

MULTITEMPORAL GEOMORPHOLOGICAL ANALYSIS TO PREDICT FLASH FLOOD IMPACTS: ITS CONTRIBUTION TO INFORM FLOOD RISK MANAGEMENT

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AEI/FEDER, UE. MINEICO



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- Geomorphological characterization 2nd steep: interpretation of the flooded area in 2019
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- Preliminary conclusions
- References

INTRODUCTION

The 2016 implementation of the *EU Flood Directive* in Spain defines within the flood-prone zones the *Preferential Flow Zone* (*Zona de Flujo Preferente, ZFP*). This zone includes

- a) broadly, the area where the floods flow is concentrated;
- b) for the 100 years return period flood, the intensive drainage waterway and the zone dangerous to persons.

However, the calculation of the 100 years flood poses multiple limitations:

- Different probability distributions produce different results for the same data series,
- For rainfall and discharge data, depending on the time interval considered in the calculation, the results are also different.
- Regarding rainfall, the meteorological radar data are still too new to extrapolate to 100 years.
- The destruction of meteorological and gauging stations during storms and floods is not rare; hence, a lack of data on major events in the data series can deeply affect the calculations.
- Similar rainfall can produce different discharges due to differences in the antecedent conditions or to land use changes.

All the above and the climate change, question the hypothesis of stationarity at the base of the floods return period concept¹ and, thus, its calculation reliability

INTRODUCTION

Since the middle of the 20th century, significant socio-economic and land use changes occurred in the western Mediterranean region, resulting in changes in the morphology of rivers (e.g., reduced channel section, entrenchment).

The record of these morphological changes, including the effects of major floods, can provide insights to define the high-energy flow zone or ZFP.

This work contributes to determine the flash flood effects and, therefore, to define the ZPF, through multitemporal geomorphological analysis applied to a case study of the upper basin of the Francolí river in Catalonia, Spain.

This river was affected by several major floods in 1874, 1930, 1994 and 2019, where the first and the last events were the largest and of quite similar, centennial magnitude.

INTRODUCTION



On October 22, 2019, a major flash flood affected the upper basin of the Francolí river (precipitation: 292,6 mm / 24 hours at Prades).

The river swept along a large quantity of vegetation, crops and infrastructures and caused a considerable economic damage (> 100 million euros) and loss of six human lives.

2019 flood morphological effects (channel migration, significant erosive and sedimentary morphologies, extension of the flooded areas through ephemeral evidence, avulsion phenomena, channel widening or bank erosion), can be detected and mapped through photo-interpretation.

Also, stereo and orthophotographs from previous dates and digital terrain models (DTMs) can be studied and analysed, and mapping oriented to flood interpretation can be carried out.

MAIN OBJECTIVES

To map:

- the 2019 flood Active Band (zone affected by this particular flood)
- the 1994 minimum area affected by the flood.
- the fluvial morphologies that can provide insights on the floods behaviour (documents of different dates: 2003 DTM, 1946 ortophoto)

To test whether:

- the main geomorphic effects of the 2019 flood could have been predicted using the multitemporal geomorphological analysis.
- the ZFP can be reasonably determined for major floods in this Mediterranean river through multitemporal geomorphological analysis.

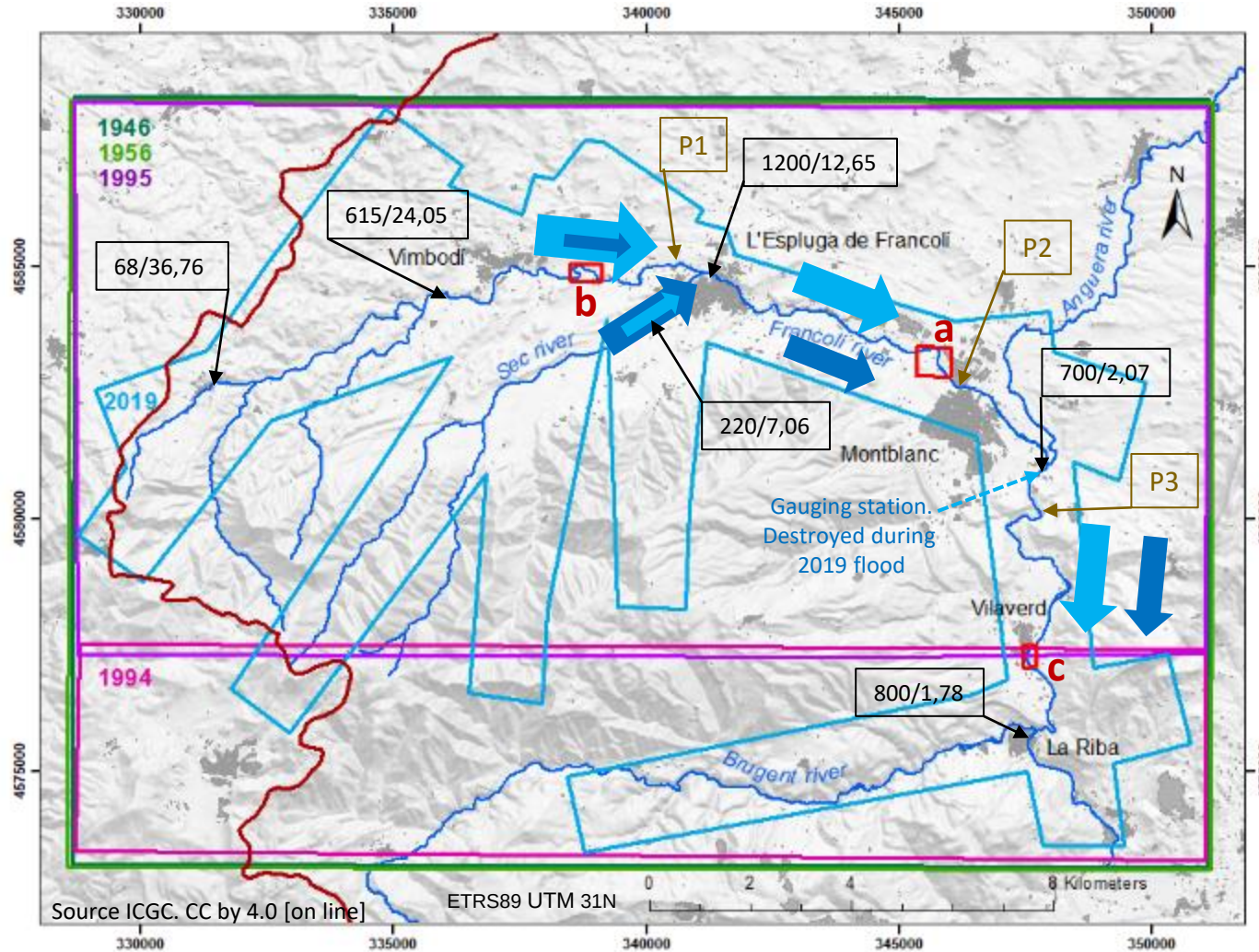
MATERIALS AND METHODS

Different reaches of the river are mapped, studied and compared to validate the analysis:

- reaches where 1994 and 2019 floods were similar and
- reaches where these floods were of very different magnitude;
- reaches where all the basic dataset is available (1946, 1956, 1995 post flood, pre and post 2019 orthophotos; 2003 detailed DTM; stereo photographs, post 2019 flood field data and GNSS-RTK data of river cross sections) and
- reaches with lack of some data (especially of the 1995 post flood image).

Historical information (water levels attained by the past floods and the calculated discharges -work in progress-) are also used to complement and validate the geomorphological analysis results.

MATERIALS AND METHODS



- Francolí basin limit
- 1946 ortophotos
- 1956 ortophotos and stereophotos

- 1994 pre flood ortophotos
- 1995 post flood ortophotos
- 2019 post flood ortophotos and stereophotos

- Example reaches: **a, b, c**

1330/13,71 2019 flood peak discharges ($\text{m}^3 \cdot \text{s}^{-1}$) and unit peak discharges ($\text{m}^3 \cdot \text{s}^{-1} \cdot \text{km}^{-2}$)

P1 Photo showing the water levels for the 2019 and 1994 floods (see next page)

Historical floods:

- 2019: ➡ severely affected all the upper Francolí river; minor affection at the Sec river
- 1994: ➡ severely affected the Sec river and the Francolí river downstream L'Espluga; affected the Francolí river upstream L'Espluga
- 1930
- 1874: most severe flood in the area

MATERIALS AND METHODS

Water levels at different sites corresponding to the 2019 and 1994 floods (see previous page)



