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Session: Hydrological processes in agricultural lands under changing environments

Cultivated floodplains of the Cambodian Mekong delta: understanding the changing balance between the flow regime and the agricultural practices

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Abstract

On the floodplains of the Cambodian Mekong Delta, rainfed and irrigated dry-season agriculture is a crucial source of revenue for the local population. Traditional rice production is being progressively complemented by the cultivation of higher-value crops like maize, fruit trees and vegetables. Fundamentally, the annual monsoon regime and the resulting flood dynamics determine the framework for these agricultural practices, with a wet season lasting from June to November and a peak high flow reached in September. Rice is cultivated after flood recession in lower-lying areas. On higher terrain, fruit trees and vegetables are widely irrigated by farmers using individual pumps to lift water from large-scale communal channels.

However, in recent years, various drivers of change have impacted these long-established dynamics. Climate change is causing shifting precipitation patterns and a modification of annual flow regimes in the Mekong river and its deltaic distributaries. In addition, the irrigation channel infrastructure is being largely rehabilitated by both local initiatives and international development agencies. These measures are rapidly changing the conveyance network for inundation, drainage, and irrigation on the floodplains, with proportions and consequences which are yet unknown. Finally, land use changes driven by market forces - such as the shift to cash crops like mango trees - are modifying the crop water demand in the area.

In this context, the present study aims to provide a thorough understanding and quantification of the effects of these changes with regard to crop water requirements, irrigation efficiency, and agricultural productivity. Extensive fieldwork was carried out on a 44-km² area to gather knowledge of agricultural practices (especially irrigation) and to identify the main local hydrological objects and drivers. The land use and seasonal inundation extents were characterized through remote sensing analyses, using optical Sentinel-2 and synthetic aperture radar (SAR) Sentinel-1 images. On that basis, an eco-hydrological model is being developed on the generic software platform OpenFLUID, explicitly representing the hydraulic connections and irrigation decisions. This tool will be used to highlight possible salient control factors for hydrological processes, and to simulate the direct and indirect effects of climate change scenarios, irrigation and water power infrastructure development, and land use changes on local hydrology, irrigation, and agricultural productivity.

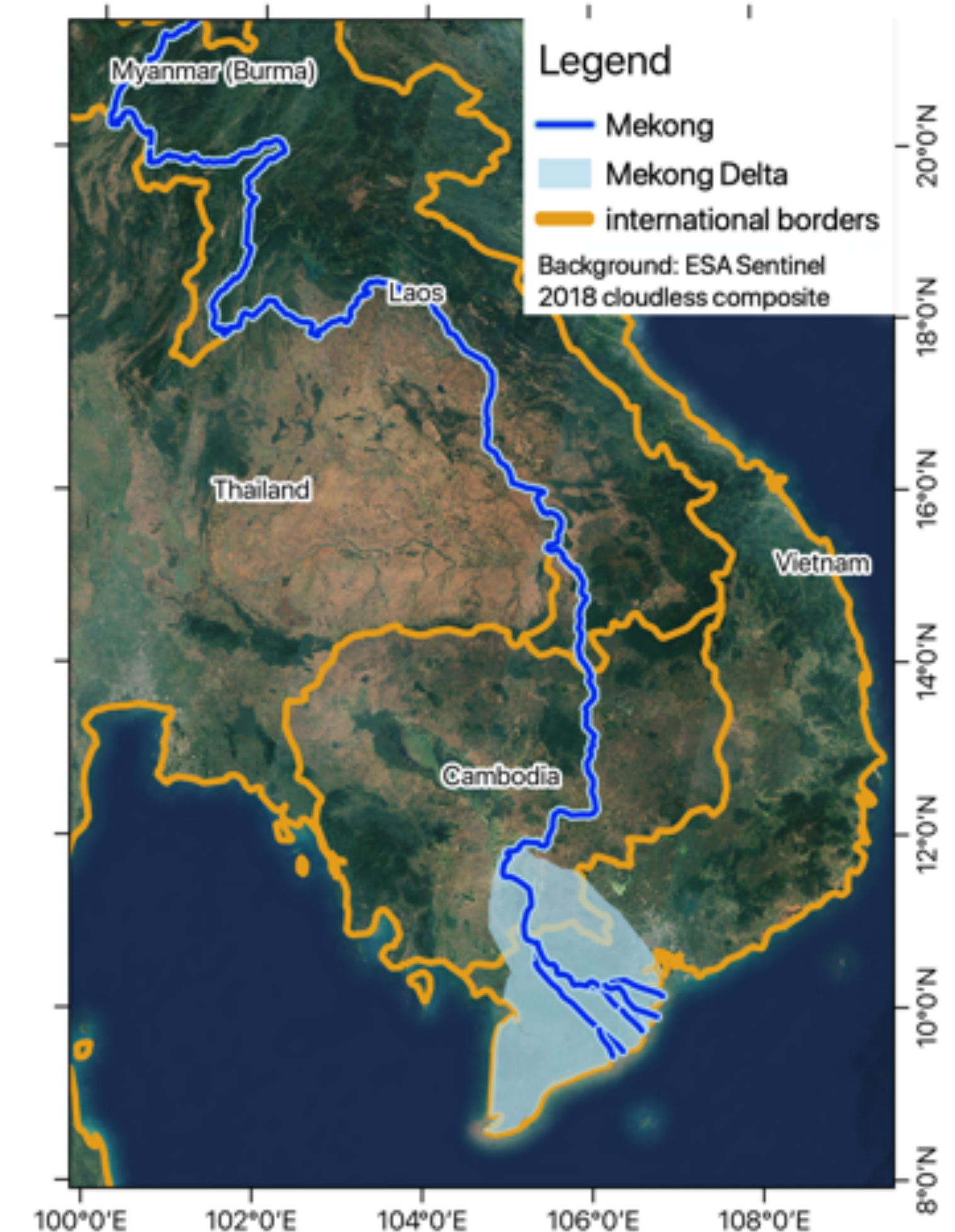
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Introduction

Agriculture in the Cambodian Mekong Delta

- Deltas worldwide as highly productive and biodiverse areas, but also particularly vulnerable to anthropogenic threats and global change
- **The Mekong Delta:**
 - 40,500 km² - spans across southern Cambodia and Vietnam
 - home to 21.5 million people
 - 4.3 million ha rice paddies, annual production of 24.2 million t, USD 2 billion worth of exports for Vietnam alone (numbers for 2016, Van Kien et al 2020)
 - challenges due to:
 - rapidly expanding hydropower infrastructure upstream (active reservoir storage expected to reach 86.8km³ by 2025=equal to 19% of discharge - Hecht et al. 2019)
 - changing precipitation and runoff patterns due to climate change
 - changes in land use in the region itself, especially removal of natural vegetation such as flooded forests and scrubland
- The Cambodian (Upper) Mekong Delta:
 - In contrast to the Vietnamese part: lack of regulatory infrastructure such as dykes, gates, and dams on the floodplain => larger impact of natural flood dynamics, equally larger threat to livelihoods
 - production of rice, maize, fruit (mango, lemur, banana), vegetables (tomato, cucumber, beans) and livestock (cattle, pigs) by smallholder farmers



