Monitoring the Quantity of Water Flowing Through the Upper Mekong Basin Under Natural (Unimpeded) Conditions

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Monitoring the Quantity of Water Flowing Through the Upper Mekong Basin Under Natural (Unimpeded) Conditions

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1. Eyes on Earth, Inc.
2. Global Environmental Satellite Applications, Inc.

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Sustainable Infrastructure Partnership (SIP)

SIP is a capacity building and coordination program managed by Pact Thailand to address shared water resource challenges in the Mekong region. SIP supports training and capacity building for managing interactions among water, energy and food systems, and promotes sharing of water data through the Mekong Water Data Initiative. SIP works under the umbrella of the Lower Mekong Initiative.

Lower Mekong Initiative (LMI)

Launched in 2009, the LMI is a multinational partnership among Cambodia, Lao PDR, Myanmar, Thailand, Viet Nam and the US. The LMI serves as a platform to address complex, transnational development and policy problems in the Lower Mekong subregion. LMI works in collaboration with the grouping of aid donors known as Friends of the Lower Mekong (FLM), including Australia, Japan, Republic of Korea, New Zealand, the European Union, the Asian Development Bank, and the World Bank.

For more information, visit the SIP Facebook page and the LMI website

SIP Facebook page

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Executive summary

This study developed a reliable and simple model that predicts the natural flow of the Upper Mekong, then used this prediction to determine how the cascade of dams built on the Upper Mekong is altering the natural flow of the river. The foundation of this study is based on satellite data from 1992 to 2019 and daily river height gauge data from Chiang Saen, Thailand. Eyes on Earth, Inc. and Global Environmental Satellite Observations, Inc. have developed proprietary software, which is based on an algorithm that translates microwave observations measured by the Special Sensor Microwave Imager/Sounder (SSMI/S) into a land surface wetness index. Using the model to predict natural flow, we calculated the quantity of water that would naturally flow versus the measurement at the Chiang Saen gauge. This difference was summarized over various periods of the 28-year record to identify the amount of water that is either impounded in the reservoirs or extracted from the river basin upstream of Chiang Saen by other means.

Currently, 126.44 meters of river height is missing at the gauge in Chiang Saen over the 28-year record. Huaneng Hydrolancang, a Chinese state-owned enterprise built a series of dams on the main stem of the Mekong during that time. There is generally a good correspondence between the gauge measurements and the satellite-derived estimates during the early years, with some deficiency in river height during the filling of the Manwan and Dachaoshan reservoirs. The relationship between gauge height and natural flow deteriorated after 2012, when a couple of major dams and reservoirs were built, which greatly restricted the amount and timing of water released upstream. The Government of China has pledged to utilize these dams to regulate downstream flow so that period of high and low flow would be more evenly distributed. This also suits their need to distribute the energy production across the annual cycle, allowing the generators to be used more equitably throughout the year. The consequence of flow regulation is that water that would normally flow during the wet season is released during the dry season.

This can clearly be seen in the annual cycle of the residuals, which are negative in the wet season and positive in the dry season. When the largest of the dams, Nuozhadu, and its reservoir were completed, the lack of water during the wet season is most pronounced after the largest generators began operating.

The dams greatly expand institutional capacity to regulate the river flow, with corresponding impacts downstream that need to be addressed through holistic solutions. The six dams built since the commissioning of the Nuozhadu Dam in 2012, are compounding the alteration of natural river flow as the reservoirs are filled and water is released. One of the greatest consequences occurred in 2019, when the Lower Mekong recorded some of its lowest river levels ever throughout most of the year. Using the wetness index to predict natural flow, it is evident that there was above-average natural flow originating from the Upper Mekong. The residuals demonstrate excess flow in the dry season, presumably to support electrical production in early 2019, while the flow during the wet season was severely restricted as the Lower Mekong received record lower levels of rainfall. The severe lack of water in the Lower Mekong during the wet season of 2019 was largely influenced by the restriction of water flowing from the upper Mekong during that time. Cooperation between China and the Lower Mekong countries to simulate the natural flow cycle of the Mekong could have improved the low flow conditions experienced downstream between May and September of 2019. If the wetness index is used as a guide to simulate natural flow, then all communities along the Mekong basin could benefit from maintaining the integrity of the Mekong River.

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I. Introduction

This study monitors river height on the Upper Mekong River and identifies how dams upstream alter the natural flow. The goal of the research is to develop a reliable and simple model that predicts the natural flow of the Upper Mekong, then use this prediction to determine how the cascade of dams built on the Upper Mekong is altering the natural flow of the river. Several articles have discussed the impacts of dams commissioned by China, and how they are altering the ecology and resources in the Lower Mekong Basin (Lu et al. 2006, Baran and Myschowoda 2009, Plinston and He Daming 2000). The study will quantify the amount of water flowing from the Tibetan Plateau towards the gauge at Chiang Saen in Thailand.

There are numerous approaches to monitor river discharge. Many of them are based on parameterization of the physical factors that influence the quantity of water accumulating in the basin (Smakhtin 2001, Kollet and Maxwell 2006, Kurtz et al. 2016). Other approaches are derived from satellite observations. Statistical models are used to translate the remote sensed signal into a statistical flow model (Blankenspoor et al. 2012, Meier et al. 2011, Scipal et al. 2005).