P1. Molí de Guasch

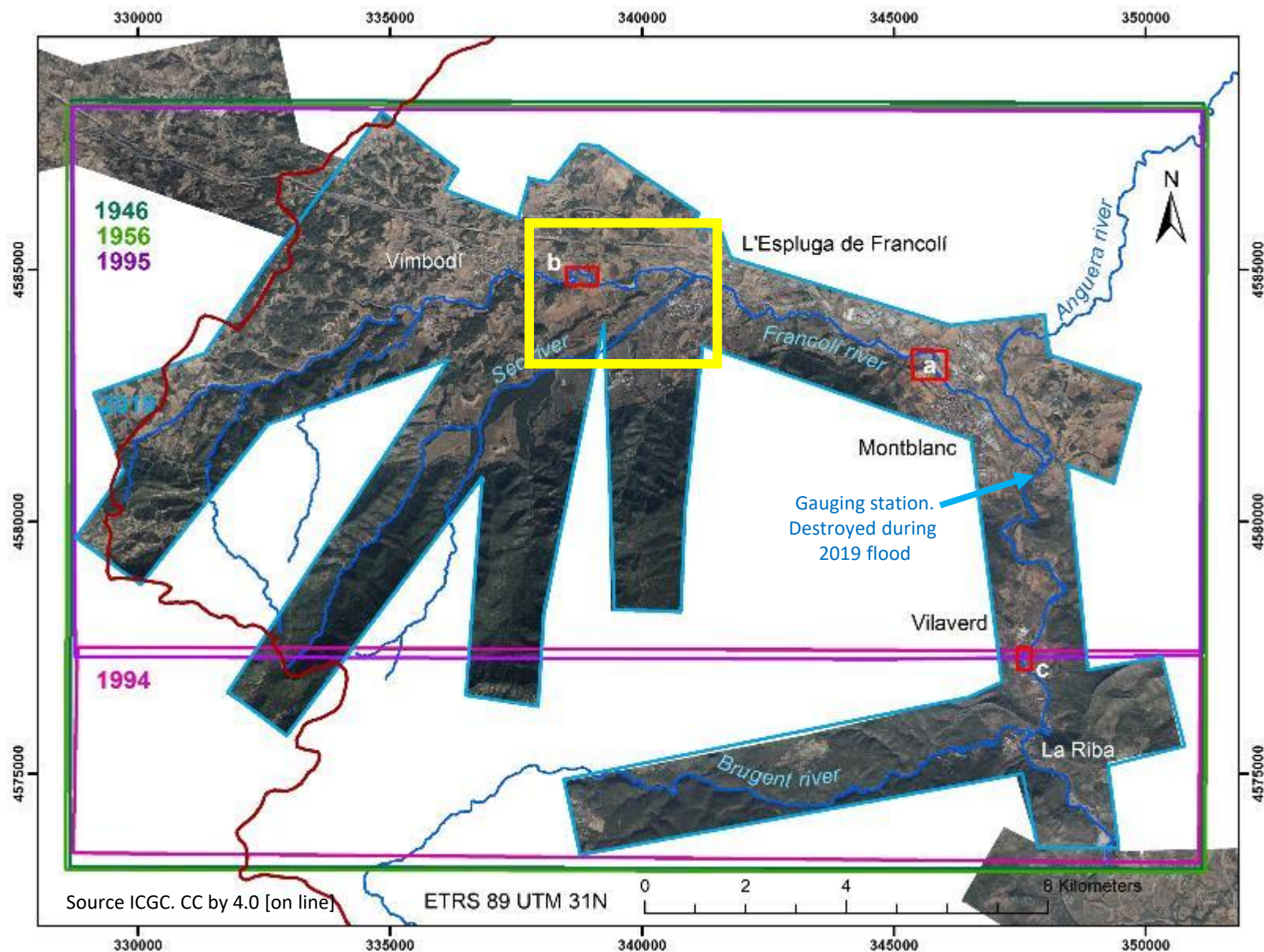


P2. Pont Montblanc

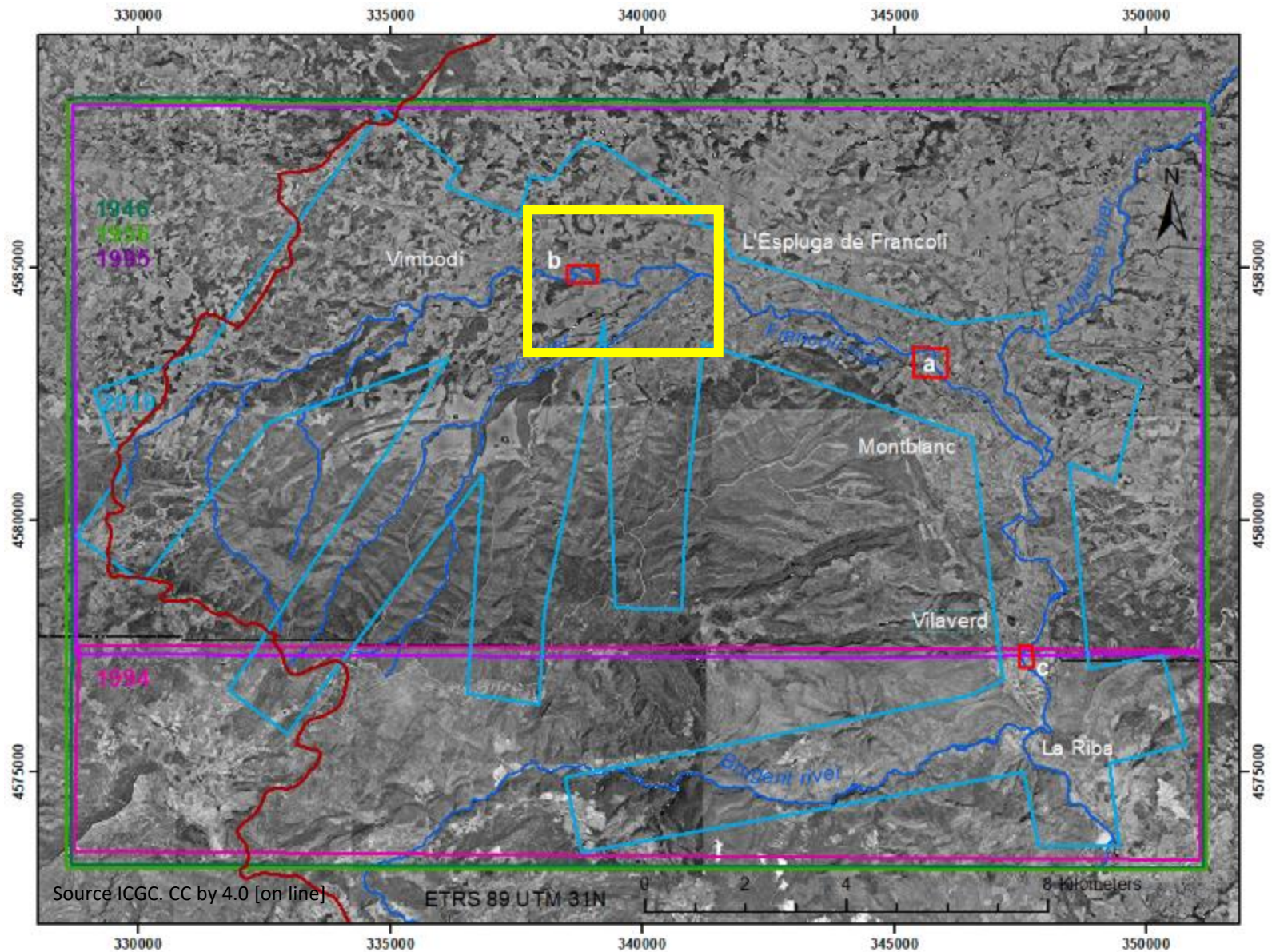


P3. Molí de la Farga

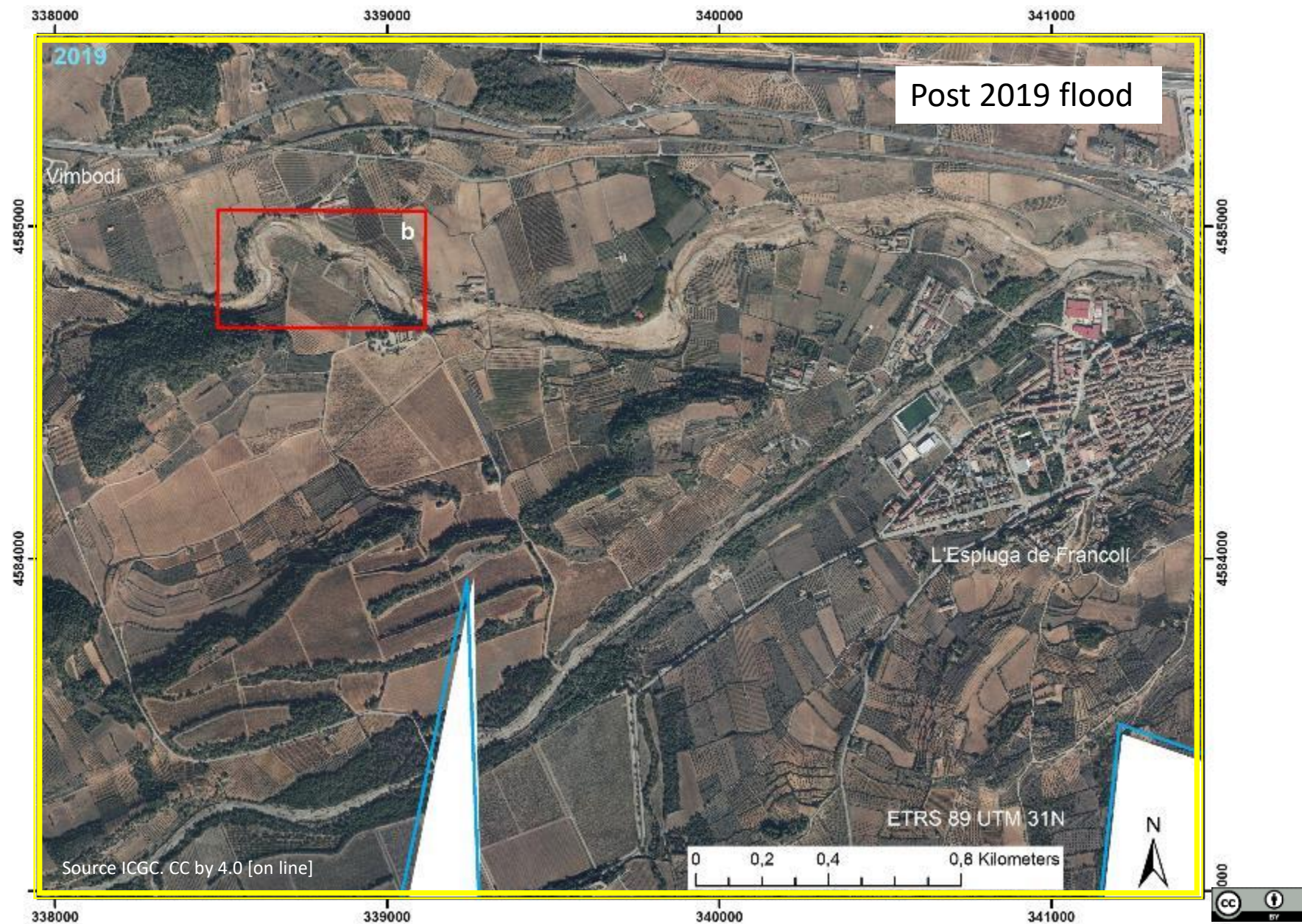
MATERIALS AND METHODS



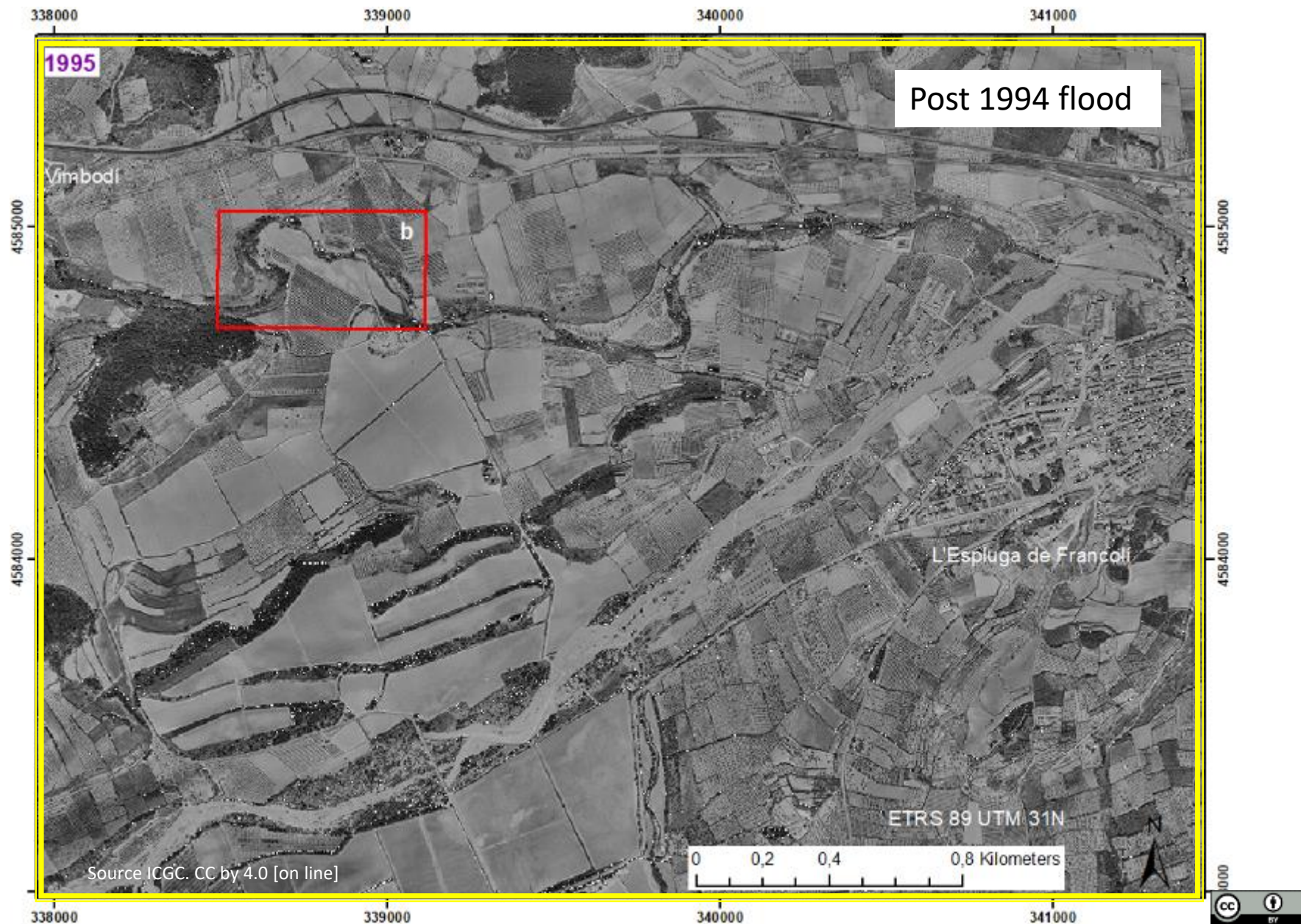
MATERIALS AND METHODS



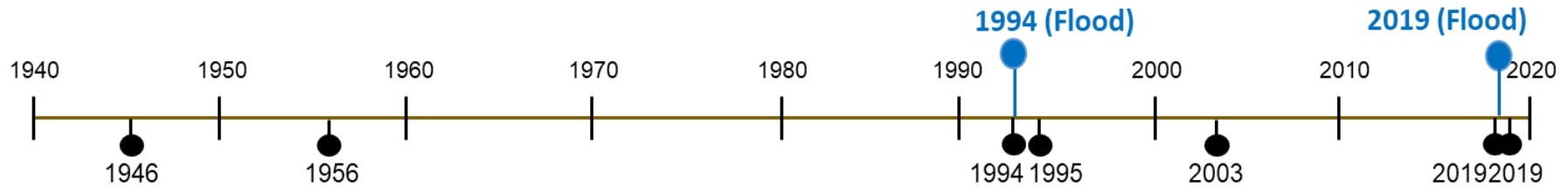
MATERIALS AND METHODS



MATERIALS AND METHODS



AERIAL PHOTOS, ORTHOPHOTOS AND DTM USED IN THIS STUDY



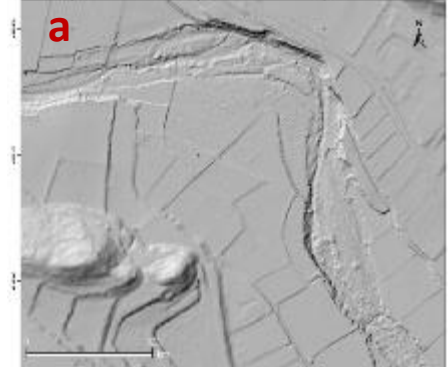
1946



1994 PRE FLOOD



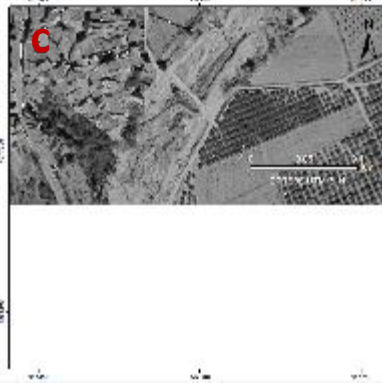
2003 DTM



1956



1995 POST FLOOD



2019 POST FLOOD



GEOMORPHOLOGICAL CHARACTERIZATION 1st STEEP: ANALYSIS CRITERIA EXAMPLES



2019

ORTHOPHOTO
POST FLOOD

ANALYSIS CRITERIA

Bank erosion

Large wood acumulation

Gravel bars

Water marks

Channel widening

Affected crops

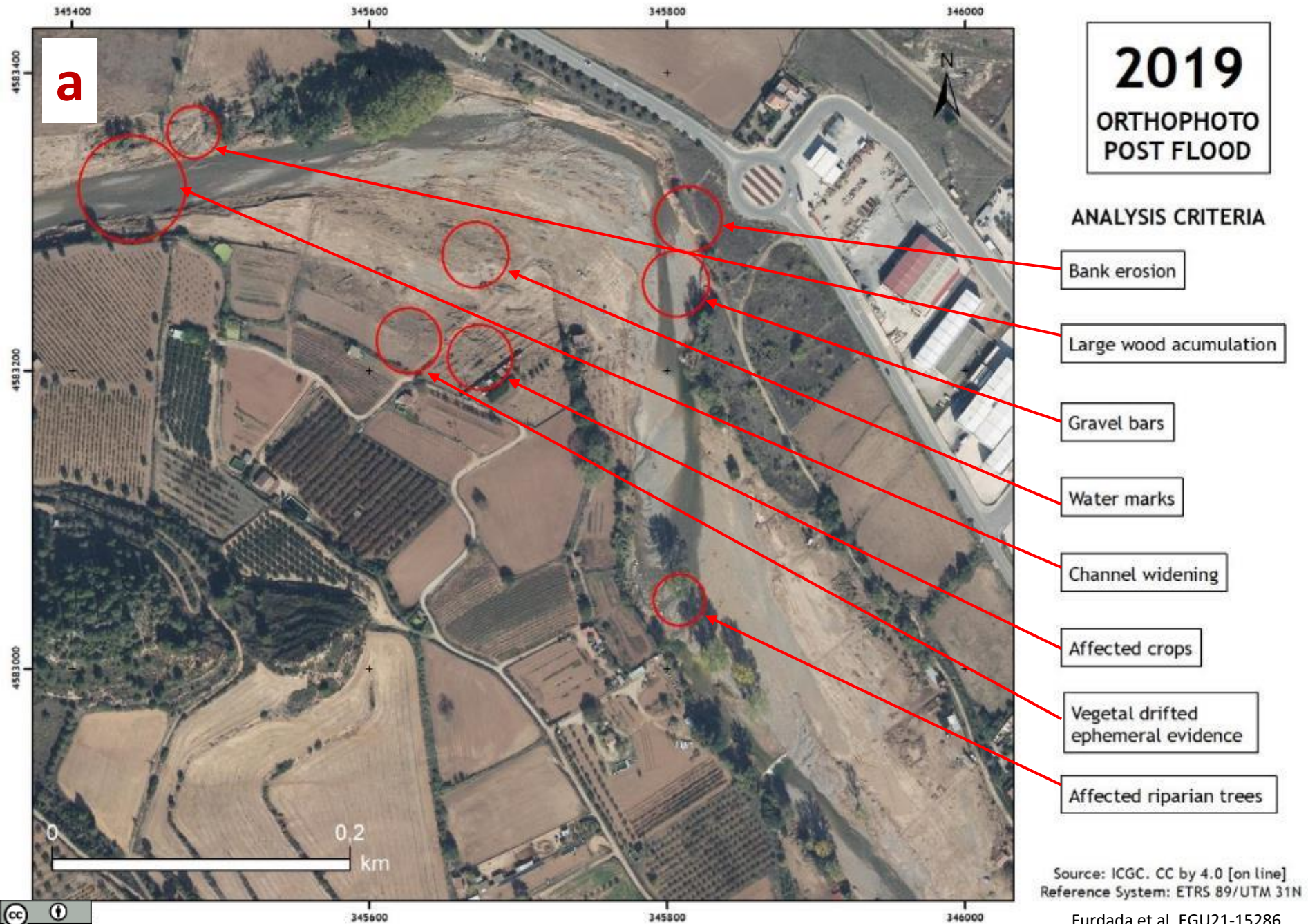