Agriculture in the Cambodian Mekong Delta



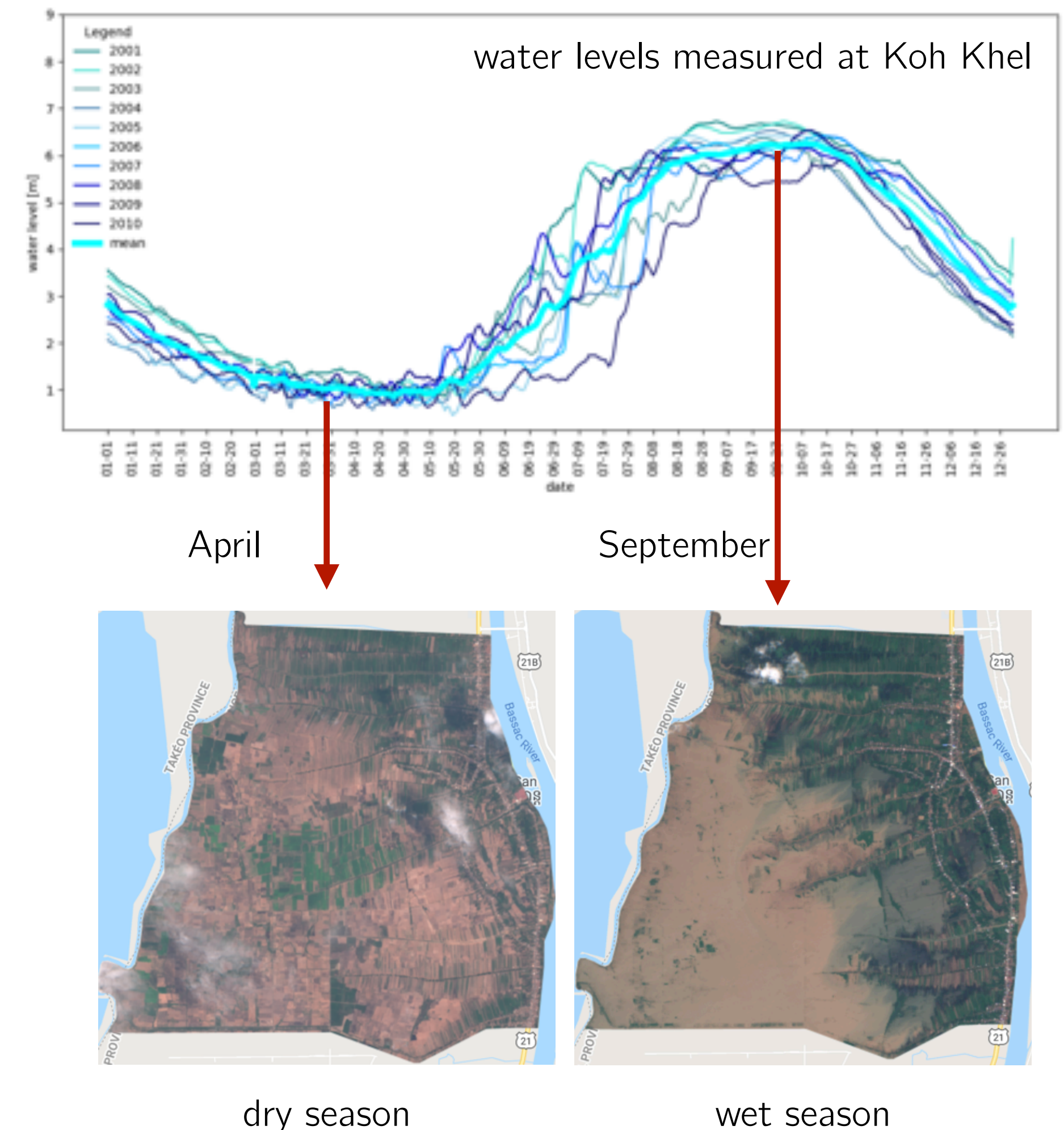
The Study Area: Location



- 44 km²
- on the left bank of the Bassac, one of the Mekong's distributaries
- 70 km south of Cambodia's capital, Phnom Penh
- hydrometric data available from measurement station of Mekong River Commission (MRC) at Koh Khel, 30 rkm north of the study area
- canal systems (built during the Khmer Rouge period) criss-crossing the floodplain
- large-scale canals ("Preks") connecting the floodplain to the main stream and facilitating flooding and drainage

The Study Area: Hydrology and Agriculture

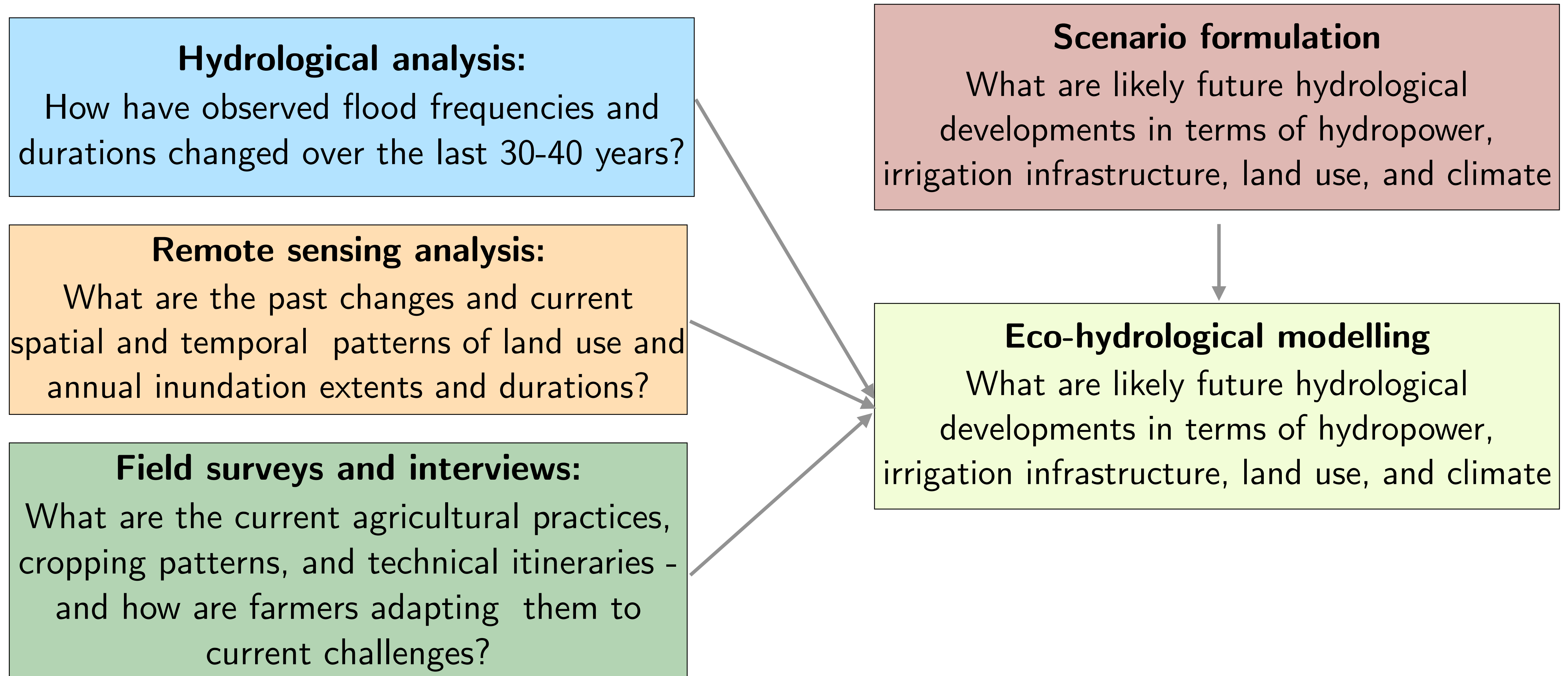
- subject to East Asian and Indian Monsoon
 - rainy season May - November
 - typically, widespread inundations July - November, with peaks in September
 - recharge of groundwater during inundations
 - deposition of nutrient-rich sediments on the floodplains
- agricultural cycles keyed to these patterns:
 - cultivation of recession rice in muddy earth when flood recedes
 - irrigation of dry-season crops with water from the communal canals
 - cultivation of rain-fed crops starting in April/May - for example, early wet season rice - and harvest just before flood