The foundation of this study is based on satellite data from 1992 to 2019 and daily river height gauge data from Chiang Saen. A regression model will identify the relationship between these two data sets. Once a reliable model is established it can be used to predict natural flow over the 28-year record. This difference between natural flow and measured flow entering Thailand identifies how the dams are altering the amount of water flowing from the Upper Mekong basin.

II. Methodology

The daily river height data measured at Chiang Saen were averaged into monthly mean values from January 1992 through September 2019. This data is compiled by the Mekong River Commission and was provided to Eyes on Earth, Inc. The boundary of the river upstream of Chiang Saen includes the entire length of the river inside China, where it starts in the Tibetan plateau. This section of the river includes a small area in Myanmar and Lao PDR (where there are no major tributaries adding to the flow) before reaching the Thai border at Chiang Saen, where the gauge is located (Figure 1). River height data during periods of natural flow serve as calibration of the model. The wetness values are used to predict the natural flow in the Upper Mekong basin.

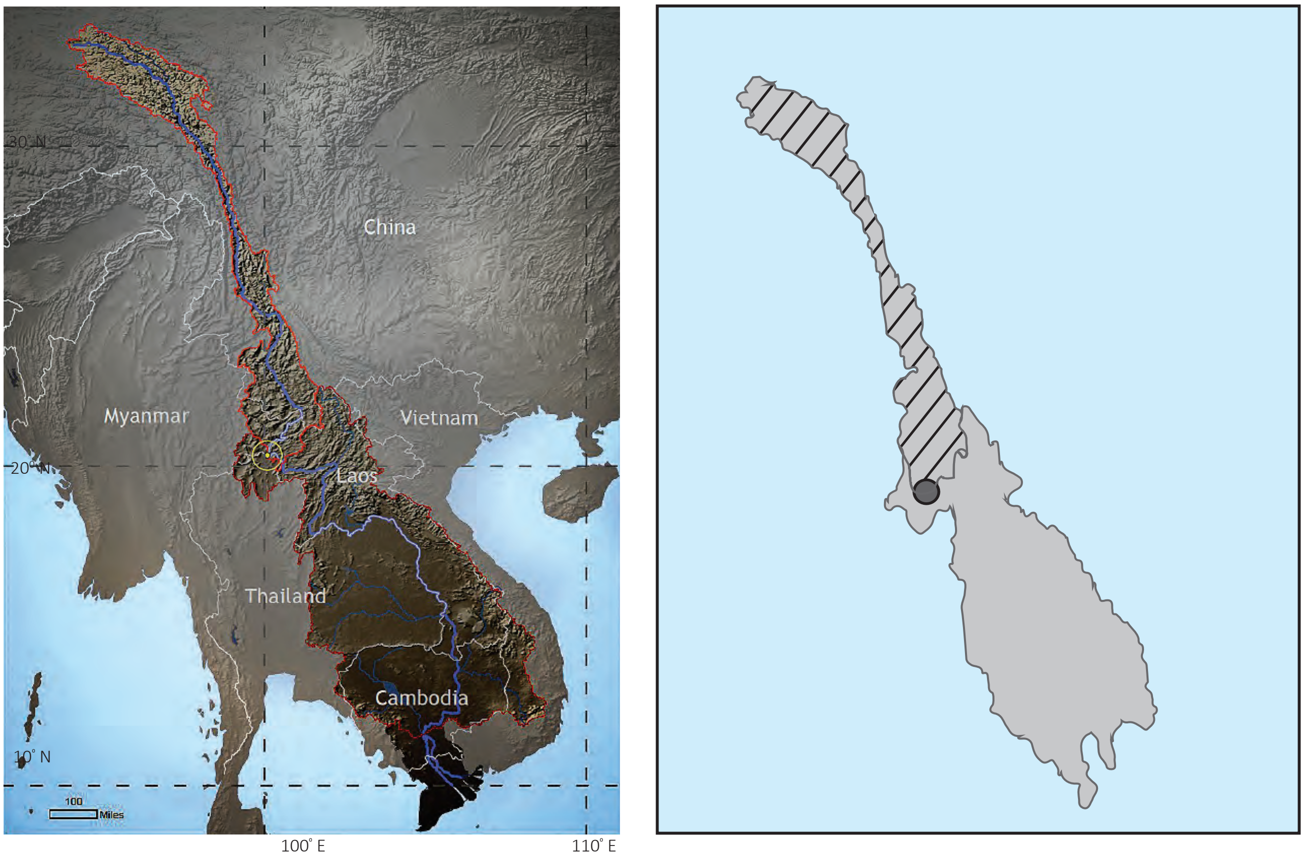


Figure 1: The map on the left shows the portion of the Mekong basin that contributes to the flow received at Chiang Saen gauge station at the intersection of the Myanmar, Lao PDR and Thai border. The circle locates the river gauge. The map on the right shows the whole Mekong basin in Southeast Asia.