Vegetal drifted
ephemeral evidence

Affected riparian trees

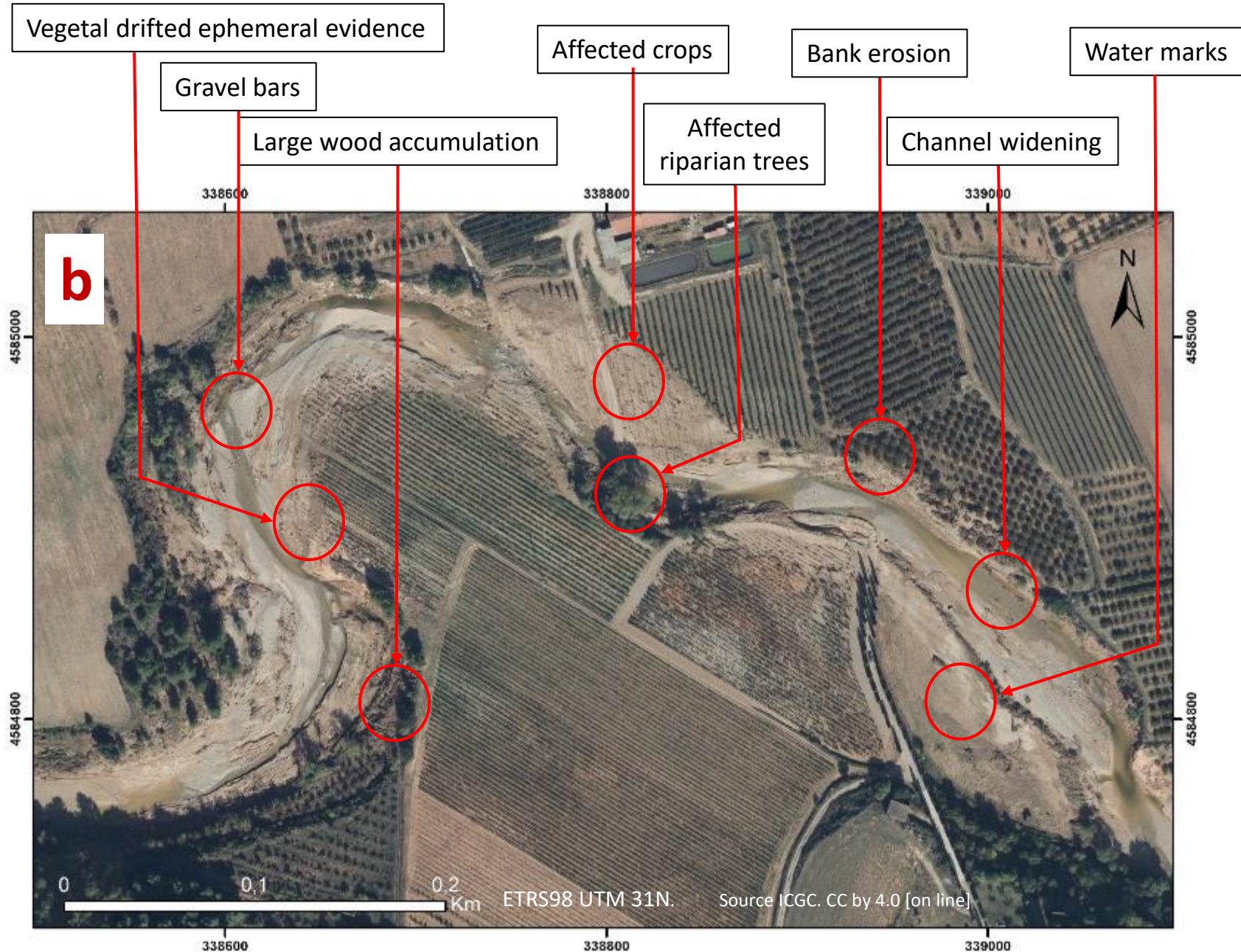
Source: ICGC. CC by 4.0 [on line]
Reference System: ETRS 89/UTM 31N

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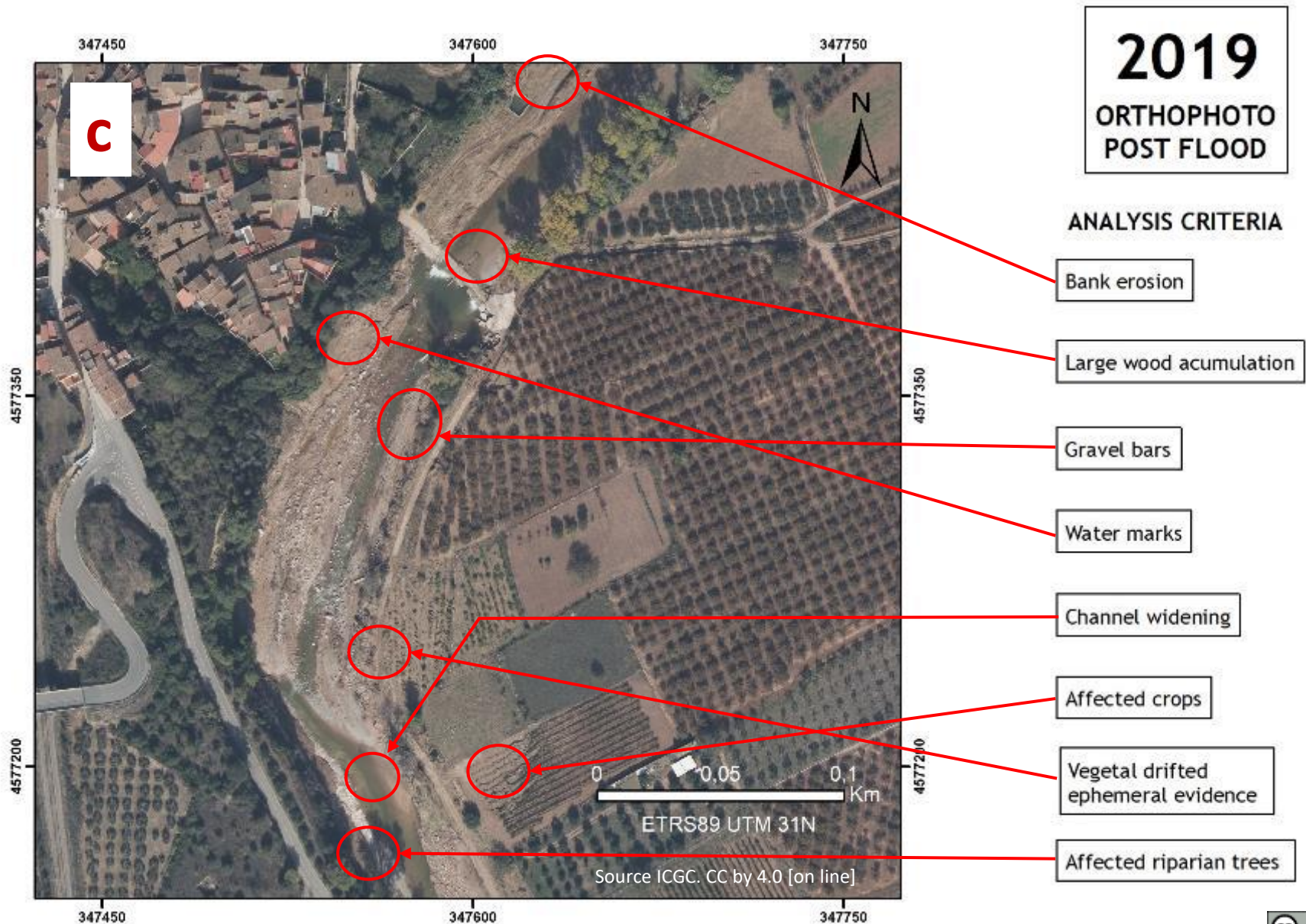
GEOMORPHOLOGICAL CHARACTERIZATION 1st STEEP: ANALYSIS CRITERIA EXAMPLES



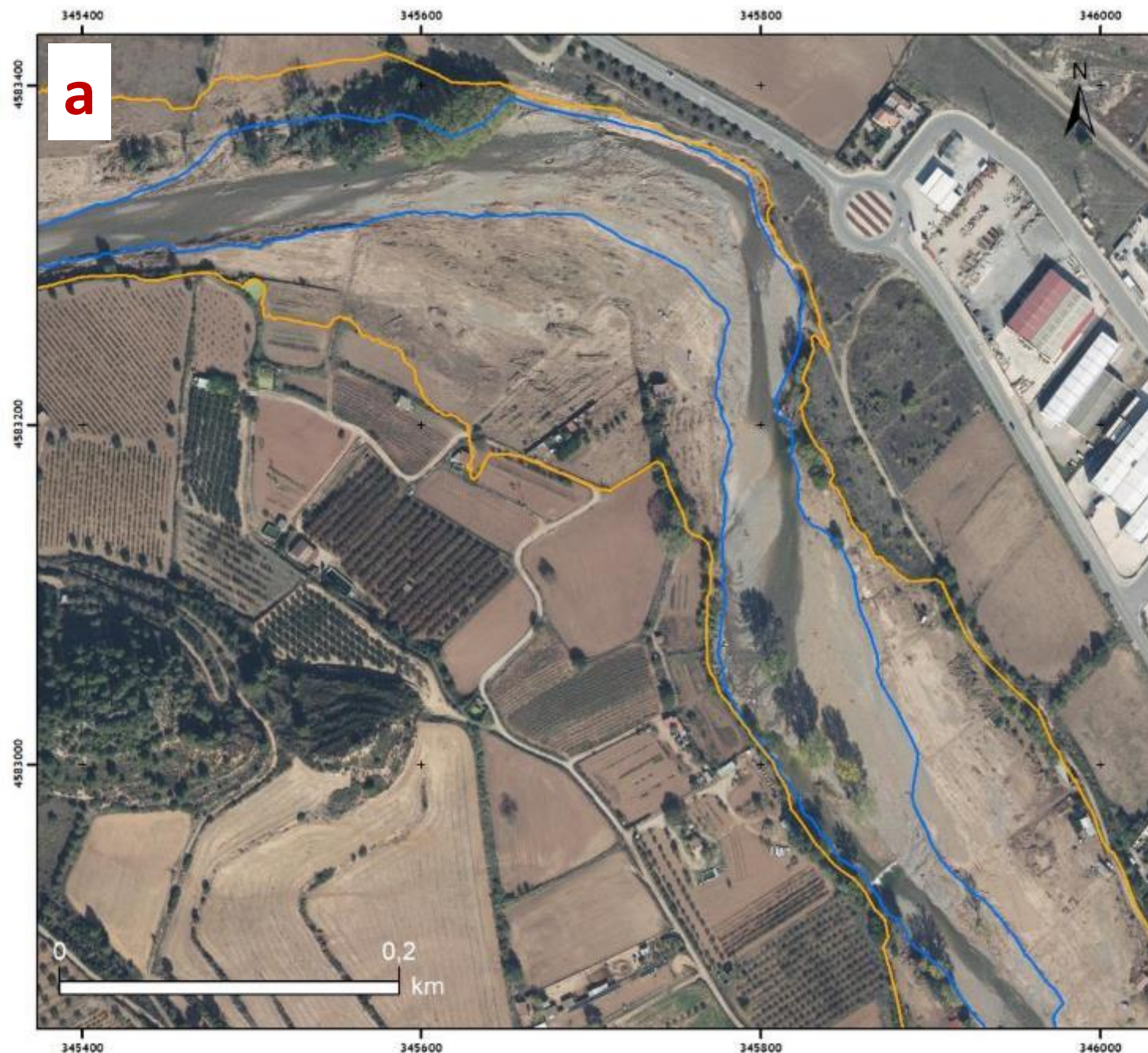
GEOMORPHOLOGICAL CHARACTERIZATION 1st STEEP: ANALYSIS CRITERIA EXAMPLES



GEOMORPHOLOGICAL CHARACTERIZATION 1st STEEP: ANALYSIS CRITERIA EXAMPLES



GEOM. CHARACTERIZATION 2nd STEEP: INTERPRETATION OF THE FLOODED AREA



2019

**ORTHOPHOTO
POST FLOOD**

Legend

 2019 FLOODED AREA:
ACTIVE BAND

This area has been determined from the visualization of ephemeral evidence such as deposited drifted vegetation, tilted and flattened vegetation, watermarks, affected crops, bank erosion, etc.