Methodology

Methodology

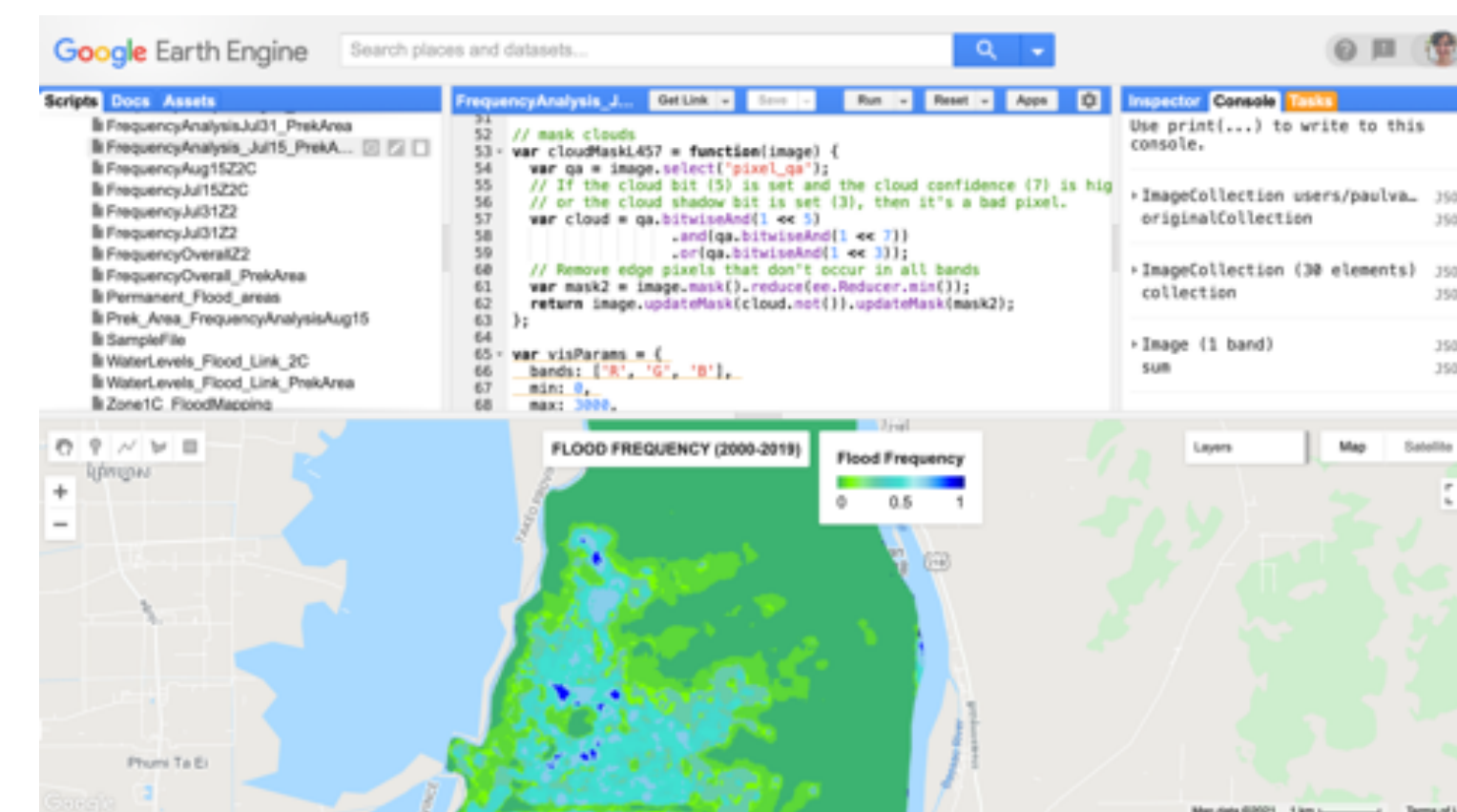
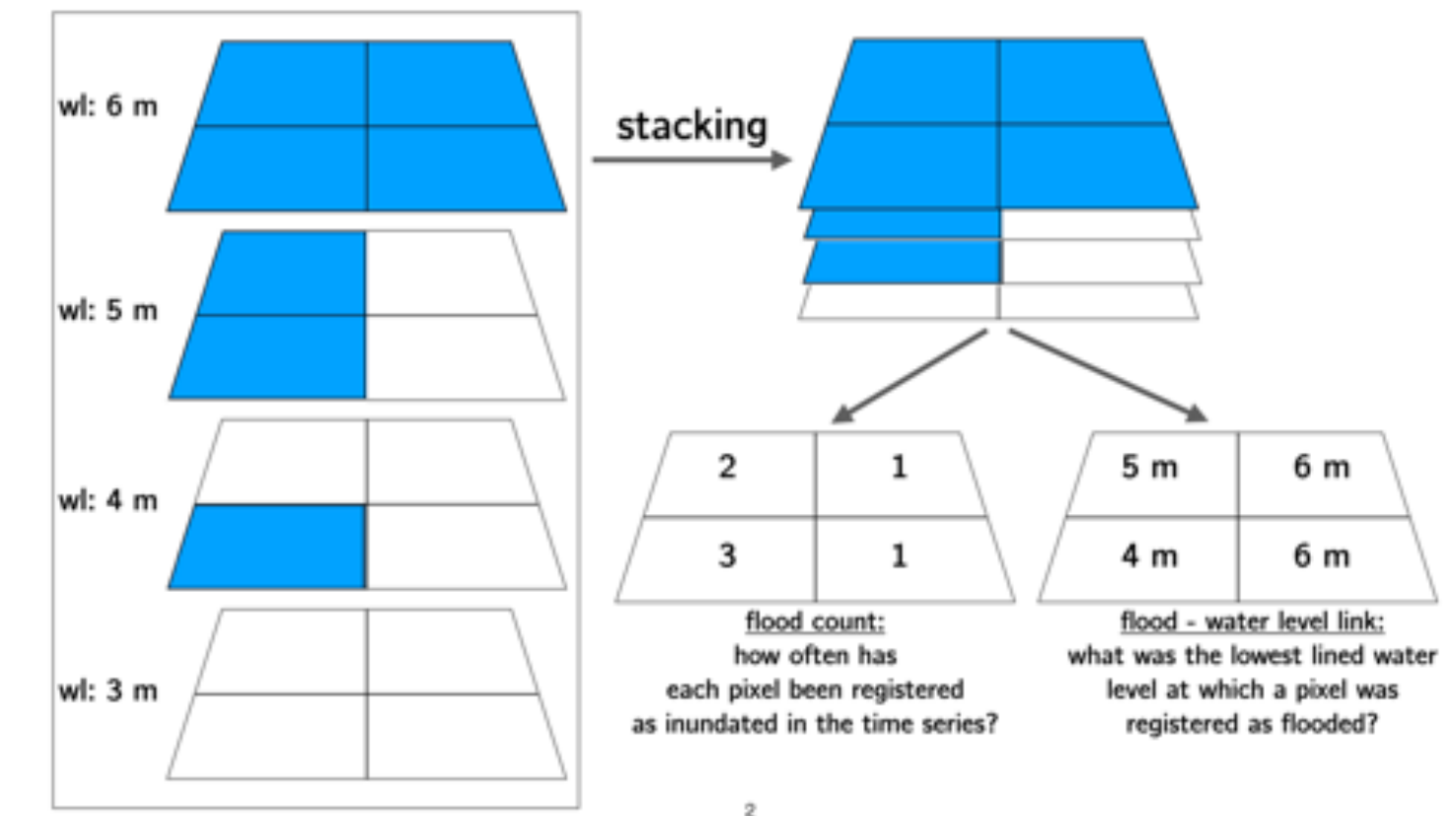