In order to calibrate a relationship between satellite observations and gauge measurements, the satellite data is based upon passive microwave observations. They are measured by the Special Sensor Microwave Imager/Sounder (SSMI/S). The SSMI/S data are observed twice a day from polar orbiting satellites flown by the Defense Meteorological Satellite Program (DMSP). These satellites go from the North Pole to the South Pole and back again 14 times a day, i.e. they make 14 global revolutions each day (Neale et al. 1990). The satellites are designed to be sun synchronous, crossing the equator around 6 am and 6 pm on every rotation around the globe. The SSMI/S senses microwave emission from the Earth surface at four frequencies in the radiative spectrum, and three of the frequencies are measured at dual polarization (vertical and horizontal). The energy detected by these sensors is passive, which means it is naturally emanating from the Earth's surface. Clouds are generally transparent at the frequencies observed by the SSMI/S instrument, which enables measurements of surface conditions (wetness, snow cover, and temperature) under almost all sky conditions (Basist et al. 1998). Eyes on Earth, Inc. and Global Environmental Satellite Observations, Inc. have developed proprietary software, which is based on an algorithm that translates microwave observations into a land surface wetness product. The stylized formula presented below demonstrates how this relationship was developed. The surface wetness index ranges from zero, which represents no water detected near the surface, to a percentage of the radiating surface that is liquid water. Therefore, the range goes from 0.0 to 100.0, where 100 means the entire surface is liquid water (Basist et al. 2001). This index is derived from a linear relationship between channel measurements (Equation 1), where a channel measurement is the value observed at a particular frequency and polarization (i.e. the SSMI/S observes seven channels).

EQUATION 1

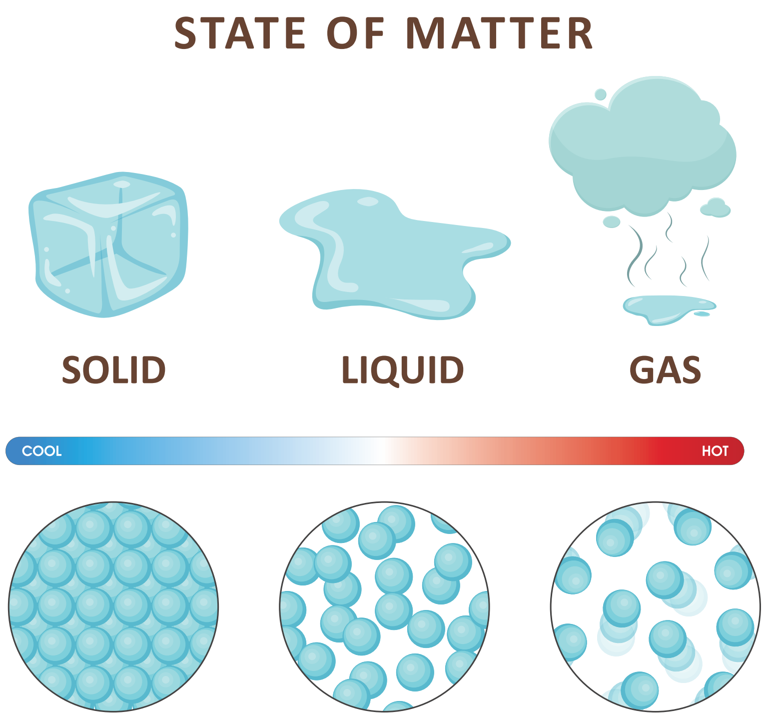
$$BWI = \Delta\varepsilon \cdot T_s = \beta_0[T_b(v_2) - T_b(v_1)] + \beta_1[T_b(v_3) - T_b(v_2)]$$

Where the change of emissivity, Δε, is empirically determined from global SSMI/S measurements, Ts is surface temperature over wet or dry land, Tb is the satellite brightness temperature at a particular frequency (GHz), υn (n=1, 2, 3) is a frequency observed by the SSMI/S instrument, and β0 and β1 are estimated coefficients that correlate the relationship of the various channel measurements to observed surface temperature at the time of the satellite overpass. Specifically, the greater the wetness, the higher the differences between the observed surface temperature and the observed channel measurements (Williams et al. 2000).

In summary, the wetness index was calibrated on the reduction of emissivity in the microwave spectrum due to the influence of liquid water in the radiating surface. Therefore, the final product is the reduction of emissivity at 19 GHz associated with liquid water in the microwave observations. These products have been used since the year 1998 by government agencies in the United States and Canada, the World Bank, and NGOs that support 'climate-smart agriculture' (Lipper et al. 2012), as well as by the insurance industry and other commercial sectors.

The wetness index is unique in that it only
observes water in a liquid state (Willams et al. 2000).
In other words, water in a vapor state is transparent and does not register as wet. Microwave observations are highly sensitive to liquid water near the surface (Basist et al. 1998); it is one of the strongest signatures at the frequencies detected by the SSMI/S instrument. In the microwave spectrum, water vapor is transparent over land and does not register as wet. Crystalline snow and ice have uniquely different microwave signatures (Hollinger et al. 1987). These are used in a snow cover product which accurately observes frozen water on the Earth's surface. An important aspect of the relationship between frozen and liquid water is that as a snowpack begins to melt the liquid water in the snow can be accurately quantified and integrated into the flow model.