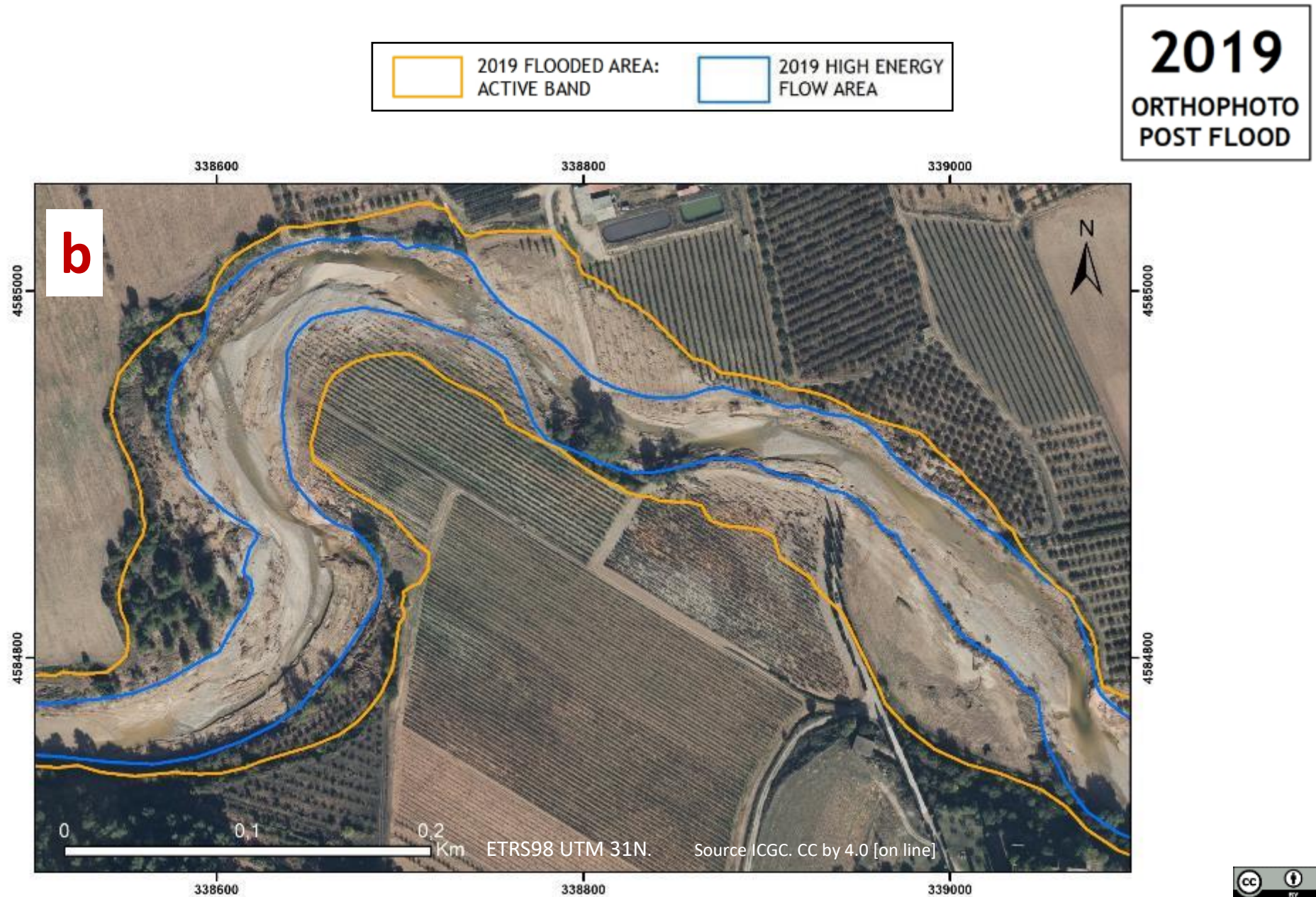
 2019 HIGH ENERGY
FLOW AREA

This area, that is part of the Active Band, has been determined from the functional channel, gravel deposits and bars and significant erosion.

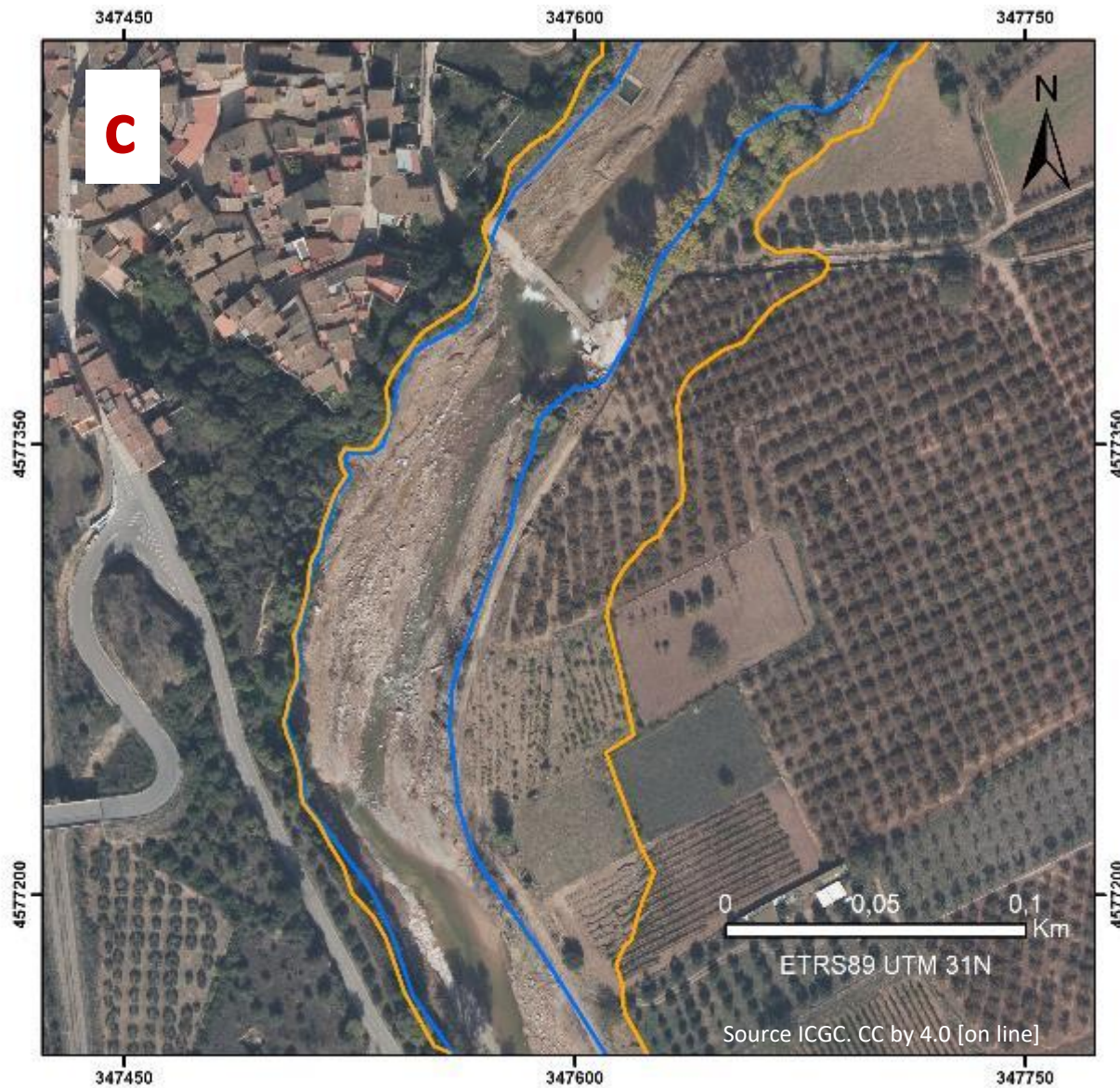


Source: ICGC. CC by 4.0 [on line]
Reference System: ETRS 89/UTM 31N

GEOM. CHARACTERIZATION 2nd STEEP: INTERPRETATION OF THE FLOODED AREA



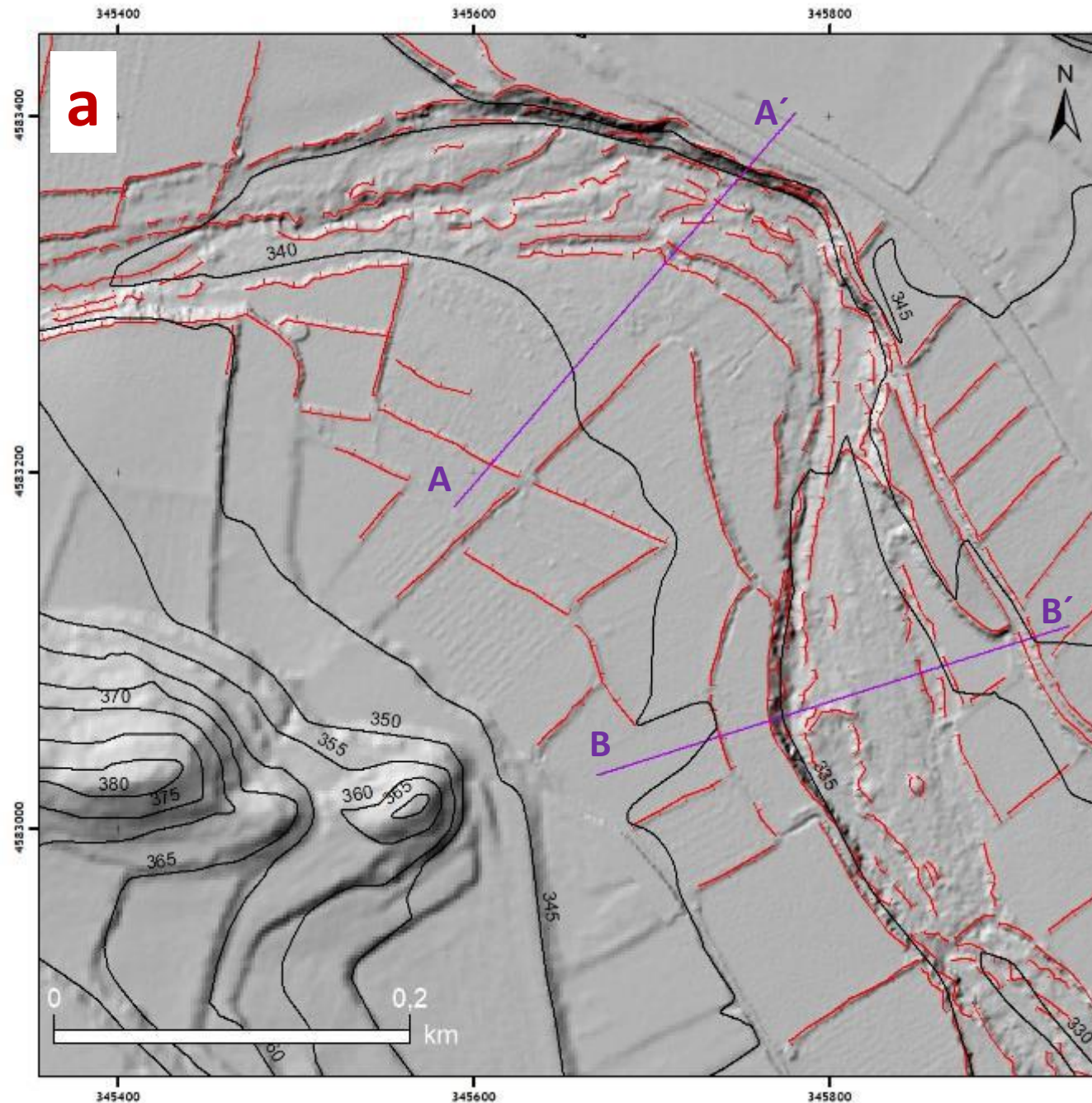
GEOM. CHARACTERIZATION 2nd STEEP: INTERPRETATION OF THE FLOODED AREA