Hydrological Analysis

- Water levels and runoffs:
 - using data by the Mekong River Commission at Koh Khel (KK) and at Neak Luong (NL)
 - consistent time series available since 1991 (KK) and 1926 (NL)
- Precipitation.
 - using data by the Mekong River Commission at KK and remote sensing data extracted from CHIRPS (Climate Hazards Group InfraRed Precipitation with Station Data)
 - constant time series available since 1981
- analysis of trends (non-parametric Mann-Kendall test, modified by Hamed and Rao 1998), break points (Pettitt test (Pettitt 1979), Buishand's range test (Buishand 1982)), and comparison of pre-/post break point values (t-test)
 - beginning of flood rise
 - beginning of flood recession
 - inundation durations $> 5m$
 - magnitude and timing of maximum flood levels
 - monthly precipitation sums
 - high-intensity rainfall events

Harnessing Satellite Data

- Data:
 - Sentinel-1 (radar) and 2 (optical)** data made available by the European Space Agency (ESA): up to 10 m resolution and 5-day return period, since 2014/15
 - Landsat-5 and 8 data** by NASA: optical, 30 m resolution, 16-day return period, since 1984
- Land use - land cover (LULC)** classification using stacked Sentinel-1 and -2 images, manually set training points, and a Random Forest classifier => trace land use dynamics and their extents throughout one year
- Inundation tracking:** delineating inundations using unsupervised Random Forest classification, linking inundation extents during wet seasons 2015-2020 to water levels measured at KK using this correlation to assess changes and trends in inundation extents and durations since 1991
- Carried out on Google Earth Engine cloud computing platform (Gorelick 2017)



Field Surveys

- installation of hydrological and meteorological measurement stations in-situ for ground truthing of remotely sensed and station data, measurements in canals and on the main stream
- interviews
 - with farmers, fishermen, local politicians, and heads of water user associations to identify agricultural practices and technical itineraries, ecosystem services from which people benefit, and adaptation strategies
 - 80+ interviews carried out in June 2019, November 2019, Feb-Mar 2020, and November 2020
 - semi-structured questionnaires
 - covering 195 agricultural plots, encompassing a total area of 160 hectares
- gathering training points for remote sensing
- UAV photography for ground truthing



Part A: Agriculture & Economics

Fill out crop table (A3)

How many **pumps** do you own?

- How big are they (HP)?
- Do you move them between plots? If yes, how often do you move them?

If they have a **well** that is not (only) used for irrigation:

- What do you use the water of the well for?
- How often/for how long do you pump water from the well?
- How much fuel do you use per hour of pumping?

Do you own **farm equipment**?

If so, what do you own?