This is particularly important in the Upper Mekong Basin where a large quantity of the precipitation falls in a crystalline state and is held in the frozen state throughout much of the year, until the snow-pack and glaciers begin to melt in the late spring and summer. Part of the lag associated with the land surface wetness observations and the response of the river gauge measurements relate to the melt cycle. As the snow begins to melt, most of the water remains in the snowpack, changing its micro-wave signal from frozen to wet. However, most of this water refreezes at night, and registers as frozen by the satellite observations in the early morning. The process of melting during the day and then refreezing at night continues until the snowpack is saturated with liquid water and temperatures at night remain above freezing (Hardy et al. 1999). At this stage the snowpack is called 'ripe' and it starts releasing significant quantities of liquid water into the ground, while some of the water flows across the surface toward local streams. It has been noted in some studies that this process can take weeks before the snowpack is effectively ripe, at which time it releases large quantities of water into the river basin. Moreover, water seeping into the ground takes even longer to reach a stream. Previous studies (Demirel et al. 2013, Sattar and Kim 2019) demonstrate that there is a significant lag before liquid water upstream is observed hundreds of kilometers downstream at the gauge.



The period of data for this study begins in 1992 and extends to September 2019. As previously noted, the Government of China built a series of dams during this period of time.

The first in this series of dams was the **Manwan**. Its first generator was commissioned in 1993 (Lu et al. 2006). The reservoir created by the dam is moderate in size, impounding up to 920,000,000 cubic meters of water. Therefore, it has a limited capacity to restrict and regulate flow.

The second operational dam on the main stem of the Mekong is the **Dachaoshan.** It also has moderate capacity to restrict flow, with a reservoir that can store up to 940,000,000 cubic meters of water. Its generators were commissioned in 2002 through 2003.

The third dam to become operational was **Jinghong.** It is slightly larger than the first two dams. It also has moderate capacity to store water, containing a reservoir restricting flow of 249,000,000 cubic meters of water. Its first generator was commissioned in 2008.

Table 1: Dams, Reservoirs and Electrical Production on the Upper Mekong

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
D2y33dz2ljλl·2	120,000,000	201н
Miaowei	660,000,000	201т
Idzl·y3ŘŜy3	1,613,000,000	нлмт
5l·Ƙdzl·ljλl·2	293,000,000	201y
[λŘλ	75,000,000	201y
² dzy2y3ƭ2y3	284,000,000	201y

The fourth dam on the main stem of the Mekong is the **Xiaowan.** The Xiaowan's capacity to restrict natural flow is an order of magnitude greater than that the previous three dams, since its reservoir can store up to 15,130,000,000 cubic meters of water. This dam's ability to restrict flow is almost seven times greater than the capacity of the previous three dams combined. Its first generator was commissioned in 2009.

The fifth dam to become operational was **Nuozhadu.**
This dam creates the largest reservoir on the Mekong River. It has a storage capacity of 27,490,000,000 cubic meters. It is considerably larger than the previous four reservoirs combined. Its first generator was commissioned in 2012.

The Gongguoqiao dam created the sixth reservoir, holding 120,000,000 cubic meters of water in late 2012. It is followed by the **Miaowei** dam in January 2017, which holds 660,000,000 cubic meters. The eighth dam was **Huangdeng,** with a large reservoir of 1,613,300,000 cubic meters of water in November 2017, followed by a ninth dam at **Dahuaqiao** in February 2018 with storage capacity of 293,000,000 cubic meters. The tenth is the **Lidi** dam, completed in June 2018 with a storage capacity of 75,000,000 cubic meters of water. And finally, the eleventh in December 2018, the **Wunonglong** dam, has a storage capacity of 284,000,000 cubic meters.

In order to commission a generator, the dam must already restrict a considerable quantity of water in the reservoir behind it. Therefore, the commissioning date of the generator indicates that a significant portion of the reservoir created by the dam is already filled. The gradient between reservoir height and base of the dam is the source of electrical production.

Credit image: Mekong River Commission

Nuozhadu, the largest dam on the Lancang (Mekong) River in China.

III. Developing the flow model

The period of data for this study begins in 1992 and extends to September 2019. As previously noted, the Government of China built a series of dams on the main stem of the Mekong during that time. In order to create the most stable, accurate and precise flow model, we need to identify the best period of record for model calibration and validation. Ideally one would think the earliest years would be most representative of natural flow. However, after research on the beginning of the satellite observations, it was determined that data from the first two years were influenced by the filling of the reservoir upstream of the Manwan dam. Therefore, the earliest years of model calibration/validation begin in 1994. Our goal was to use approximately five years of data for calibration, leaving other years prior to 2001 as validation of the model stability. The upper end of the optimum calibration/validation period is based on evidence that river flow during 2002 was used to fill the reservoir behind the recently constructed Dachaoshan dam, as it was generating electricity in 2003. This leaves eight years as the period to perform a calibration/validation study on the optimum relationship between gauge data and the wetness value averaged upstream.