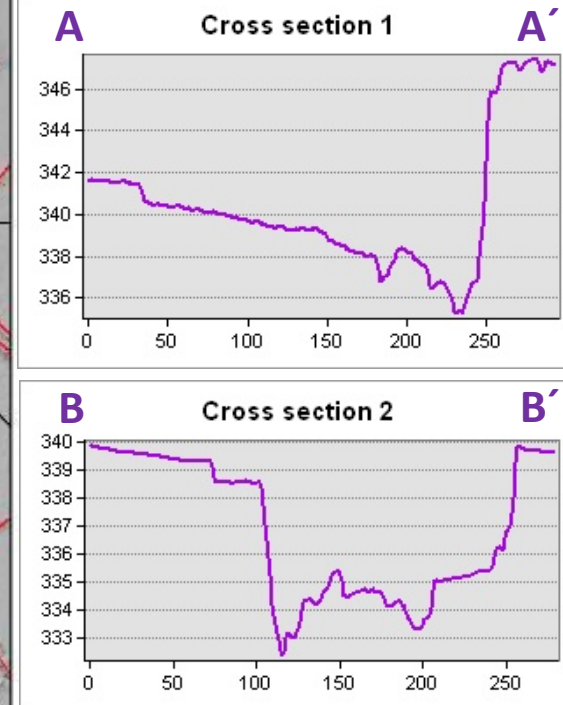
2019
ORTHOPHOTO
POST FLOOD

-  2019 FLOODED AREA:
ACTIVE BAND
-  2019 HIGH ENERGY
FLOW AREA

GEOM. CHARACTERIZATION 3st STEEP: PREVIOUS SITUATIONS

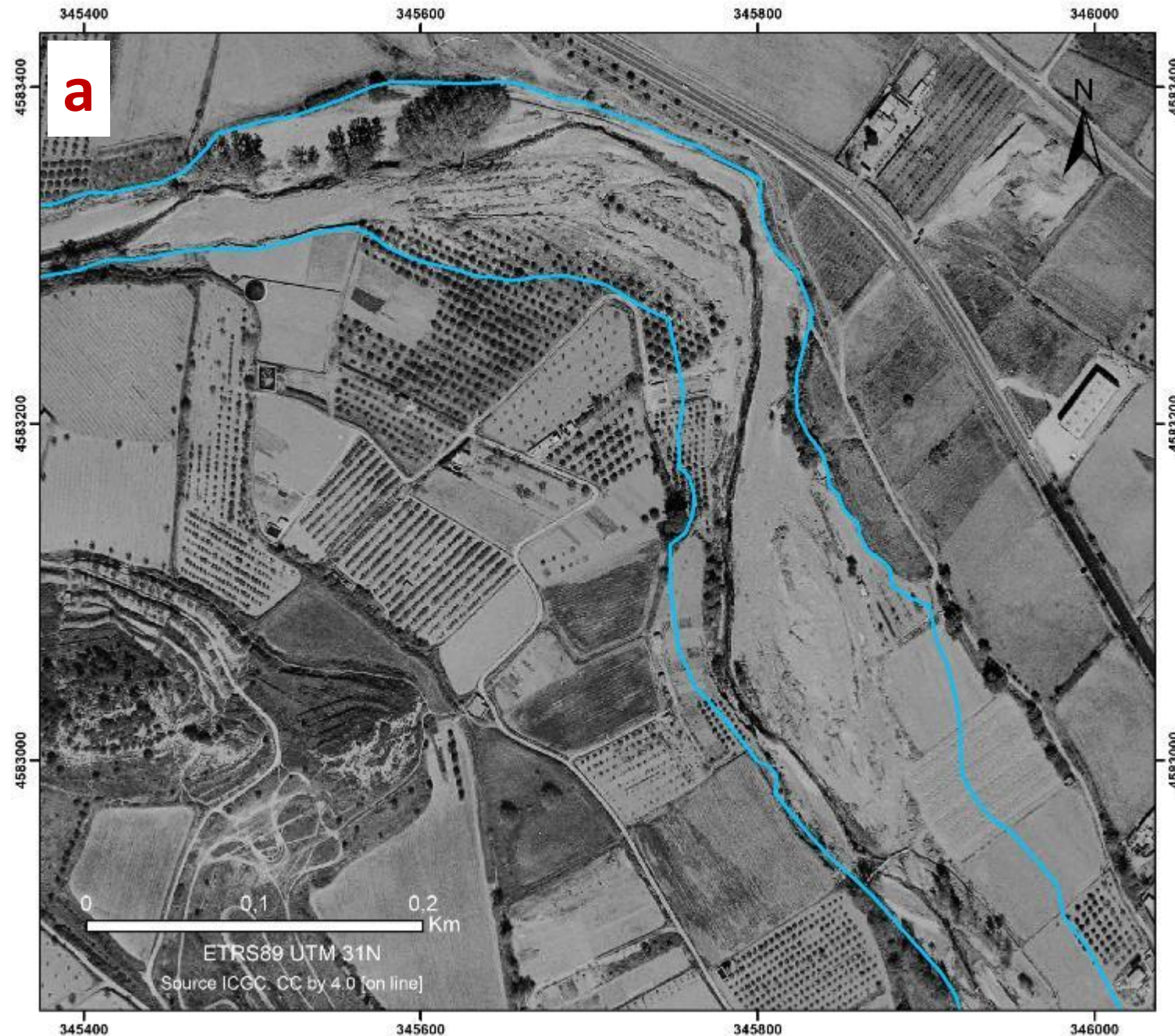


2003 DTM 1X1 SCARPS ANALYSIS



Source: ICGC. CC by 4.0 [on line]
Reference System: ETRS 89/UTM 31N
Furdada et al. EGU21-15286

GEOM. CHARACTERIZATION 3st STEEP: PREVIOUS SITUATIONS



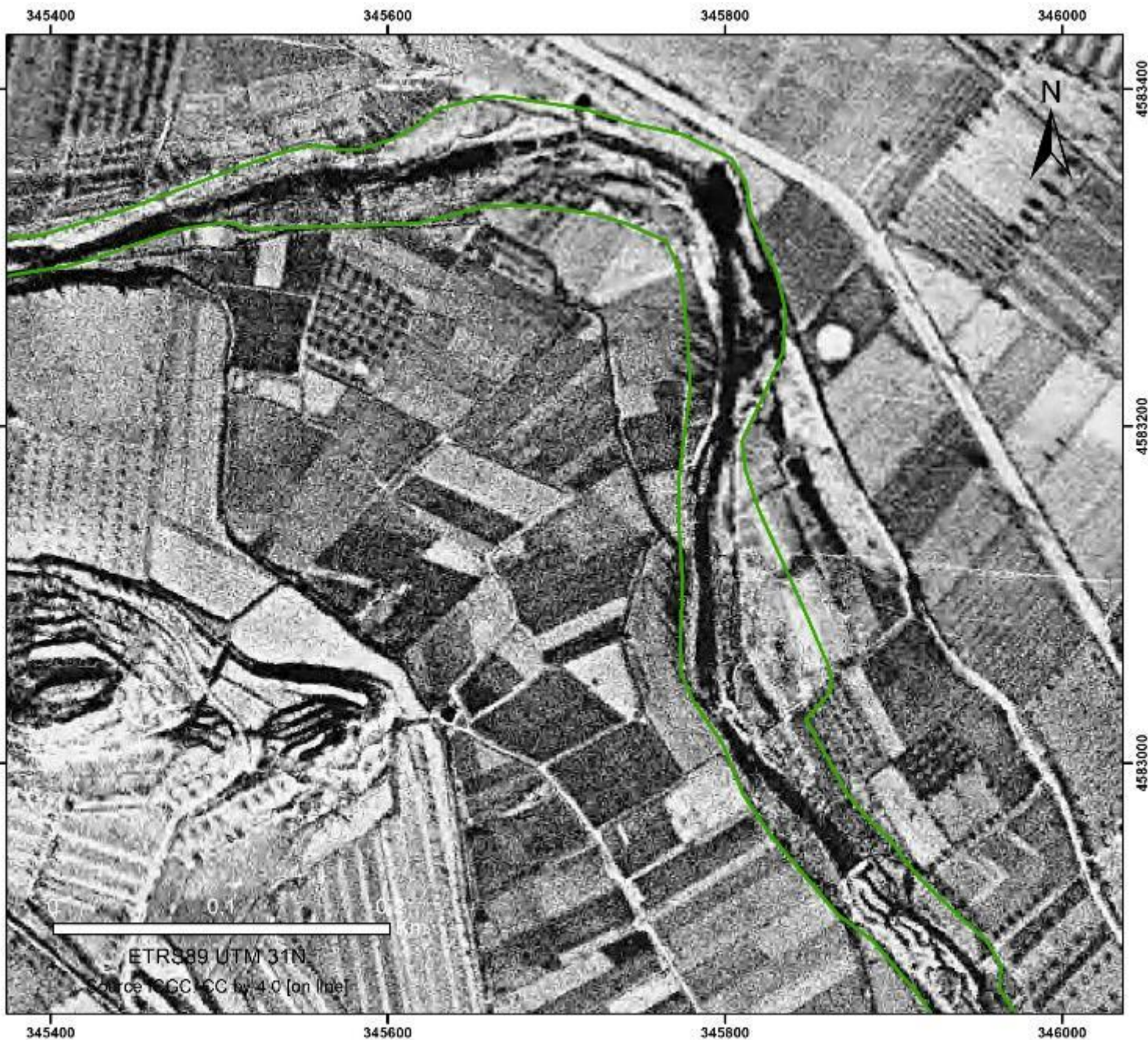
1995
ORTOPHOTO
(POST 1994
FLOOD)



MINIMUM AREA
FLOODED IN 1994



GEOM. CHARACTERIZATION 3st STEEP: PREVIOUS SITUATIONS



1946
ORTOPHOTO



1947 RIVERBED

GEOM. CHARACTERIZATION 3st STEEP: PREVIOUS SITUATIONS

2003

DTM 1X1
SCARPS ANALYSIS

SCARPS 2003



GEOM. CHARACTERIZATION 3st STEEP: PREVIOUS SITUATIONS



MINIMUM AREA FLOODED IN 1994

1995

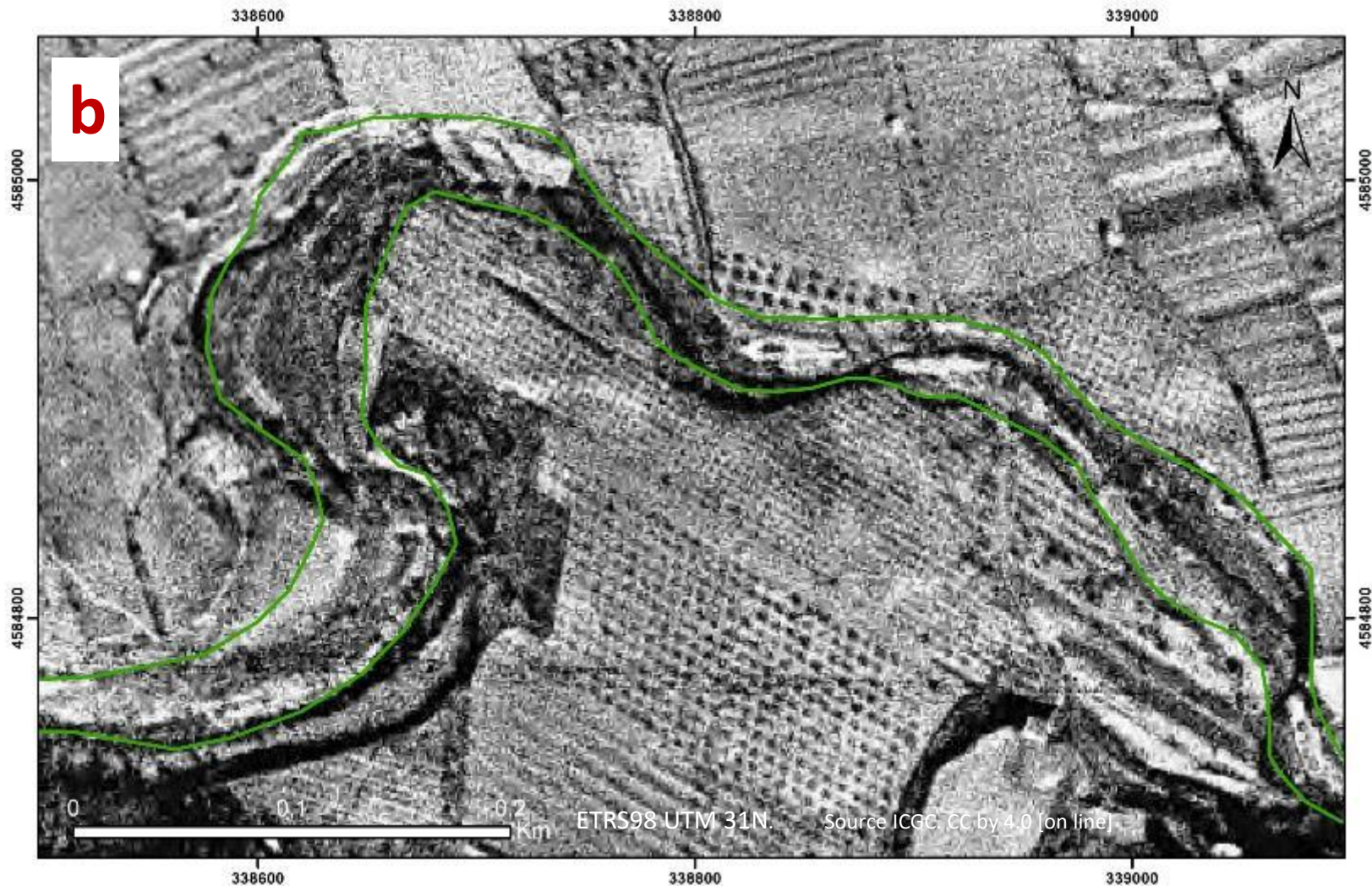
**ORTOPHOTO
(POST 1994 FLOOD)**



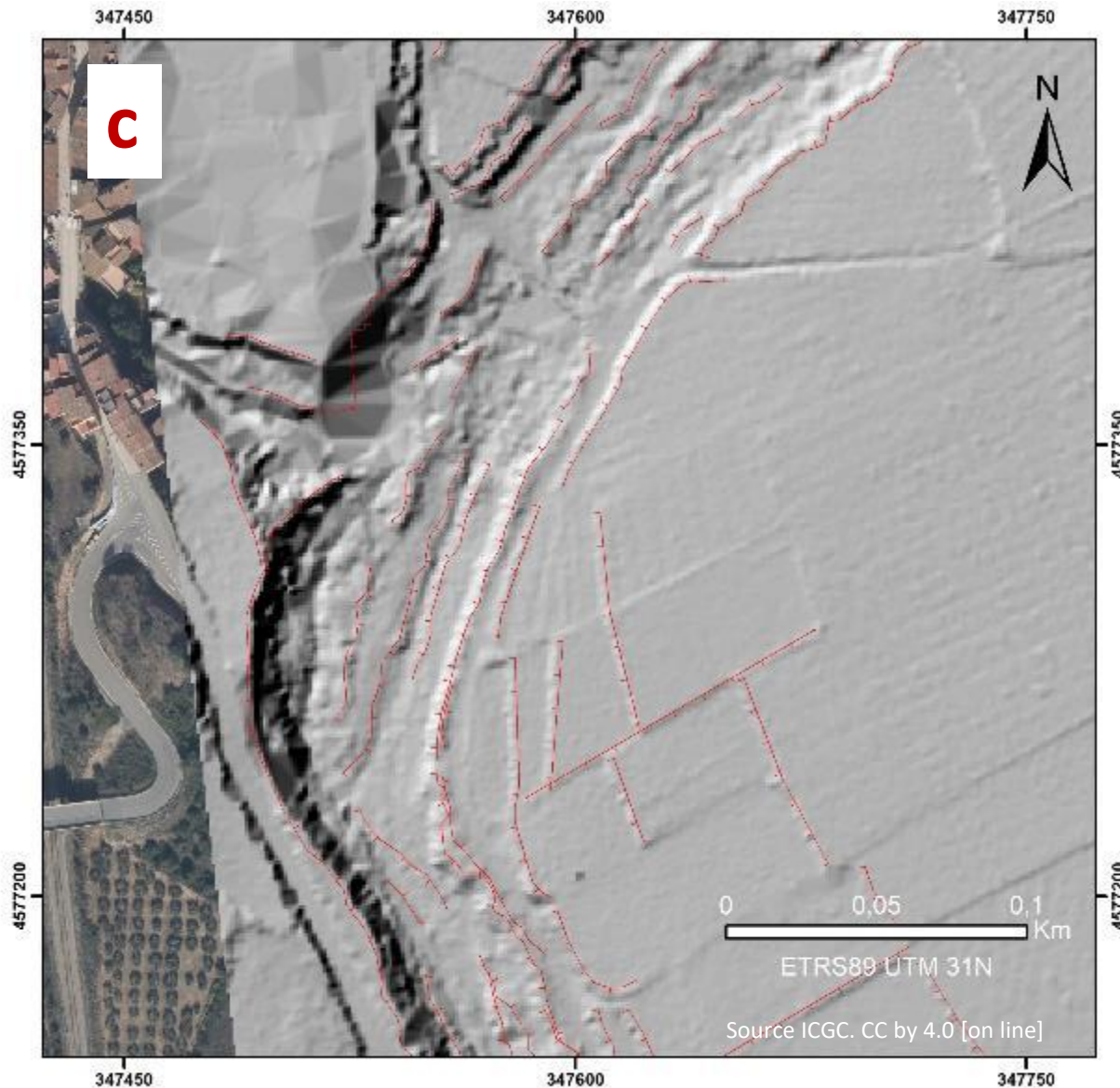
GEOM. CHARACTERIZATION 3st STEEP: PREVIOUS SITUATIONS

