. Not only is the Delta threatened but slightly further upriver in Cambodia, the normative water flow of Tonle Sap Lake is disturbed as well, Fig. 21 (Mekong River Commission, 2020). Tonle Sap Lake is one of the world's biodiversity hotspots and the Mekong's wealthiest fishery (Mekong River Commission, 2020). Roughly 80% of the population of Cambodia depends upon the Mekong on a daily basis (Mekong River Commission, 2020).

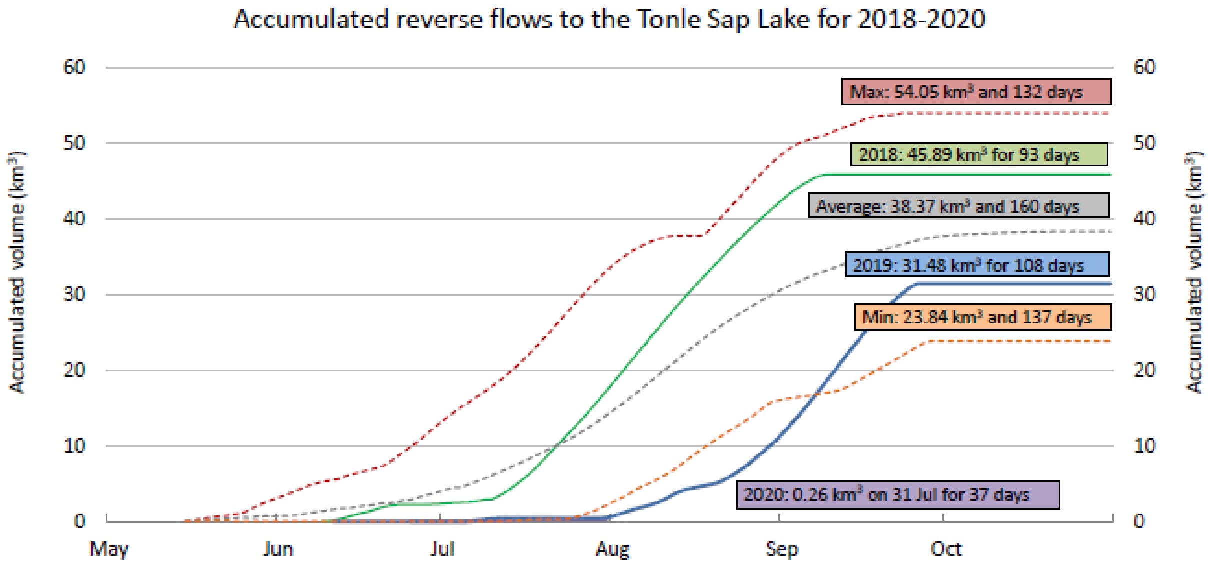


Figure 38. Characteristics of accumulated flows for 2018, 2019, and 2020, compared to the minimum, maximum, and average of 1997-2017 (Mekong River Commission, 2020)

In 2019 the Mekong River Basin's future was balancing on the edge of a knife. Due to the sundry environmental conditions in 2020, it is no longer balanced. The Mekong River Basin, especially the Delta and Tonle Sap Lake, are in the process of collapsing. The increased salinization up the Mekong will eventually poison the great fishery of Tonle Sap Lake in Cambodia and an avoidable, catastrophic environmental disaster will occur.

An examination of Lao PDR damming efforts must be conducted by the Mekong River Commission and a course of action decided to remove or mitigate the worst offending dams. Without this resolute, timely action the Mekong River Basin will acidify to the point where Vietnam and Cambodia lose approximately 51% of its rice and 80% of its protein consumption, respectively (The Mekong River Commission, 2018).

Only through a concerted effort between harmonious partners can an effective, efficient solution be considered, crafted, and implemented.