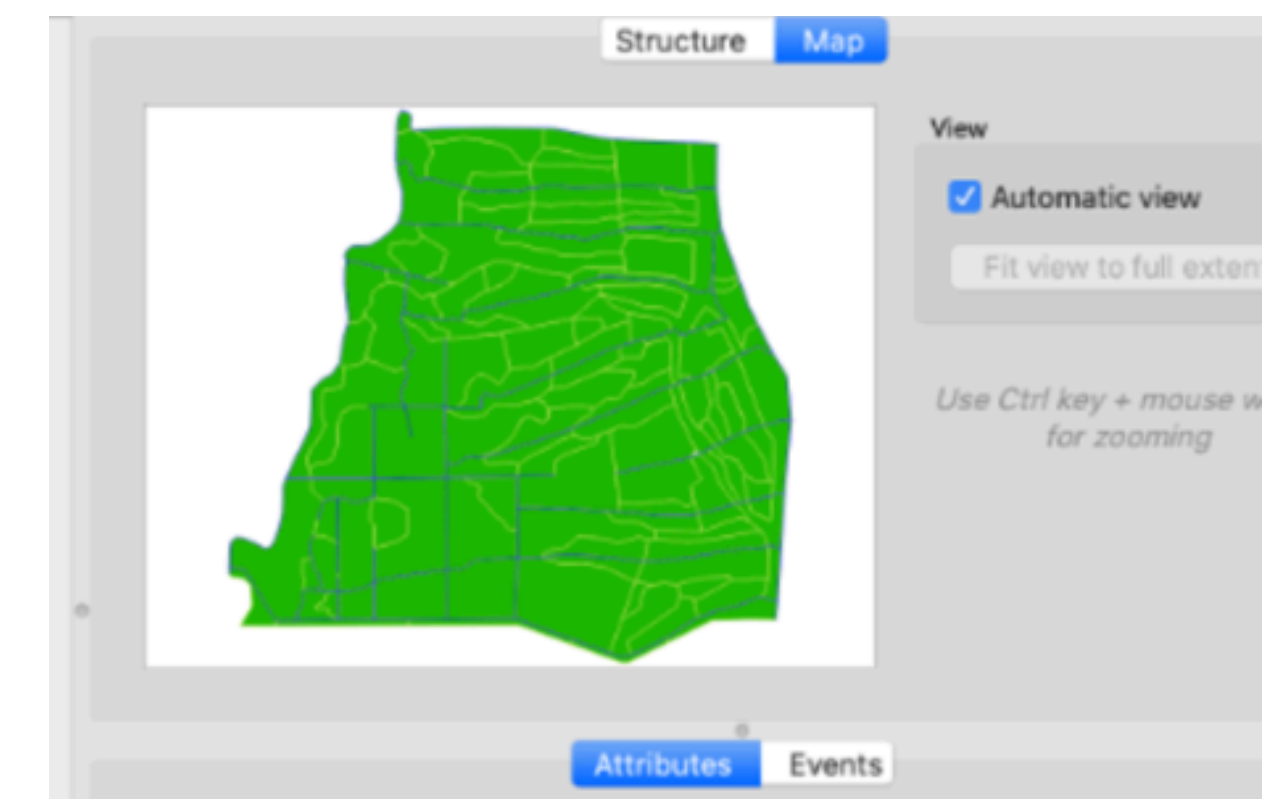
☐ Moto tiller	☐ Sprayer
☐ Pump	☐ Plough
☐ Other :	

If not, do you rent it? From whom and for how much?

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Eco-Hydrological Modelling

- development of eco-hydrological model on OpenFLUID platform (developed by UMR-LISAH, see Fabre et al. 2013)
- both hydrological processes and ecosystem services **incorporated as simulators**, with connection variables as inputs/outputs of each
- spatially explicit representation of study area as ensemble of channels and surface units
- two **timescales** for calculation: **daily** (for hydrological variables such as inflow/outflow, precipitation, evaporation/evapotranspiration, infiltration), and **seasonally** (for provision of ecosystem services)
- use of daily water balance equation in every unit to calculate **seasonal parameters** such as flood durations and extents => then linking these parameters to ecosystem services on the basis of the field survey data

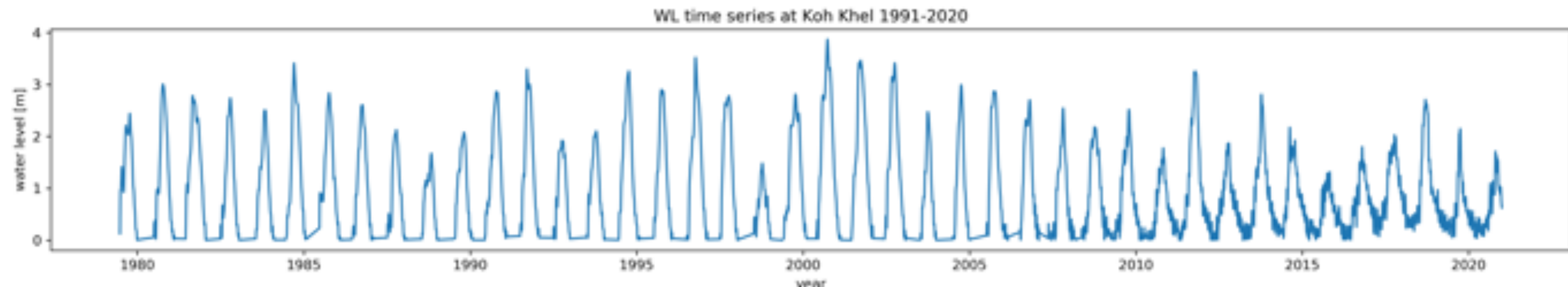


An aerial photograph showing a winding river or canal through a rural landscape. The land is divided into large, rectangular fields, some of which are brown (possibly dry or harvested) and others are green. The river is a light blue color, contrasting with the surrounding land. The sky is a pale blue.