IV. Findings of the study

Based on the reasoning given above, we used 1997 to 2001 as the best representatives of natural flow. Therefore, this calibration period was used to form the foundation of a regression equation to quantify the relationship between the wetness and gauge measurements. Results of the model are shown in Table 2. The regression model explained 89% of the variability in river height at the gauge. It has a regression coefficient of .94, and a standard error margin of 0.67. The model is significant at the confidence interval of .99999 as defined by an F score of 231.

There are 57 degrees of freedom with 60 observations, which represents monthly values from 1997 through 2001. This regression equation was based on a two-month accumulated lag, as presented in the methodology section. We tested the validity of using a two-month lag, by running the same model with a one-month lag. The explanatory power decreased by about 10% and the standard error increased by 10 centimeters of river height, using a one-month lag. This finding confirms that a two-month lagged model provides a superior relationship between the wetness value and the gauge measurements.

Table 2: Results of the Regression Model Monitoring Natural Flow on the Upper Mekong River

The Skill of the Predictive Model (R2)	89%
Months in Model / Degrees of Freedom	60 / 57
Significance of the Model / F-score	.99999 / 231
Standard Error in Meters	0.67
Y-Intercept (Alpha)	0.92
Linear Slope Beta1	0.55
Squared Slope Beta2	0.95

The regression model (Equation 2) has an intercept of 0.921, followed by a linear coefficient of 0.554 and a quadratic coefficient of 0.954. The intercept represents the basin flow when the wetness value would have a value of zero. However, a zero value has not occurred in the 28-year record, therefore the intercept is a theoretical concept. If there was an extremely dry period and the river was only dependent upon groundwater, this would be the predicted flow. The linear term shows the direct relationship between the mean wetness value and the river height measured at the gauge. The squared term represents the non-linear component of the relationship between the wetness and gauge value (Singh 2007). The non-linear term is based on the fact that when there is a small quantity of water near the surface, it is largely held in the soil and does not flow towards a river. However, as the wetness value increases, a higher percentage of the water flows towards the river. When the soil is saturated, all the water flows downstream or raises the groundwater level. Therefore, the relationship between the wetness index and river height is non-linear.

EQUATION 2

*River Height = 0.921 + (0.554 * Wetness Index) + (0.954 * Wetness Index * Wetness Index)*

Since there is lagged response between surface wetness accumulated upstream and the river height at the border between Thailand, Lao PDR and Myanmar, the wetness value is the average from the concurrent month plus the wetness index from the previous two months. Therefore, the flow is based on the wetness index from the recent three months. It is also known as a three-month accumulated lag model, since it takes an extended period of time for water in the upper basin to reach the gauge location.

As mentioned above, we avoided using data from the years 1992, 1993, and 2002 to represent natural flow, since water, in these three years, was used to fill reservoirs behind the recently constructed dams. Instead, we use the years 1994 through 1996 as the validation period to test the stability of the model. The average of the residuals during the calibration period was 0.43 cm of river height, and during the validation period was 0.52 cm. The difference in residuals of 9 cm of river height during the validation and calibration periods is not substantial.

To further understand the relationship between predicted and measured flow, we plotted the two curves over the period of record. These curves are presented in Figure 2 below. As an overview, there is generally a good correspondence during the early years, with some notable exceptions that will be discussed below. One can note the strong correspondence in the annual cycle and flow during the calibration and validation periods. During the dry season, precipitation is limited and most of it falls and remains in a frozen state between November and April, whereas during the wet season from May through October, the snow melts and much of the precipitation falls in a liquid form. The correspondence of the annual cycle between the predicted and gauge measurements remained strong even after the second dam, Dachaoshan, was completed and the reservoir was filled. Specifically, one can look at the predicted and measured flow during the period 1994 and 2008 and see that there is generally excellent correspondence, with some notable exceptions. The relationship between gauge height and natural flow began to deteriorate after 2012, when a couple of major dams and reservoirs were built, which greatly restricted the amount and timing of water released upstream.