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Annotated Bibliography

I. *Annotated Bibliography:*

a. *Background:*

i. *A Dam-building Race Threatens the Mekong River*. (2019, August 16). Retrieved from DW: https://www.dw.com/en/a-dam-building-race-threatens-the-mekong-river/a-50049206

1. This article describes the ascendancy of dam erection on the Mekong River and its subsequent environmental consequences. It illustrates the complex ecosystem and aquatic environment already present on the Delta. It is extremely relevant to couch the terms of environmental impact in a meaningful manner to gauge the impact of Chinese damming of the Mekong River.

ii. *Izhar. (2017, September 19). Why the Mekong Delta is the Most Threatened Delta in the World? Retrieved from University of Applied*

Sciences: https://blog.hz.nl/en/why-the-mekong-delta-is-the-most-threatened-delta-in-the-world

1. This blog was written by a GIS student from the Netherlands who identified why the Mekong River Delta is exceptionally threated by rising sea levels from climate change. This is important as it identifies the amount of sea level necessary to inundate and ruin the Mekong River Delta. With the decrease in river water pressure from the Mekong the sea level necessary to ruin the Mekong River Delta decreases and approaches current levels.

iii. *Mekong Region Transport and Tourism*. (2021, January 16). Retrieved from MekongRegion: https://www.mekongregion.com/

1. The Mekong Region Transport and Tourism article provides a vivid account of activities on the river. The activities are important to document healthy levels of activity on the Mekong River Delta and inland riverine stretches. The use of the Mekong River as an economic corridor is threatened due to Chinese damming.

iv. Nachemson, A. (2019, September 23). *Cambodia's Lifeline Threatened as Mekong Recedes to Historic Low*. Retrieved from Al Jazeera: https://www.aljazeera.com/news/2019/9/23/cambodias-lifeline-threatened-as-mekong-recedes-to-historic-low

1. This article covers Cambodia's use of the Mekong River; before it reaches Vietnam. It reveals silting and riverine fishery challenges on dams upriver and on the Mekong tributaries. This helps illustrate the destabilizing affects of dams upriver in general and the massive Chinese dams in particular as they seek to control the politics of downriver states.

v. Union of Concerned Scientists. (2021, January 16). *Mekong River Delta Vietnam*. Retrieved from Climate Hot Map: http://www.climatehotmap.org/global-warming-locations/mekong-river-delta-vietnam.html

1. This report helps drill down to the economic impact of losing the arability of the Mekong River Delta. The economic impact on over a million people in the Mekong River Delta and the loss of almost half of the country's rice production cannot be understated. Although the material is a little dated, in that it attributes these issues to climate change vice Chinese damming and a reduction in CO2 pollution as the chief solution, it is still a useful benchmark to gauge the economic impact which a healthy Mekong River Delta may have on Vietnams economy.

vi. World Wildlife Fund. (2021, January 16). *Protecting the Mekong River Ecoregion*. Retrieved from World Wildlife Fund: https://www.wwf.org.kh/where_we_work_cambodia/protecting_the_mekong_river_ecoregion/

1. This article from the World Wildlife Foundation reveals the environmental impact on the Mekong River and the efforts made to organize the different communities economically. This economic synchronization should translate to political clout in dealing with other members of the Mekong River watershed. If enough cohesion can be knit together and differences set aside it may be possible to find a political and/or diplomatic solution to the challenging environmental crisis on the Mekong River Delta.

b. ***Methodology and Workflow:***

i. Amini, S., Rohani, A., Aghkhani, M. H., Abbaspour-Fard, M. H., & Asgharipour, M. R. (2019). *Assessment of Land Suitability and Agricultural Production Sustainability Using a Combined Approach (Fuzzy-AHP-GIS): A Case Study of Mazandaran Province, Iran.* Beijing: China Agricultural University.

1. This study fields a fuzzy-logic GIS approach to understanding the impact of climate change on rice production. With some modification of the criteria utilized (Table 1 of the report), some impact to rice fields on the Mekong River Delta may be extrapolated. Although the report is able to work in usable criteria much of the data collected was recovered via ground samples of landcover. Remote sensing of Landsat data will be able to provide landcover classification.

ii. Baroudy, A. A., & Moghanm, F. S. (2014). *Combined Use of Remote Sensing and GIS for Degradation Risk Assessment in Some Soils of the Northern Nile Delta, Egypt.* Cairo: The Egyptian Journal of Remote Sensing and Space Sciences.