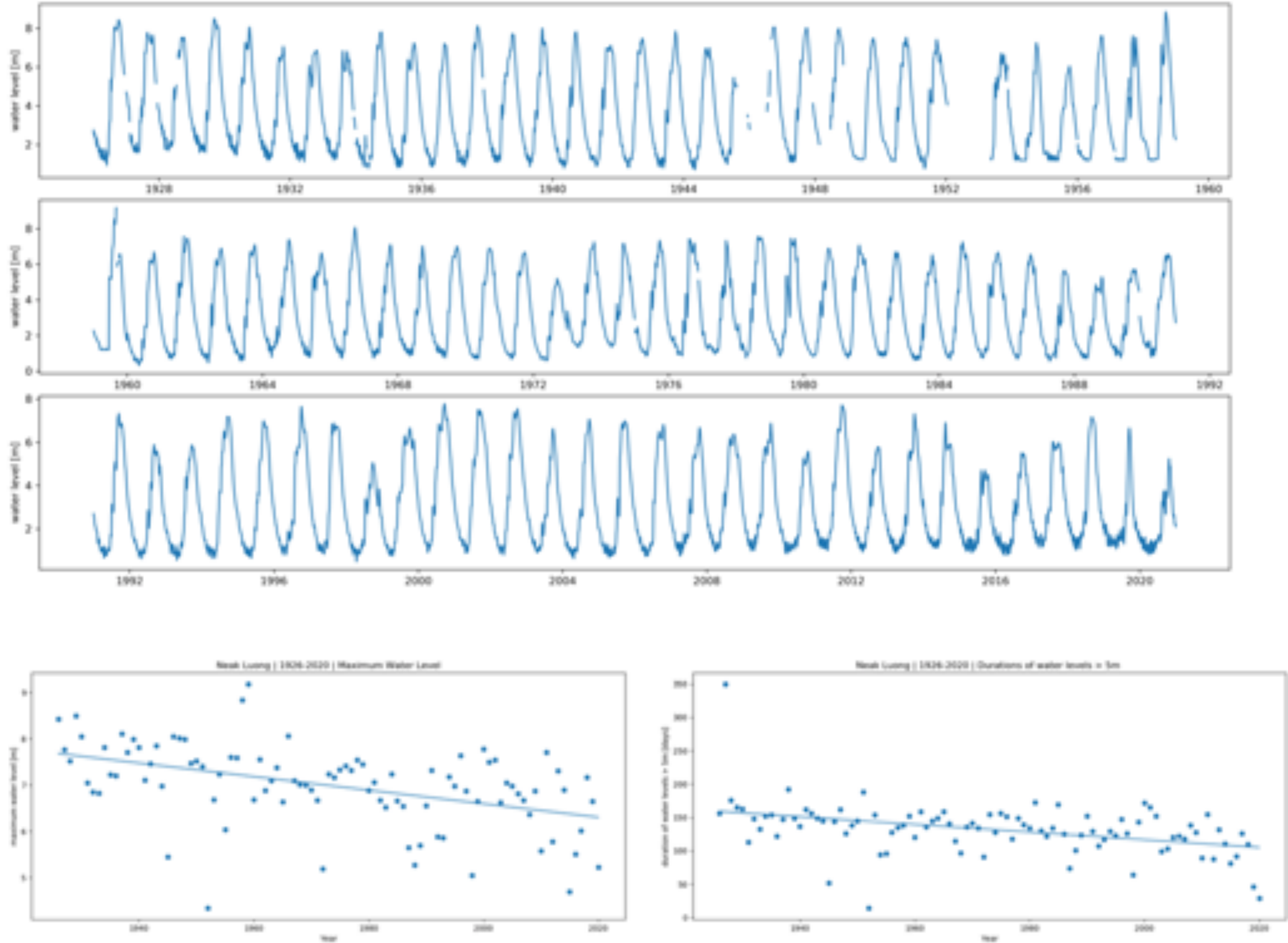
Preliminary Results

Trends and Changes in Hydrological Patterns

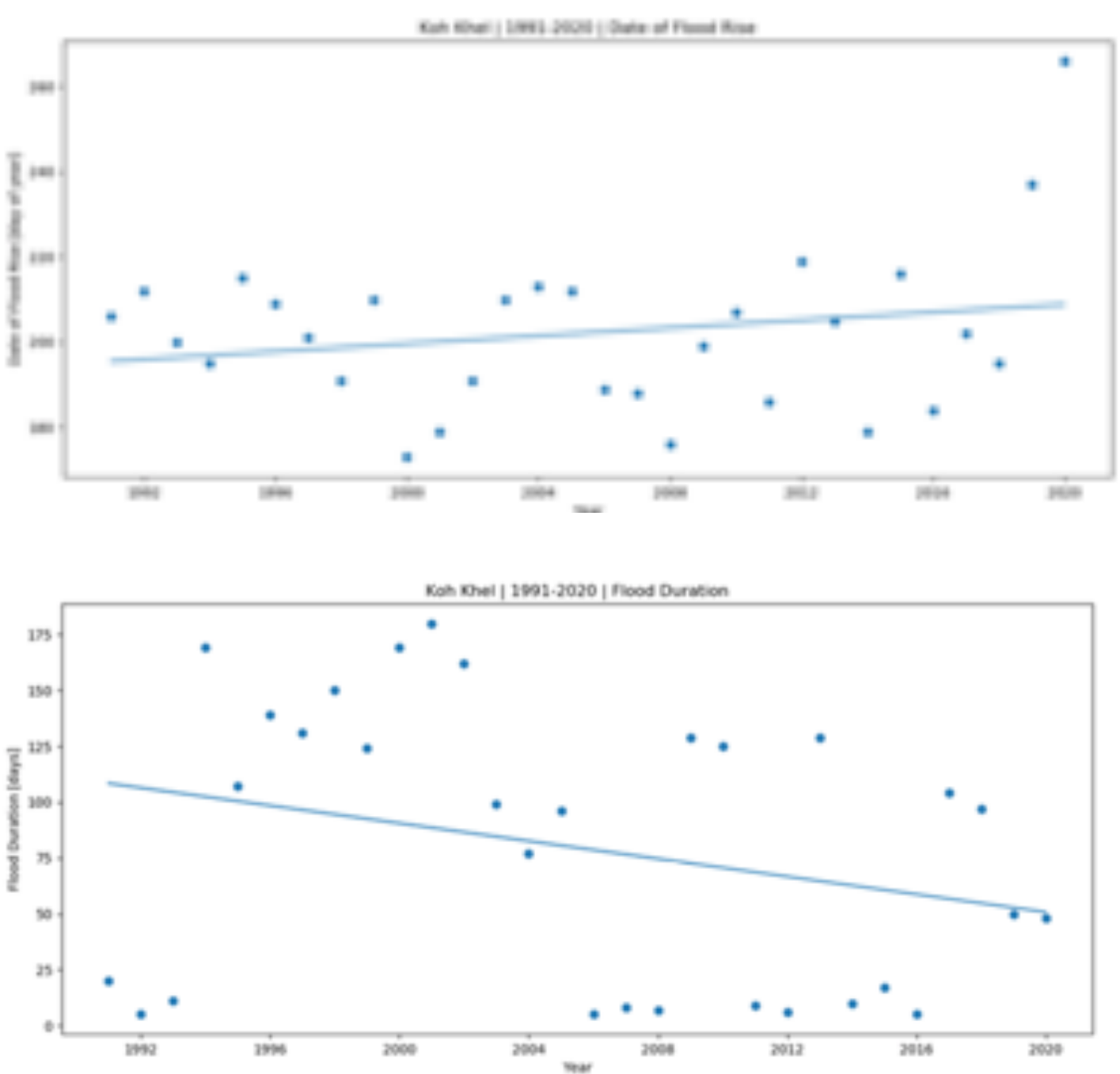
- 2008 indicated as break point in terms of hydrology by Pettitt and Buishand tests, coincides with the construction of large hydropower projects upstream, in accordance with basin-wide studies (e.g. Yun et al. 2020)
- decrease in overall inundation durations, and especially at high magnitudes
- significantly later flood rise, and earlier recession
- no significant trends in the maximum water levels or extents could be observed since the 1990s, but since the 1920s
- decrease in monthly precipitation sums in early wet season (April, May)



Trend analysis: Neak Luong



Trend analysis: Koh Khel



Identifying Cropping Patterns and Dependence on Hydrological Factors and Timing

- construction of current typical technical farming itineraries and distribution patterns of crops across the study area
- assessment of vulnerabilities related to timing of flood events and precipitation:
 - flooding named as reason for crop losses by 30% of farmers
 - 75% of early wet season rice plots have been flooded in the last 5 years, with yield losses amounting to 50% - increasing proportion due to later start of cultivation because of rainfall deficit in the early monsoon months
 - low flood intensity and duration, coupled with a dearth of irrigation water in the canals, lead to losses in dry season vegetables (30% of plots, 40% yield loss) and recession rice (20% of plots, 30-40% yield loss)