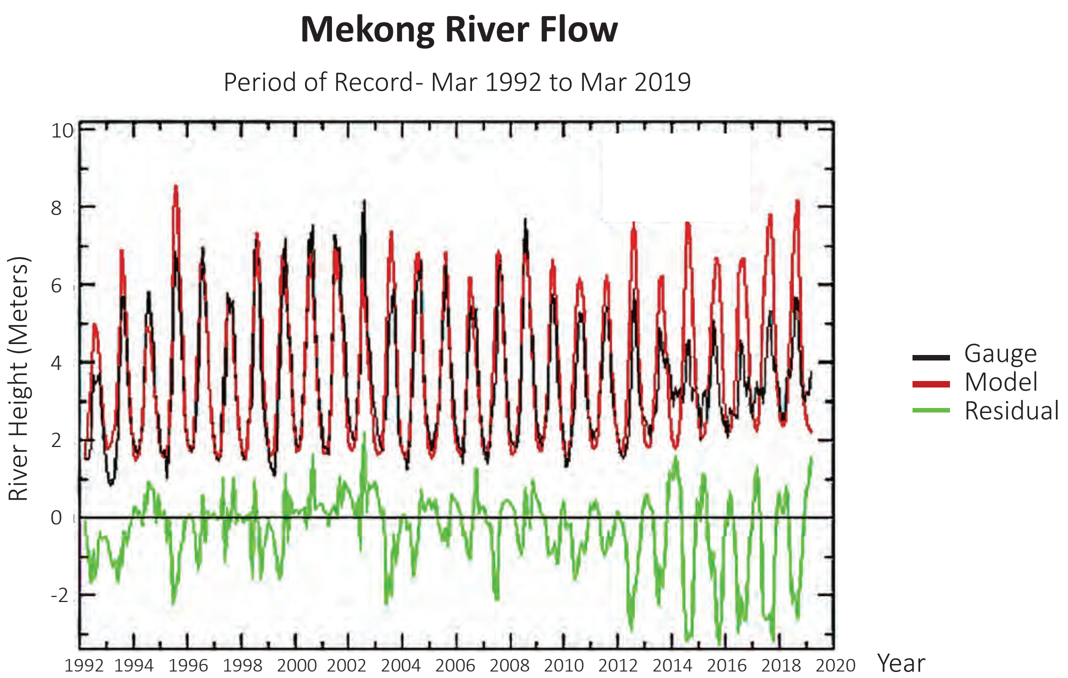


Figure 2: Time series of gauge and model predicted measurements at Chiang Saen from Jan 1992-March 2019. The green is the difference field. If the values are negative, the gauge is missing water, and if they are positive there is excess water at the gauge.

The deficiency of water in the river as measured by the wetness value during the period 1992 and 1993 demonstrates Mekong water was used to fill the reservoir behind the Manwan dam during the wet season (summer) of 1992 (Figure 3). This is illustrated by the negative value of the green line (residual), meaning the gauge measurement is lower than the predicted flow. During winter the stored water was released, allowing more energy production during the dry season, which distributed energy production more evenly through the year, one of the goals of the project. A large portion of extremely high natural flow in 1995 was used to fill the Manwan reservoir, which reduced the amount of water reaching the gauge. It appears the reservoir was near capacity by the end of 1995, therefore there was limited potential to store water or restrict the natural flow. Therefore, the following five years illustrated an excellent relationship between natural and dam release flow to Chiang Saen.

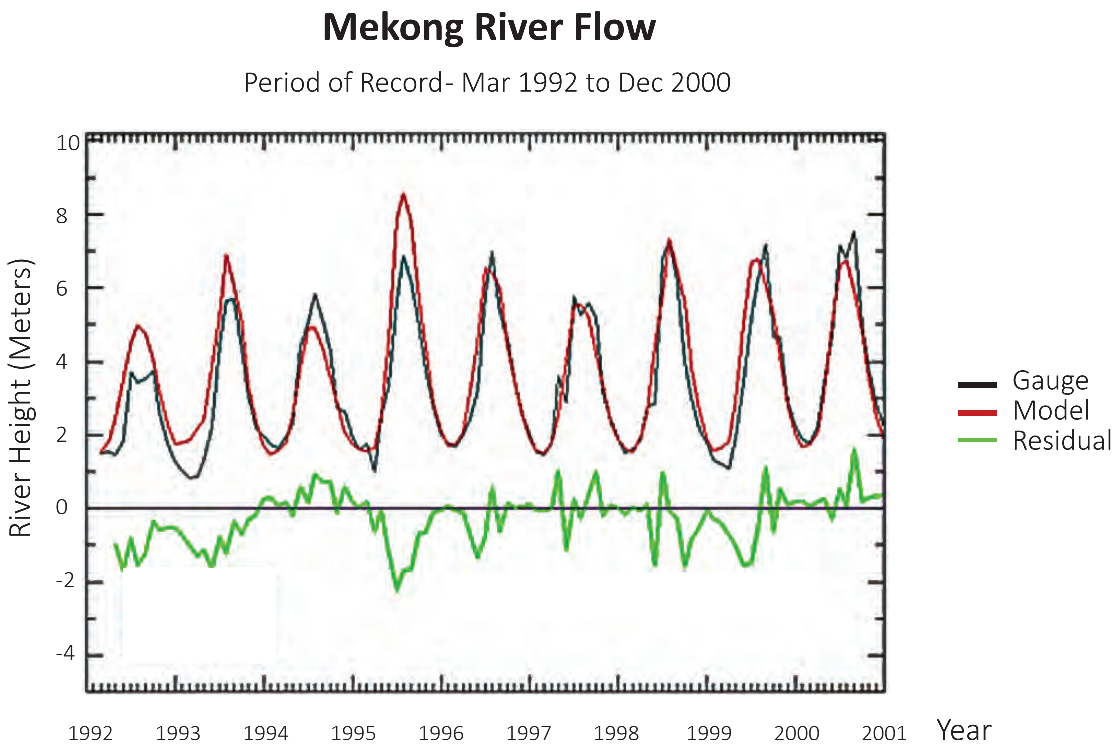


Figure 3: This is an enlargement of figure 2 over the years 1992-2000.