1946
ORTOPHOTO

 1947 RIVERBED



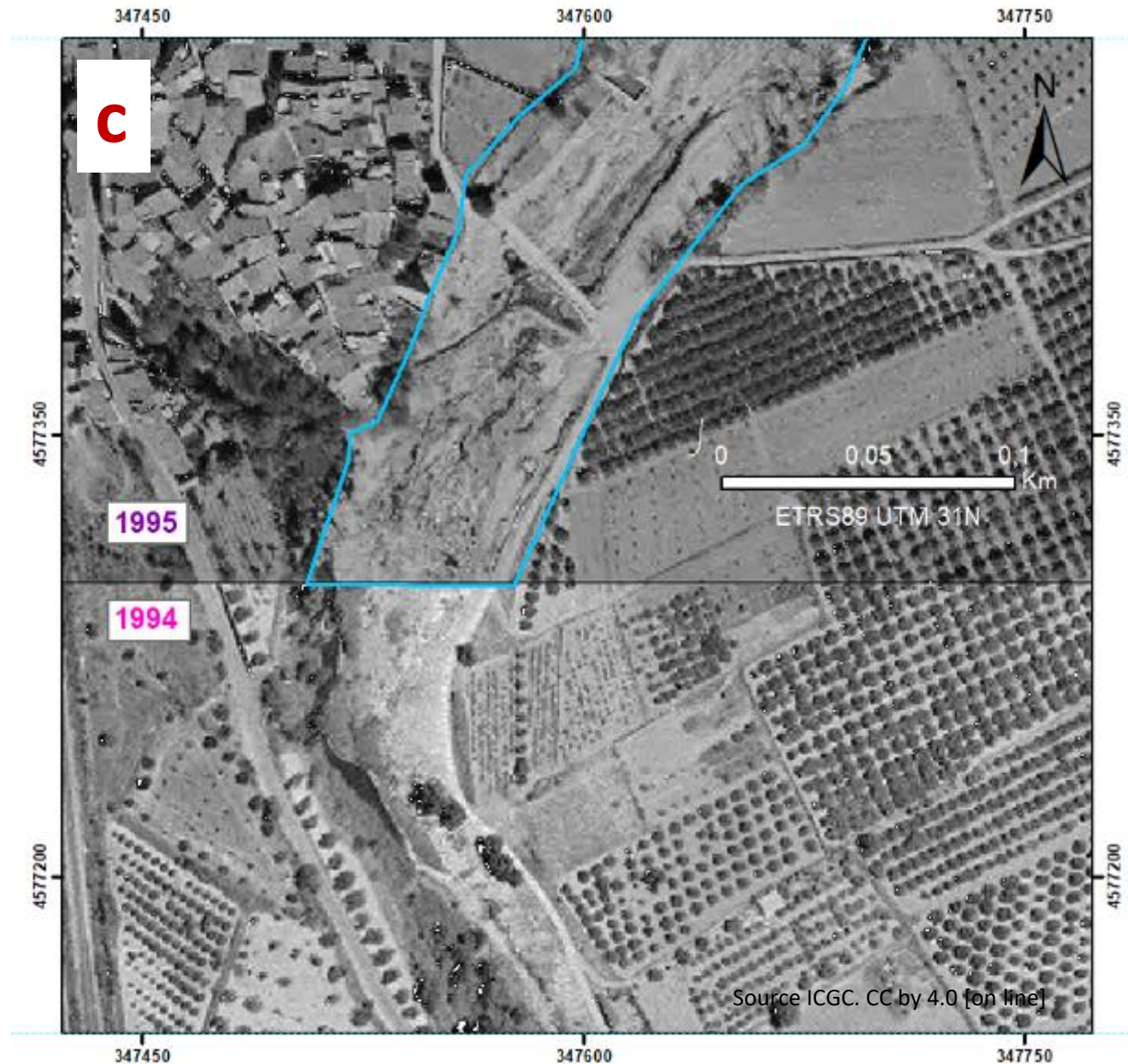
GEOM. CHARACTERIZATION 3st STEEP: PREVIOUS SITUATIONS



2003
DTM 1X1
SCARPS ANALYSIS

SCARPS 2003

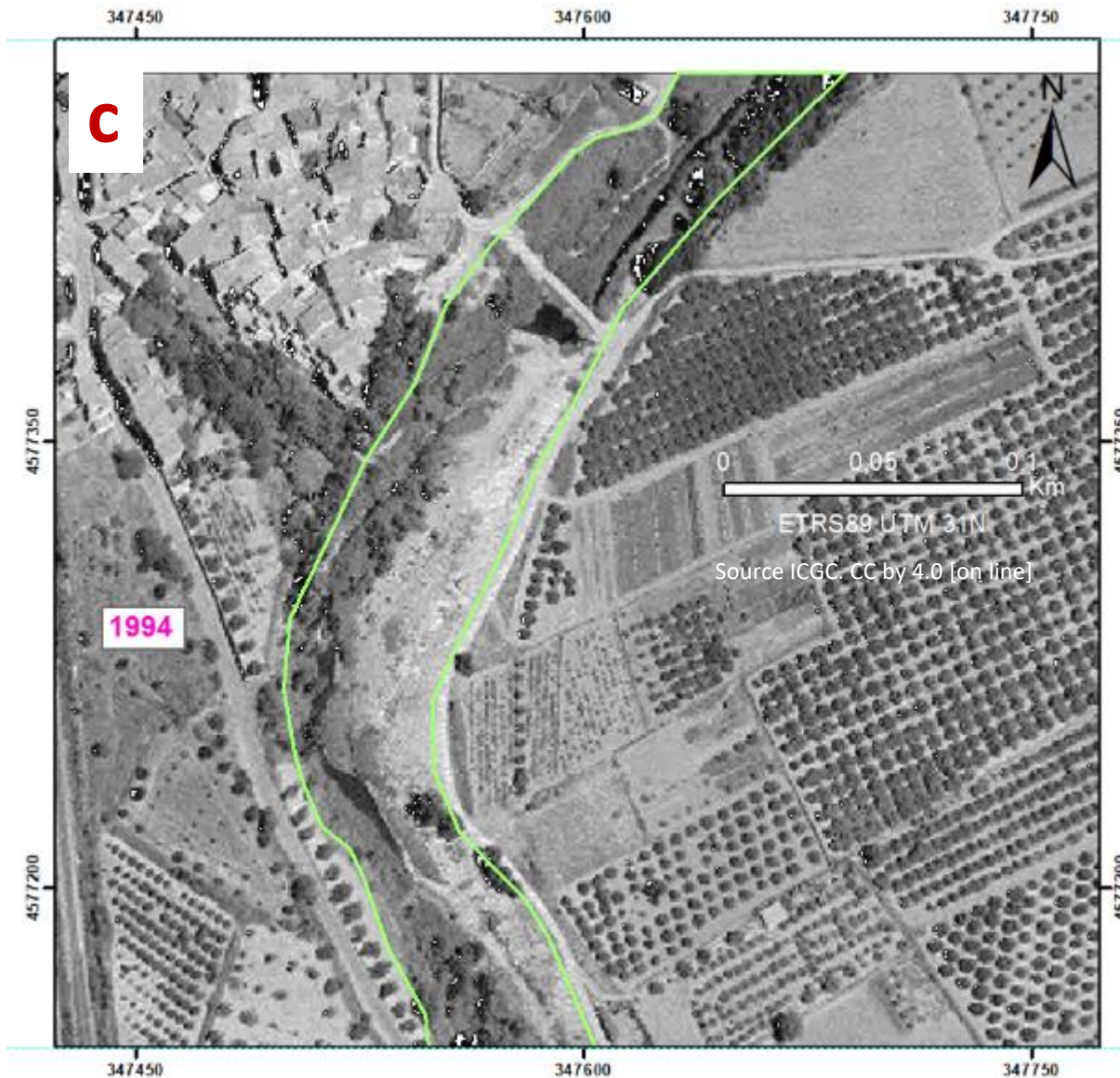
GEOM. CHARACTERIZATION 3st STEEP: PREVIOUS SITUATIONS



1995
ORTOPHOTO
(POST 1994 FLOOD)

 MINIMUM AREA
FLOODED IN 1994

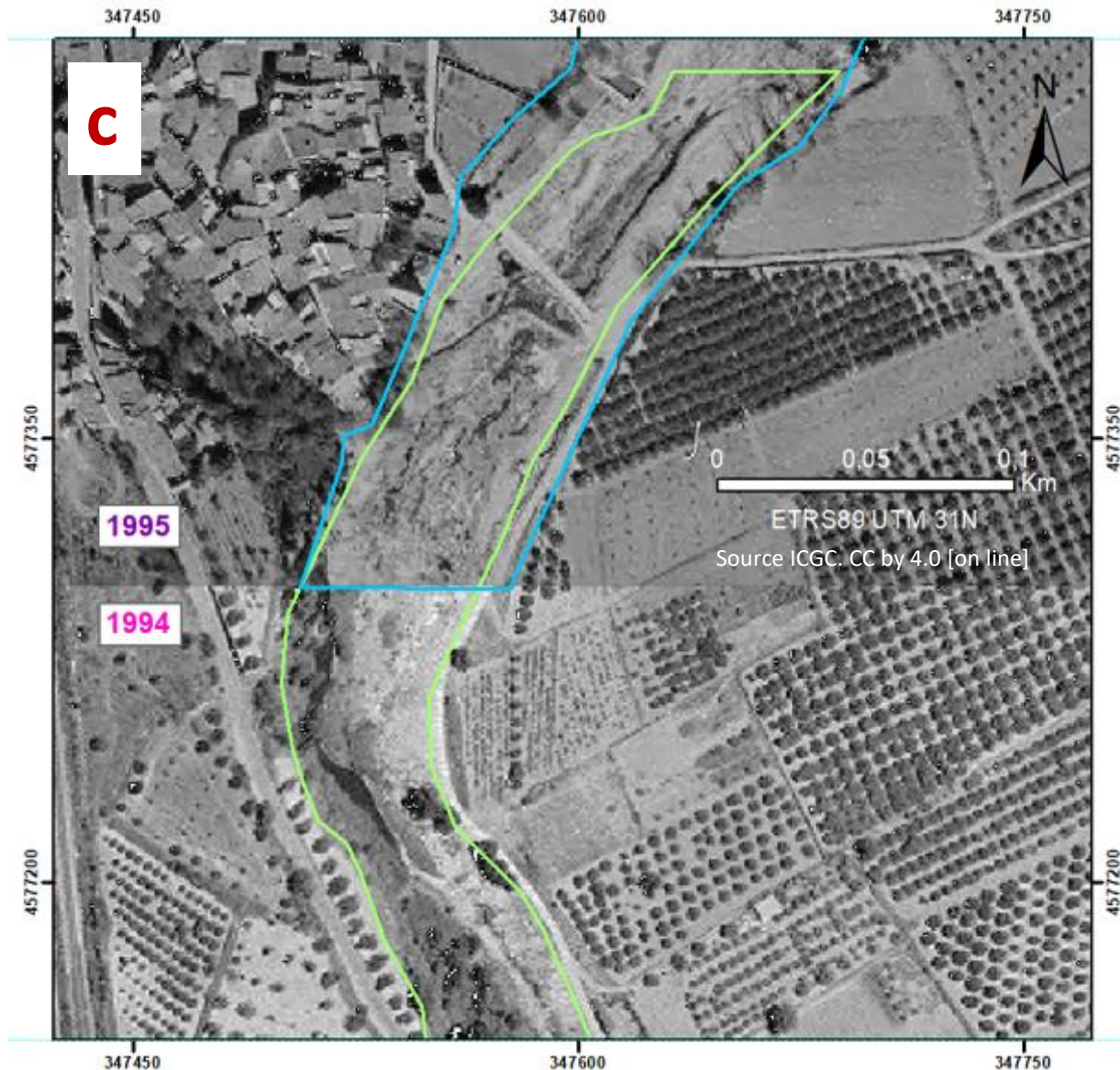
GEOM. CHARACTERIZATION 3st STEEP: PREVIOUS SITUATIONS