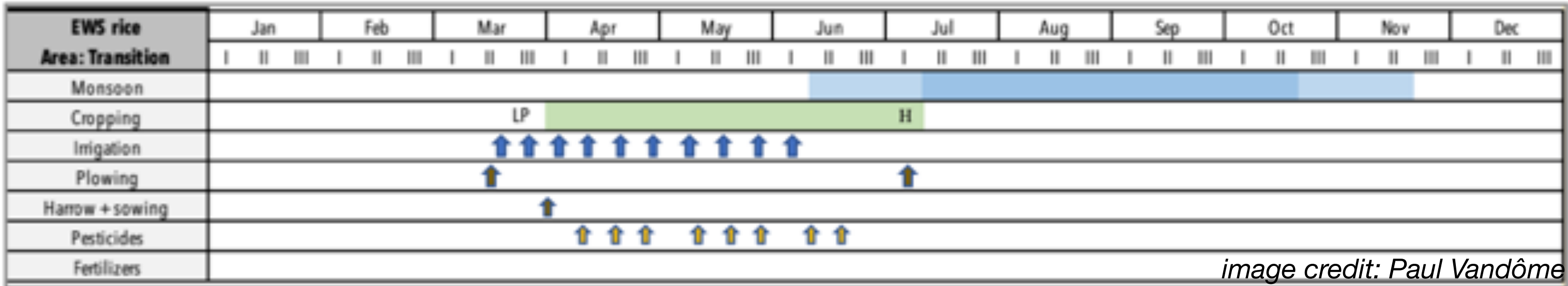
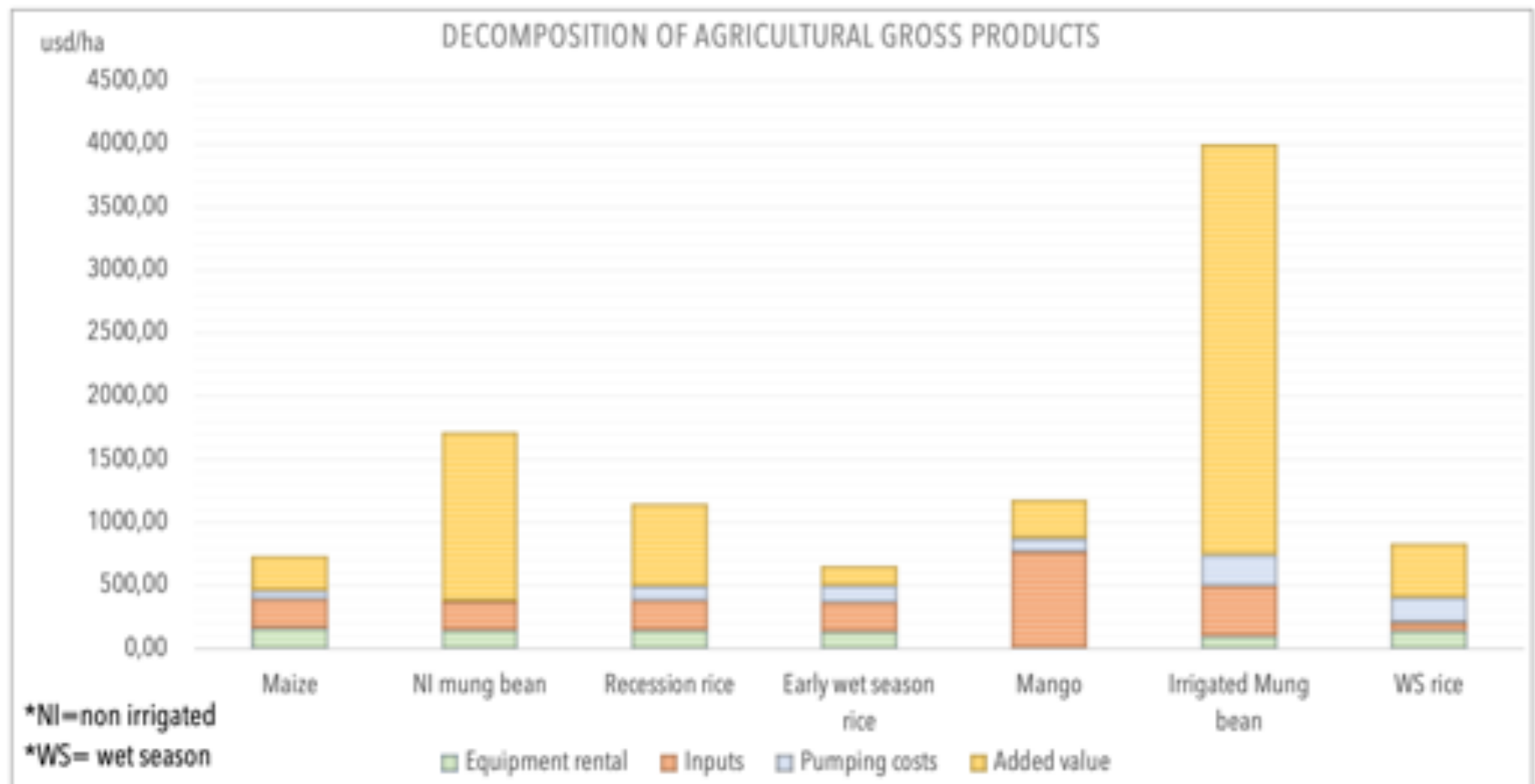
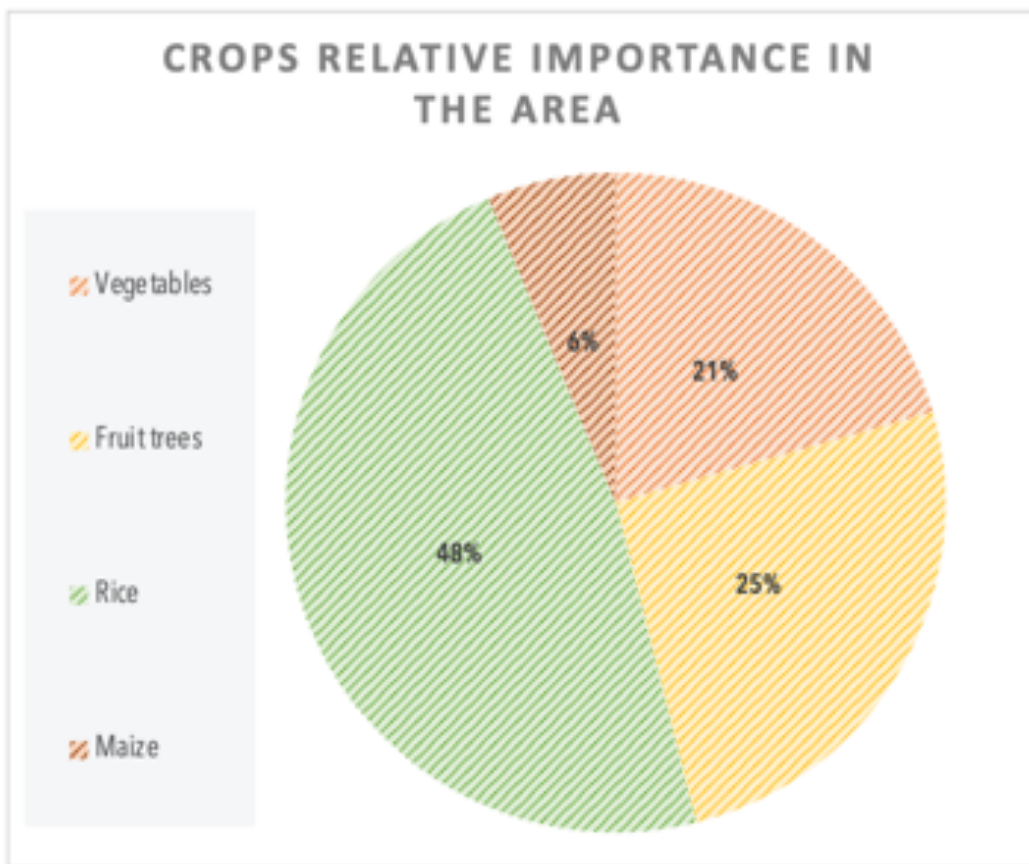
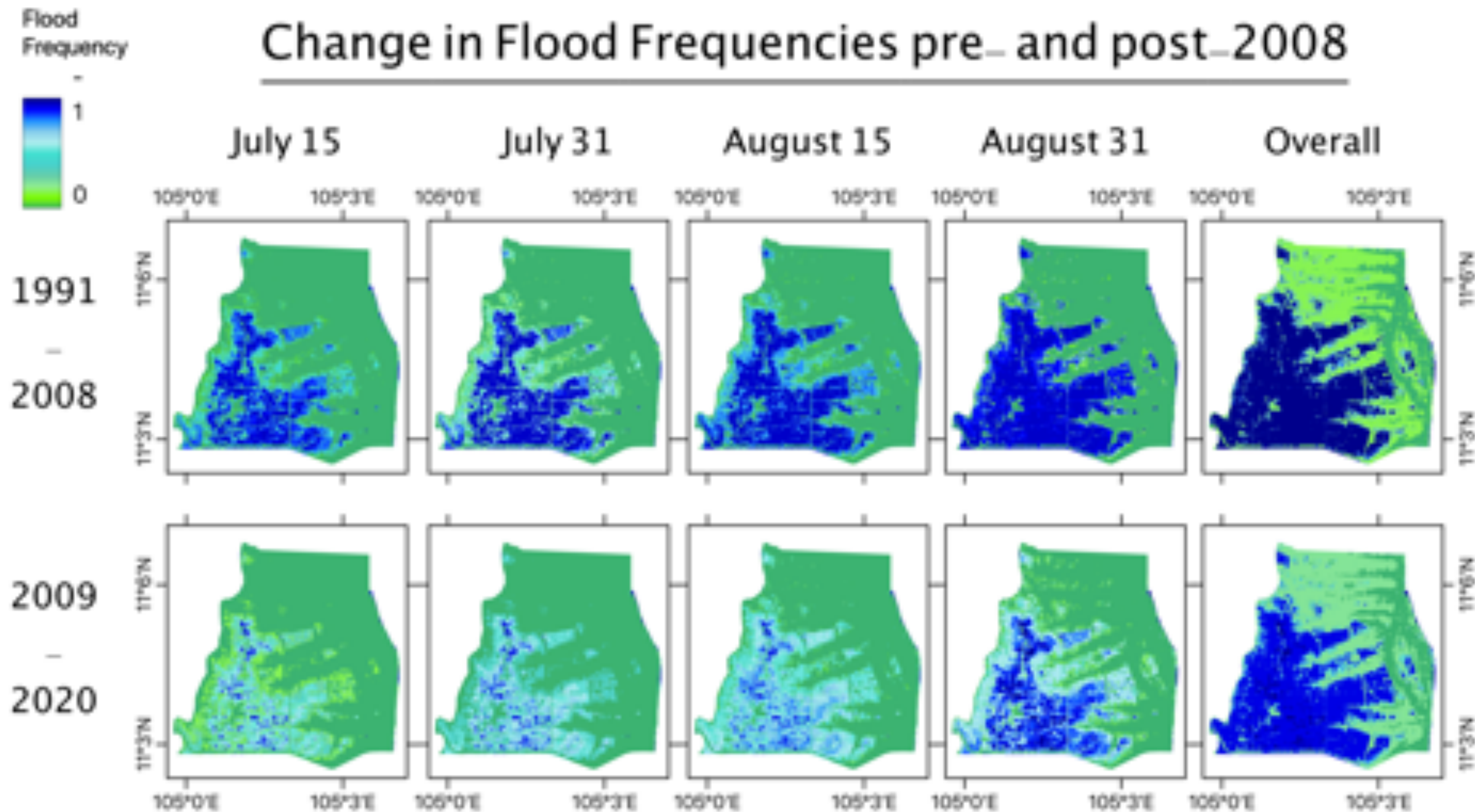