The next major difference in measured and predicted flow occurs in 2002 (Figure 4). The gauge data demonstrate that in 2002 there was a huge release of water from the Dachaoshan dam. This event likely corresponded to the inauguration of the turbines on the dam to generate electricity. Specifically, a major release of water occurred in July and August of 2002. The daily data is even more revealing, indicating that something unexplained occurred upstream of the gauge in Thailand during this period of time. Normally there is a gradual increase and decrease of river flow over the course of months. This was not the case in 2002. The maximum flow in the river usually occurs in August, September, and October, peaking in September. However, in 2002 the highest flows were in July and August. Specifically, the river height was 8.16 meters in August, dropping to 4.88 meters in September, about a 40% decrease in the middle of the wet season. Even more unnatural is the speed at which the river flow increased and then subsequently decreased. It was 10.17 meters on 21 August and 6.96 meters five days later. The wetness index shows no support for this event in 2002. Therefore we can only conclude that there were some significant releases of water behind the dam for a short period, which greatly altered the river from its natural flow state.

It appears an unnatural pulse of water was released after the commissioning of generators on both the Manwan and Dachaoshan dams. Similar findings were discovered around the time of commissioning the generator on the Jinghong dam in 2009. There seems to have been an unnatural pulse of water around that time. It may be that the Government of China generates electrical production at near maximum capacity through the turbines when the dams are commissioned (inaugurated), thereby releasing a large pulse of water downstream for a short period of time. However, there is no confirmation of this fact, and more research will be required to better understand these unnatural flows around the time that the generators came online.

Mekong River Flow

Period of Record- Jan 2001 to Dec 2009

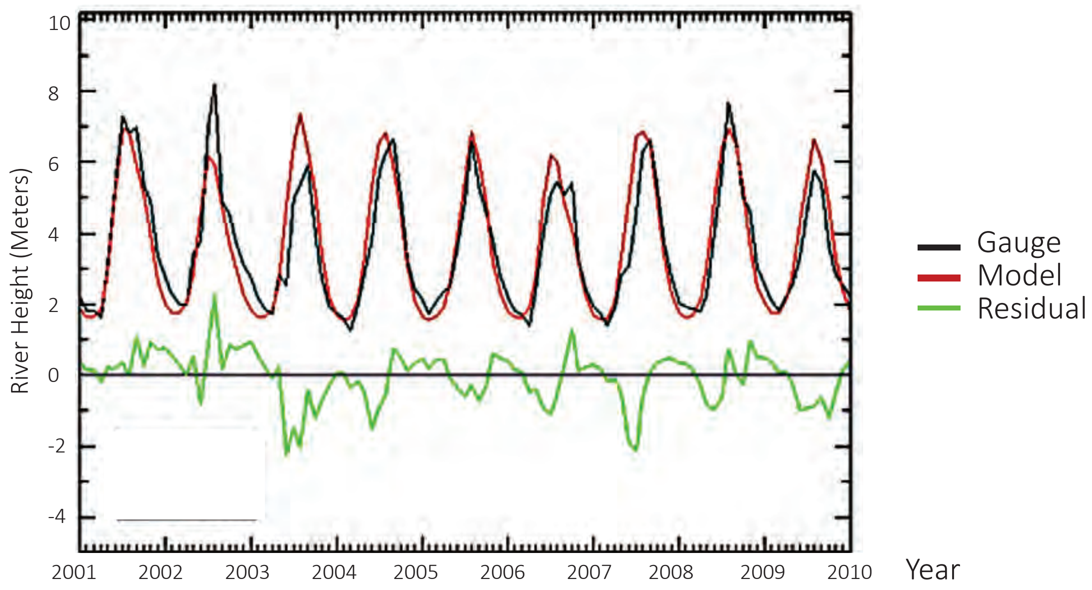


Figure 4: This is an enlargement of figure 2 over the years 2001-2009.

It appears the high natural flow of the 2003 wet season (summer) was restricted by the two dams upstream, thereby recharging the reservoirs that were depleted during the previous year, when the generators were commissioned and excess water was released downstream during electrical production in 2002. Data from the years 2006 and 2009 also show 'missing' water at the Chiang Saen gauge, corresponding to the periods when water is restricted upstream. It appears that the reservoir water levels are lowered in the winter to support energy production during the dry season. The reminder of the decade showed a fairly similar pattern between measured and predicted flow.

Considerable differences in measured and predicted flow occurred in 2010, when the major Xiaowan dam was completed and the generators came online. Figure 5 is an enlarged section of the time series for the period 2010 to 2019. As noted earlier, this reservoir can hold about seven times the amount of water as the previous three reservoirs combined, therefore its ability to regulate and restrict flow rises to another order of magnitude. The capacity to restrict flow is clearly demonstrated in the relationship between predicted natural flow and measured flow, since a large quantity of water is 'missing' at the gauge during the warm season, when river flow normally would greatly increase, due to melting snow and recent precipitation on the Tibetan plateau.