1994
ORTOPHOTO
(PRE 1994 FLOOD)

 RIVERBED 1994

GEOM. CHARACTERIZATION 3st STEEP: PREVIOUS SITUATIONS



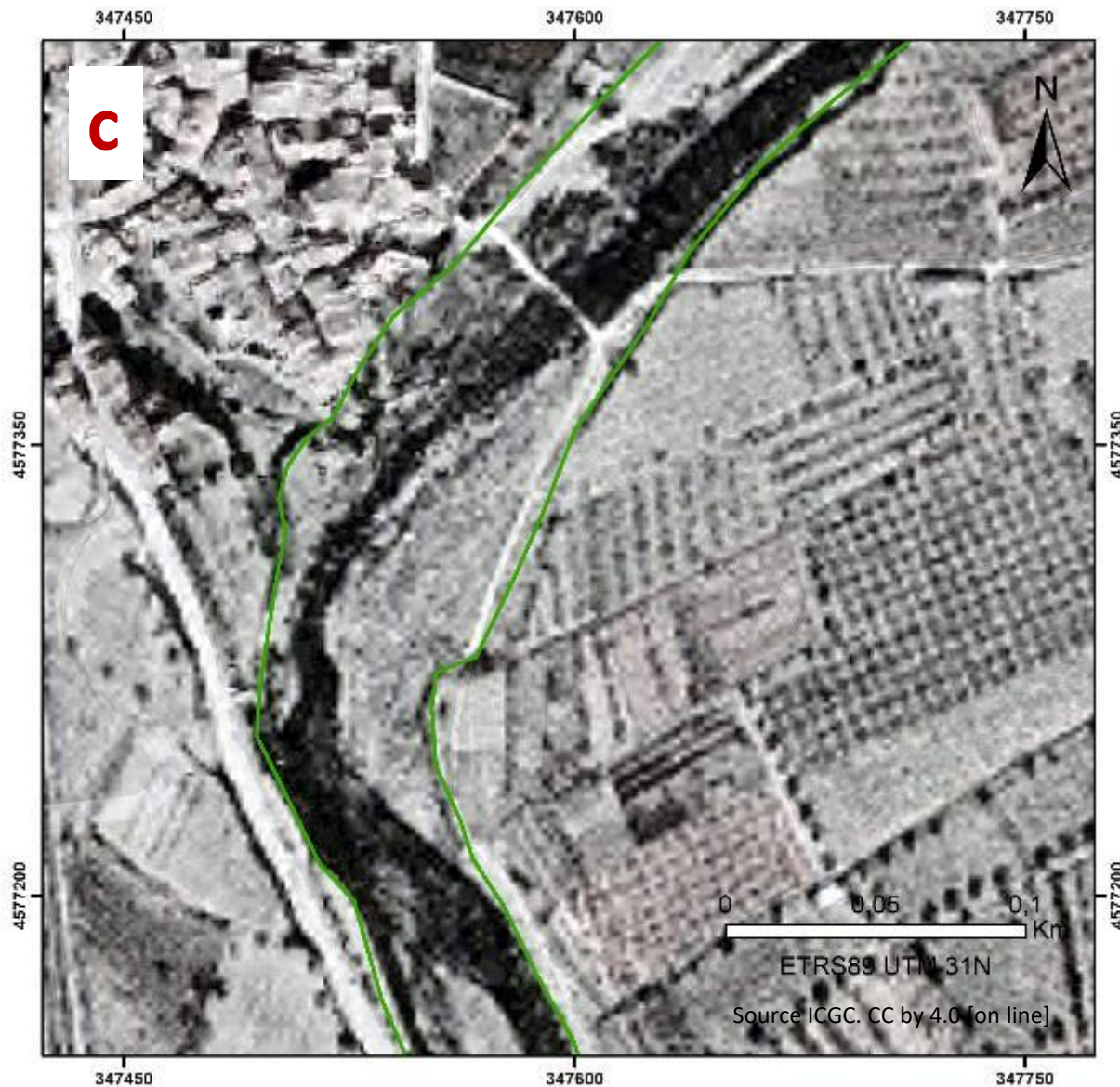
1995
ORTOPHOTO
(POST 1994 FLOOD)

1994
ORTOPHOTO
(PRE 1994 FLOOD)

 MINIMUM AREA
FLOODED IN 1994

 RIVERBED 1994

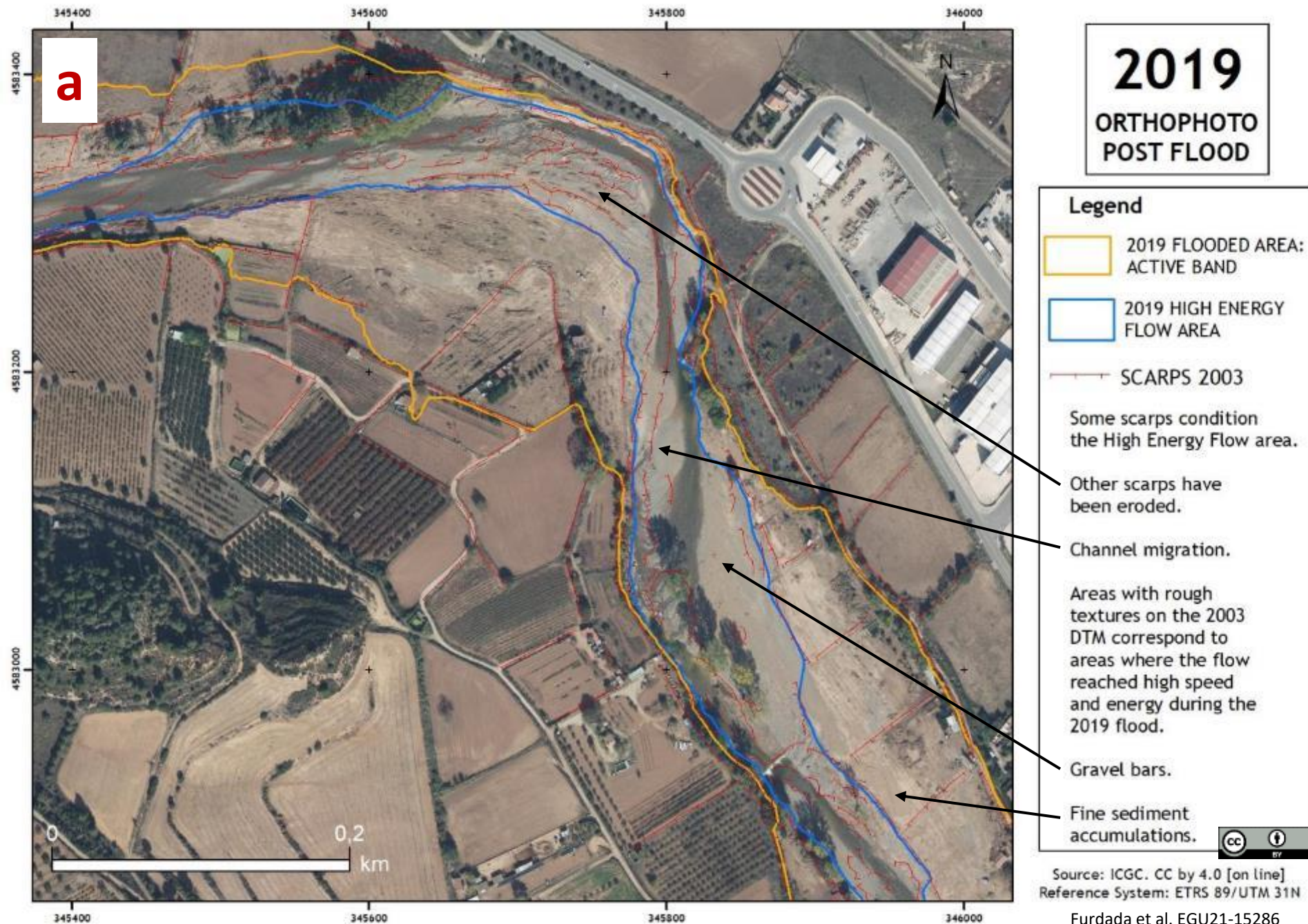
GEOM. CHARACTERIZATION 3st STEEP: PREVIOUS SITUATIONS



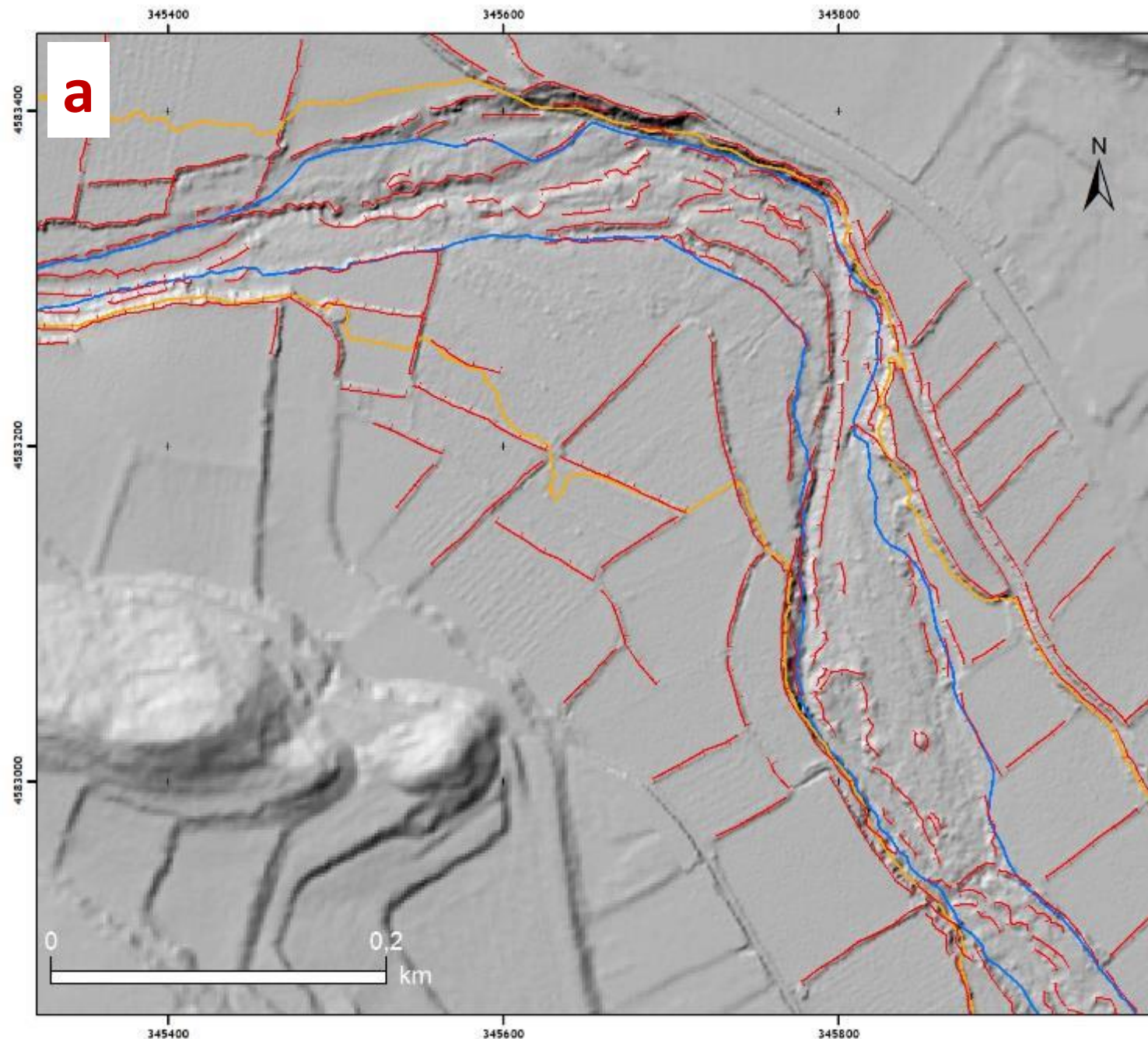
1946
ORTOPHOTO

 1947 RIVERBED

RESULTS AND COMPARISON



RESULTS AND COMPARISON



2003

DTM 1X1

Legend

-  2019 FLOODED AREA: ACTIVE BAND
-  2019 HIGH ENERGY FLOW AREA
-  SCARPS 2003

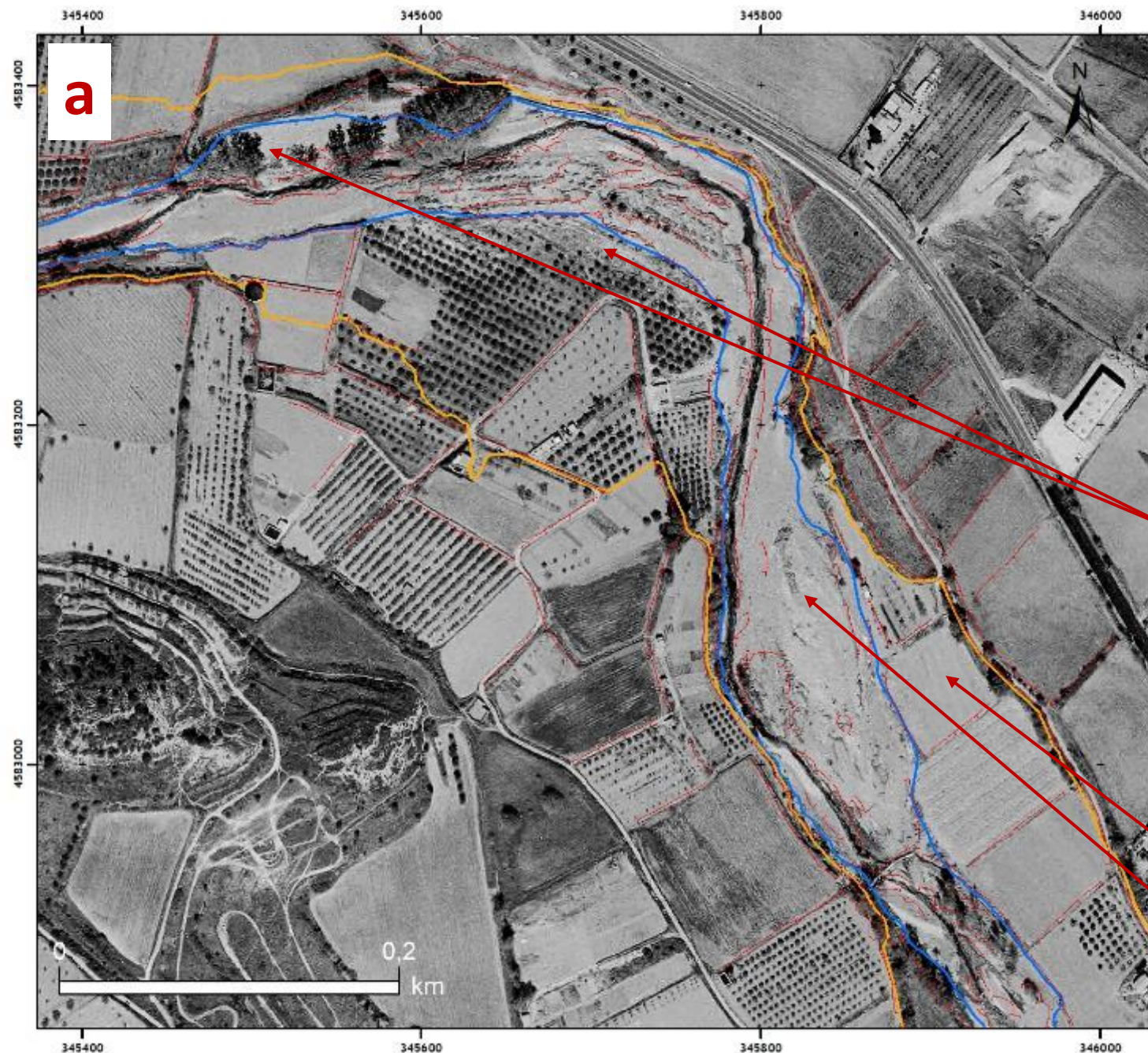
Some scarps limited the area with High Energy Flow (HEF) in 2019.