image credit: Paul Vandôme

Linking water levels, inundations, land use, and ecosystem services through simulators

- identification of **key dates** for agriculture: harvesting of early wet season crops (rice, maize) before the flood rise, depending on elevation of plots (July 15, July 31, August 15), planting of wet season crops (August 31, September 25)
- codifying risk **tradeoffs** from the farmers' perspective (eg. planting early wet season crops later due to lack of rainfall in April and May => higher risk of losing crops to flood in July due to later harvest date)
- relating magnitude, duration, and timing of to ecosystem service provision:
 - shorter than normal flood duration => lack of groundwater recharge, increased need for irrigation during the dry season
 - later-than-normal flood peak => delayed cultivation start for recession rice, crops will not be able to profit from December / January rainfall => increased need for irrigation
 - changing flood extents => changing cultivation potential for crop types in affected areas (extension of flood sensitive crops such as mangoes)

Calibration and validation from remote sensing and in-situ data



An aerial photograph of a vast green field, likely a golf course or agricultural land. A long, straight row of trees runs vertically through the center of the field. In the background, there is a body of water and a distant shoreline under a blue sky with light clouds.

Conclusion and Outlook

Conclusion and Outlook

- **Conclusions:**

- “typical” hydrological patterns on which agricultural practices have long relied effectively have ceased to be applicable : shorter flood durations, esp. at higher levels, later flood rise, decrease of monthly rainfall in early wet season
- consequently greater uncertainty for farmers and threats to livelihoods => need for adaptation strategies

- **Outlook:**

- numerical representation of qualitative links established between flood parameters such as magnitude, duration, and timing, on the basis of field data completed in April 2021
- formulation and assessment of likely future development scenarios with respect to upstream hydropower development, changing precipitation and runoff patterns, and local land use and infrastructure development

The background image shows a rural landscape with a green truck parked on a dirt path. Two people are standing on the truck's bed; one is wearing a green shirt and yellow pants, and the other is wearing a white shirt and dark pants. The truck is loaded with yellow sacks. In the foreground, there are several white and yellow sacks scattered on the ground. The background features a line of trees and a clear sky.

Thank you for your attention!

Questions?
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