Moreover, some of the missing water is released during the dry season. The Government of China has pledged to utilize its upstream dams to regulate the flow so that periods of high and low flow would be more evenly distributed. This also suits their need to distribute the energy production across the annual cycle, allowing the generators to be used more equitably throughout the year. The consequence of flow regulation is that water that would normally flow during the wet season is released during the dry season. This can clearly be seen in the annual cycle of the residuals, which are negative in the wet season and positive in the dry season.

The residuals (gauge measurements minus predicted natural flow) have shown a very clear and recurring annual cycle over the last decade. Relative to the gauge, the satellite measurements show there is missing water during the wet season. Conversely, excess water is released during the dry season. This is presumably to distribute electrical production more equitably throughout the year. This is particularly so after 2012, when the largest of the dams, Nuozhadu, and its reservoir were completed. The lack of water during the wet season is most pronounced after the largest generators began operating. The dams greatly expand institutional capacity to regulate the river flow, with corresponding impacts downstream that need to be addressed through holistic solutions (Wolfe et al. 2003).

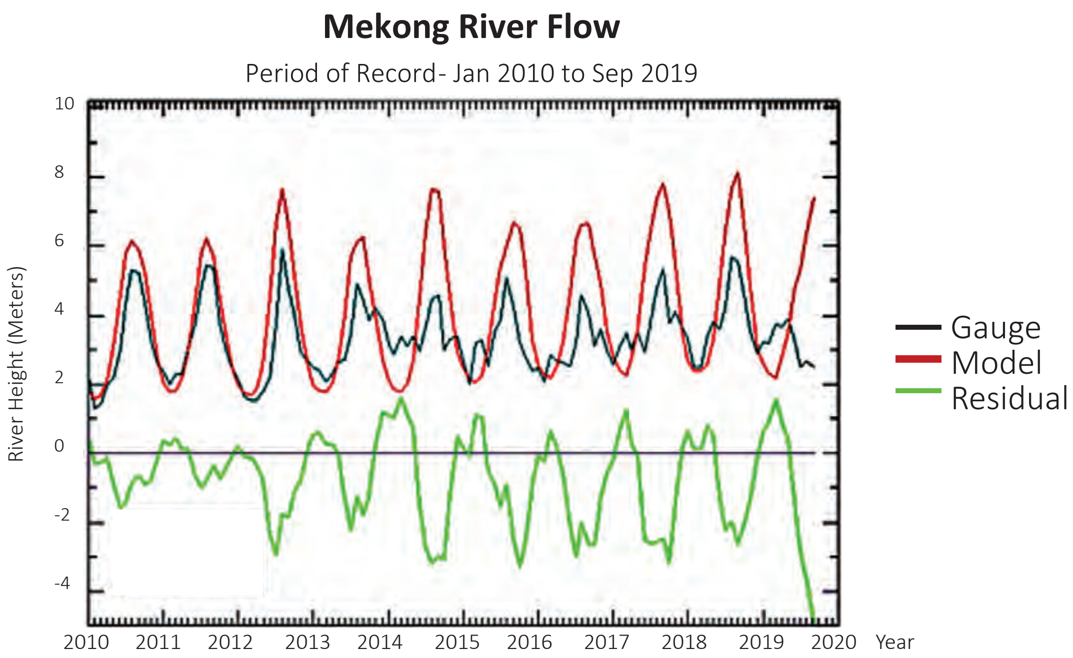


Figure 5: This is an enlargement of figure 2 over the years 2010-2019.

The five dams built since 2017 are compounding the alteration of natural river flow as the reservoirs are filled and water is released. One of the greatest consequences occurred in 2019, when the Lower Mekong recorded some of its lowest river levels ever. Using the wetness index to predict natural flow, it is evident that there was above-average natural flow originating from the Upper Mekong. The residuals demonstrate excess flow in the dry season, presumably to support electrical production in early 2019, while the flow during the wet season was severely restricted. The severe lack of water in the Lower Mekong during the wet season of 2019 is largely influenced by the restriction of water flowing from the Upper Mekong during that time. Cooperation between China and the Lower Mekong countries to simulate the natural flow cycle of the Mekong could have improved the low flow conditions experienced downstream in the summer of 2019.

Using the model to predict natural flow,
we can calculate the quantity of water that would naturally flow versus the measurement at the Chiang Saen gauge. This difference can be summarized over various periods of the 28-year record to identify the amount of water that is either impounded in the reservoirs or extracted from the river basin upstream of Chiang Saen by other means. Currently, we calculate that 126.44 meters of river height is missing at the gauge in Chiang Saen over the 28 years of record. When a capacity to convert river height to volume of flow is developed, we can calculate the amount of water that is impounded or released in the upper basin, relative to the amount to water that naturally flows through the basin.

Now that we have an independent measurement of natural flow, the information could be applied to simulate the natural river cycle by releasing water at the dam closest to the China border at the time when flows would normally peak. Specifically, flow across the border could be achieved by releasing water during the wet season - in other words, by draining the reservoir. The reservoir could be refilled during the dry season by releasing water stored upstream, generating energy as the water flows downstream into the reservoirs closest to the border. If the wetness index is used as a guide to simulate natural flow, then all communities along the Mekong basin could benefit from maintaining the integrity of the Mekong River (Dinar et al. 2007).

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