1. This report utilizes remote sensing to quantify the soil degradation risk of some soils in the Northern Nile Delta. It utilizes Physiographic units mapped using Landsat ETM + imagery from (2003). Physiographic units are important to building a measurable understanding of the Mekong River Delta. This study also identifies landcover and landscapes of a river delta which is a suitable mock-up for understanding the Mekong River Delta. It also articulates chemical degradation; specifically salinity, alkalinity, and water logging. These are chief concerns of the Mekong

River Delta ecosystem and the remote sensing methodology for detecting health therein.

iii. Du, J., Li, Q., Zhao, R., Yang, J., Zhou, S., Chen, C., . . . An, S. (2020). *Effect of Influent Salinity on the Selection of Macrophyte Species in Floating Constructed Wetlands.* Nanjing: Journal of Environmental Management.

1. This report breaks down the science behind why salinity is bad and its desultory effect on freshwater flora and fauna; specifically aquatic macrophytes. It specifically addresses influent salinity which is an activity occuring along a depressurized (lacking in river water pressure) Mekong River Delta. Although highly specialized in detailing the effects of Constructed Wetlands (CW), the science and scene which it captures is effective in capturing exactly why the environmental collapse of the Mekong River Delta may be attributed to salinization.

iv. Islam, M. S., Uddin, M. A., & Hossain, M. A. (2020). *Assessing the Dynamics of Land Cover and Shoreline Changes of Nijhum Dwip (Island) of Bangladesh Using Remote Sensing and GIS Techniques.* Dhaka: Department of Geography and Environment, Jagnnath University.

1. This report utilizes a supervised classification method of shorelines in Bangladesh via remotely sensed Landsat images. This highly relevant methodology will assist in determining the extent of forests, expansion of settlement area, sea level rise, and river level fall. Although it only uses eight significant lancover classifications, the methodology of selecting different landcover classifications on the Mekong River Delta will make this a useful source for determining environmental health and economic impact.

v. Jamali, A. A., Naeeni, M. A., & Zarei, G. (2020). *Assessing the Expansion of Saline Lands Through Vegetation and Wetland Loss Using Remote Sensing and GIS*. Yazd: Department of GIS-RS and Watershed Management, Azad University.

1. This report utilizes NDVI and Soil Salinity Indes (SSI) derived from remotely sensed Landsat imagery from 1985 to 2016. The two indices (NDVI and SSI) landcover classification was executed with six classes, vegetation, and salinity identified and entered into the Land Change Modeler (LCM). Smart modeling was continued by Multi-Layer Perceptron (MLP) Neural Network method. This methodology was utilized to forecast a 2025 map and will be useful in attaining similar results along the Mekong River Delta.

vi. Metternicht, G. (2000). *Assessing Temporal and Spatial Changes of Salinity Using Fuzzy Logic, Remote Sensing, and GIS. Foundations of an Expert System*. Perth: Department of Spatial Sciences, Curtin University of Technology.

1. This report conducts a multi-temporal image classification of Landsat TM data from 1986 to 1994 of saline-alkaline areas in the Punata-Cliza Valley. The image classification included supervised training, signature evaluation and selection of the best band combinations and pixel labelling. Nine classes ranging from non-saline to very strongly saline-alkaline were discovered. Determining healthy soil salinity levels will assist in determining what a healthy Mekong River Delta looks like. This will enable the interpretation of further alkaline signatures as we watch the Mekong River Delta increase with salinity. Although this study does not provide for a river delta environment, the science and phenomenology of alkaline detection is useful.

vii. Mohamed, E. S., Schutt, B., & Belal, A. (2013). *Assessment of Environmental Hazards in the North Western Coast - Egypt Using RS and GIS*. Cairo: The Egyptian Journal of Remote Sensing and Space Sciences.

1. An interesting report that utilizes the Universal Soil Loss Equation (USLE) which is an empiracal model used for assessing long-term annual soil loss. It also estimates salinity and sodicity hazards based on FAO method as a standard reference. River deltas are notorious environments for errosion and silt, this methodology will be useful in determining whether or not the Mekong River Delta is also being adversely affected by Chinese dams silting up the river as the water flow decreases. By determining the effects of silting on the river, different courses of action may be at hand for rectifying this slow-moving environmental disaster.

viii. Subramaniam, S., & Saxena, M. (2011). *Automated Algorithm For Extraction of Wetlands From IRS ResourceSat LISS III Data*. Hyderabad: RS&GIS Applications Area, National Remote Sensing Centre (NRSC), ISRO.

1. This report identifies a methodology for automatically extracting wetlands from IRS ResourceSat imagery by using the Normalized Difference of Water Index (NDWI). With slight modifications it can be used to determine river levels in the Mekong River Delta. Coupled with a methodology used to determine Enhanced NDVI, NDTI, BI, it may be possible to measure the salinity of water based on green and red properties of an enhanded NDTI.

c. ***Data:***

i. **Datasets:**

1. **Landsat 8:**

    a. LC08_L2SP_125053_20150124_20200910_02_T1
    b. LC08_L2SP_125053_20200106_20200824_02_T1
    c. LC08_L2SP_125053_20150209_20200909_02_T1
    d. LC08_L2SP_125053_20200223_20200822_02_T1
    e. LC08_L2SP_125053_20150313_20200909_02_T1
    f. LC08_L2SP_125053_20200310_20200822_02_T1
    g. LC08_L2SP_125053_20150430_20200909_02_T1
    h. LC08_L2SP_125053_20200427_20200822_02_T1
    i. LC08_L2SP_125053_20150516_20200909_02_T1
    j. LC08_L2SP_125053_20200513_20200820_02_T1
    k. LC08_L2SP_125053_20150617_20200909_02_T1
    l. LC08_L2SP_125053_20200614_20200823_02_T1
    m. LC08_L2SP_125053_20150703_20200909_02_T1
    n. LC08_L2SP_125053_20200716_20200911_02_T1
    o. LC08_L2SP_125053_20150804_20200908_02_T1
    p. LC08_L2SP_125053_20200817_20200920_02_T1
    q. LC08_L2SP_125053_20150905_20200908_02_T1
    r. LC08_L2SP_125053_20200902_20200906_02_T1
    s. LC08_L2SP_125053_20151007_20200908_02_T1
    t. LC08_L2SP_125053_20201020_20201105_02_T1
    u. LC08_L2SP_125053_20151124_20200908_02_T1
    v. LC08_L2SP_125053_20201121_20210315_02_T1
    w. LC08_L2SP_125053_20151226_20200908_02_T1
    x. LC08_L2SP_125053_20201207_20210313_02_T1

ii. ***Websites:***

1. USDA. (2021, January 16). *Data Gateway*. Retrieved from USDA Geospatial Gateway: https://datagateway.nrcs.usda.gov/GDGOrder.aspx?order=iMapOrder

    a. USDA website for pulling remotely sensed data. It is a useful website for calling in satellite imagery of the United States and its waterways. Unfortunately, exploitation of the website for overseas locations has proven challenging.

2. USGS. (2021, January 16). *GLOVIS*. Retrieved from USGS: https://glovis.usgs.gov/app?fullscreen=0
    a. This site is a USGS portal for downloading remotely sensed data from around the world.
3. EarthExplorer. (2021, January 16). *Earth Explorer*. Retrieved from US Geological Survey: https://earthexplorer.usgs.gov/
    a. Another USGS portal for downloading remotely sensed data from around the world. Similarities and capabilities between GLOVIS and EarthExplorer exist as both are hosted by the US Geological Survey. Options within EarthExplorer allow access to NASA imagery databases. See below.
4. NASA. (2021, January 01). *Earth Data Search*. Retrieved from Earth Data: https://search.earthdata.nasa.gov/search
    a. NASA site for remotely sensed data on the Earth. EarthExplorer at the USGS may direct users to this site for accessing sea surface, cloud map, and other atmospheric data not particularly inherent to the USGS mission. This site is a great source for studying atmospherics and even localized weather phenomenon making this a valuable tool to study possible climate change impacts on the Mekong River Delta as well as backwaters of dams on the Mekong River.
5. NOAA. (2021, January 16). *Imagery Data*. Retrieved from NOAA: https://www.nesdis.noaa.gov/content/imagery-data-0
    a. NOAA website for remotely sensed data of the surface of the earth. Good website for finding LIDAR datasets of the United States.