Furthermore, HEF corresponds to the roughest texture likely modelled by the effects of previous floodings.



Source: ICGC. CC by 4.0 [on line]
Reference System: ETRS 89/UTM 31N

RESULTS AND COMPARISON



1995
ORTHOPHOTO
POST 1994 FLOOD

Legend

- 2019 FLOODED AREA: ACTIVE BAND
- 2019 HIGH ENERGY FLOW AREA
- SCARPS 2003

Some effects of the 1994 overflow can be observed

The High Energy Flow area of 2019 corresponds to the HEF of 1994.

Rough textures correspond to areas where the flow reached high speed and energy.

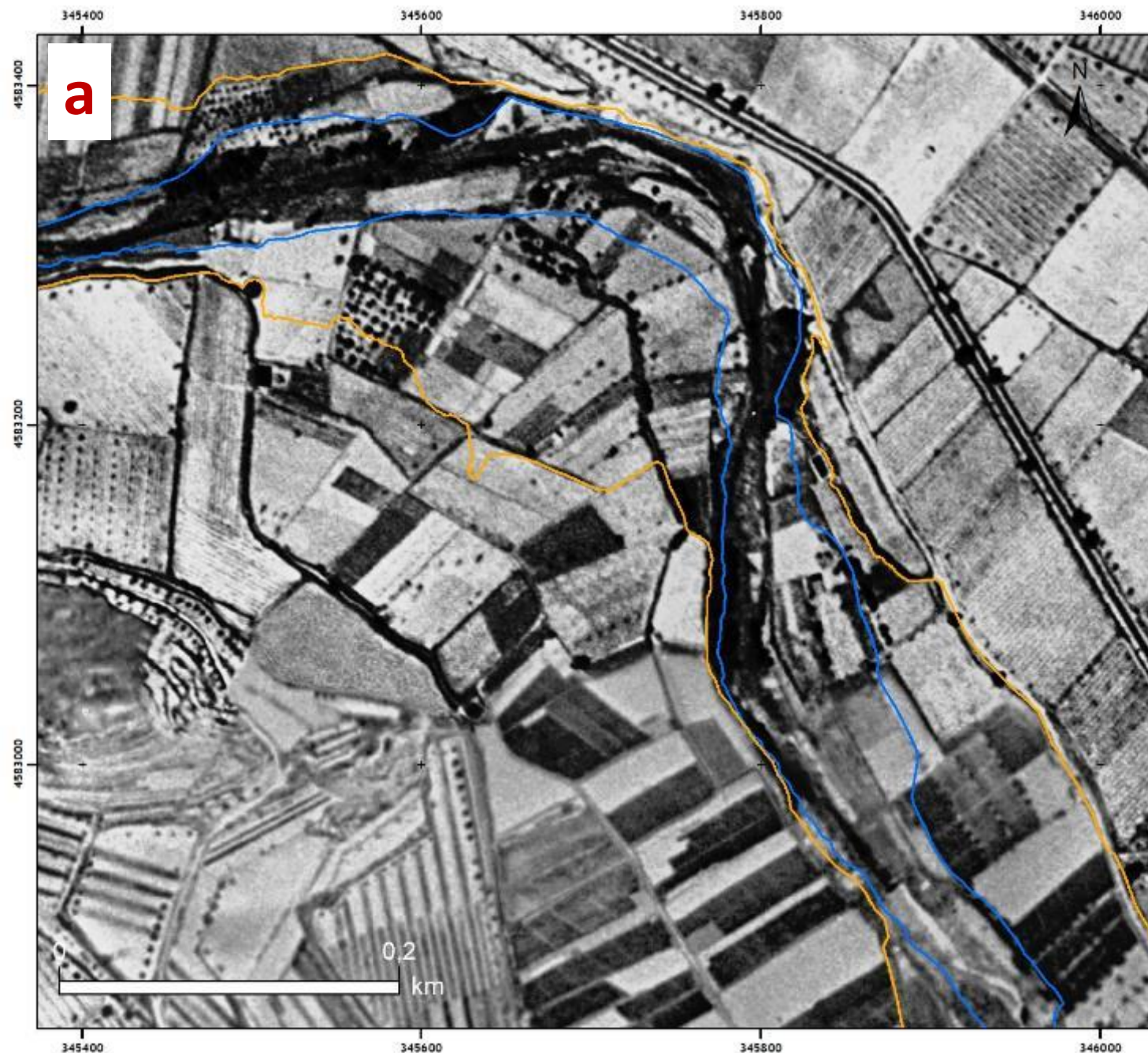
Fine sediment accumulation, low energy.

Gravel bars, high energy.



Source: ICGC. CC by 4.0 [on line]
Reference System: ETRS 89/UTM 31N

RESULTS AND COMPARISON



1956-57

AMERICAN FLIGHT B SERIES

Legend

-  2019 FLOODED AREA: ACTIVE BAND
-  2019 HIGH ENERGY FLOW AREA

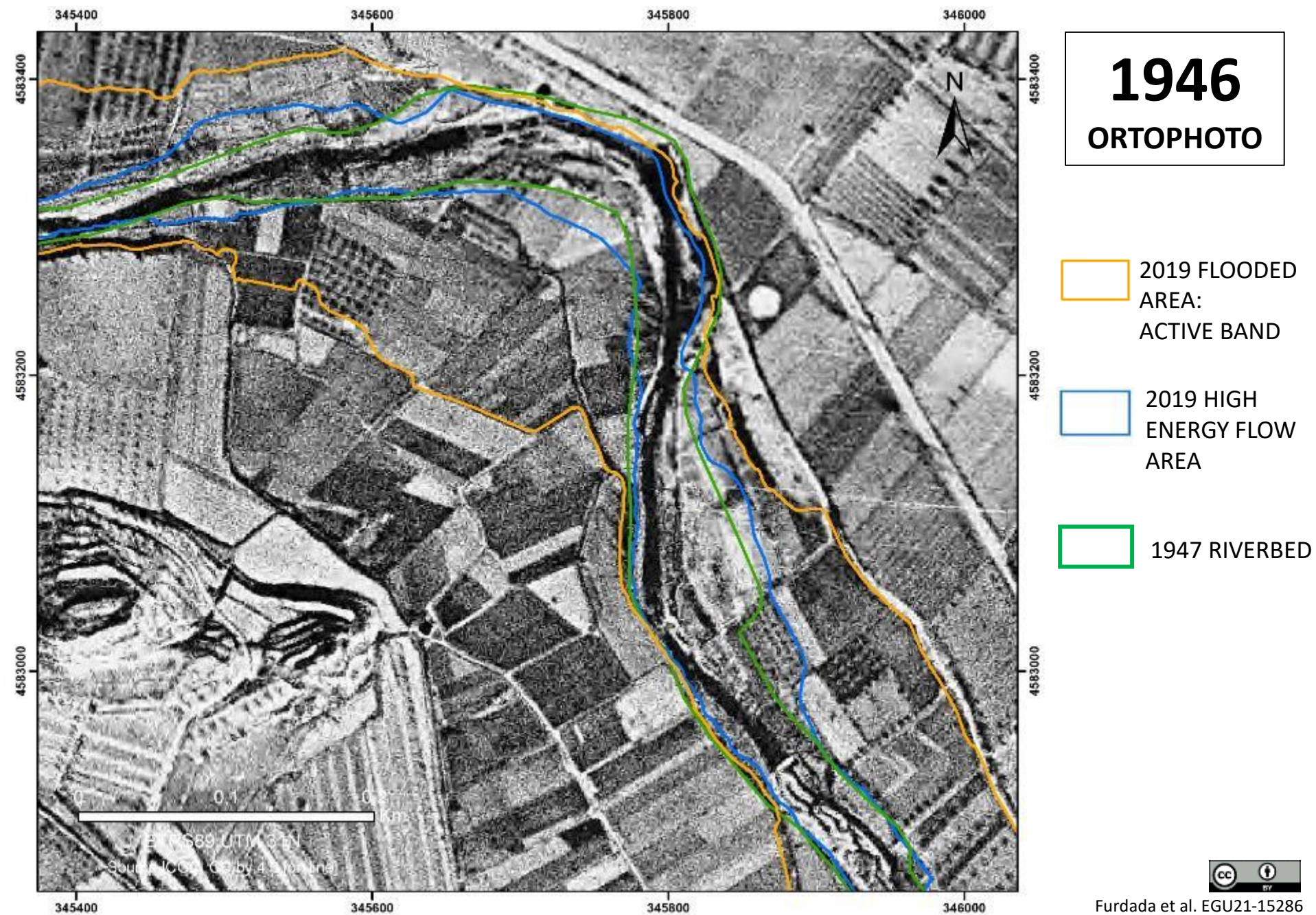
At this time, land use was more intensive. There was more crops near the channel.

Bend of the meander is a widening area in the following floods.

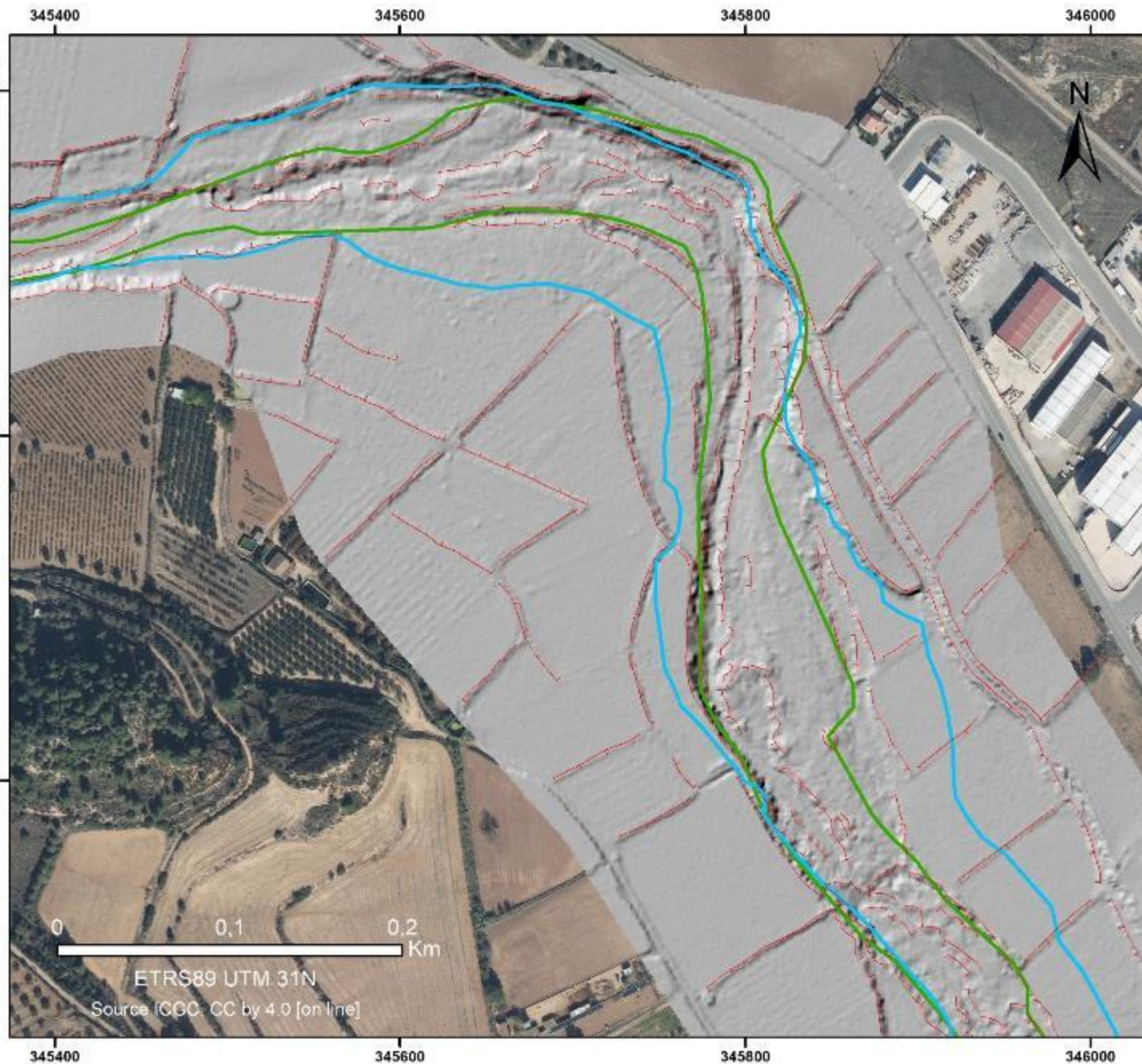


Source: ICGC. CC by 4.0 [on line]
Reference System: ETRS 89/UTM 31N

RESULTS AND COMPARISON



RESULTS AND COMPARISON



Elements mapped:
previous to the
2019 flood.

Is it possible to
delineate the
High Energy
Flow area of
2019?



SCARPS 2003

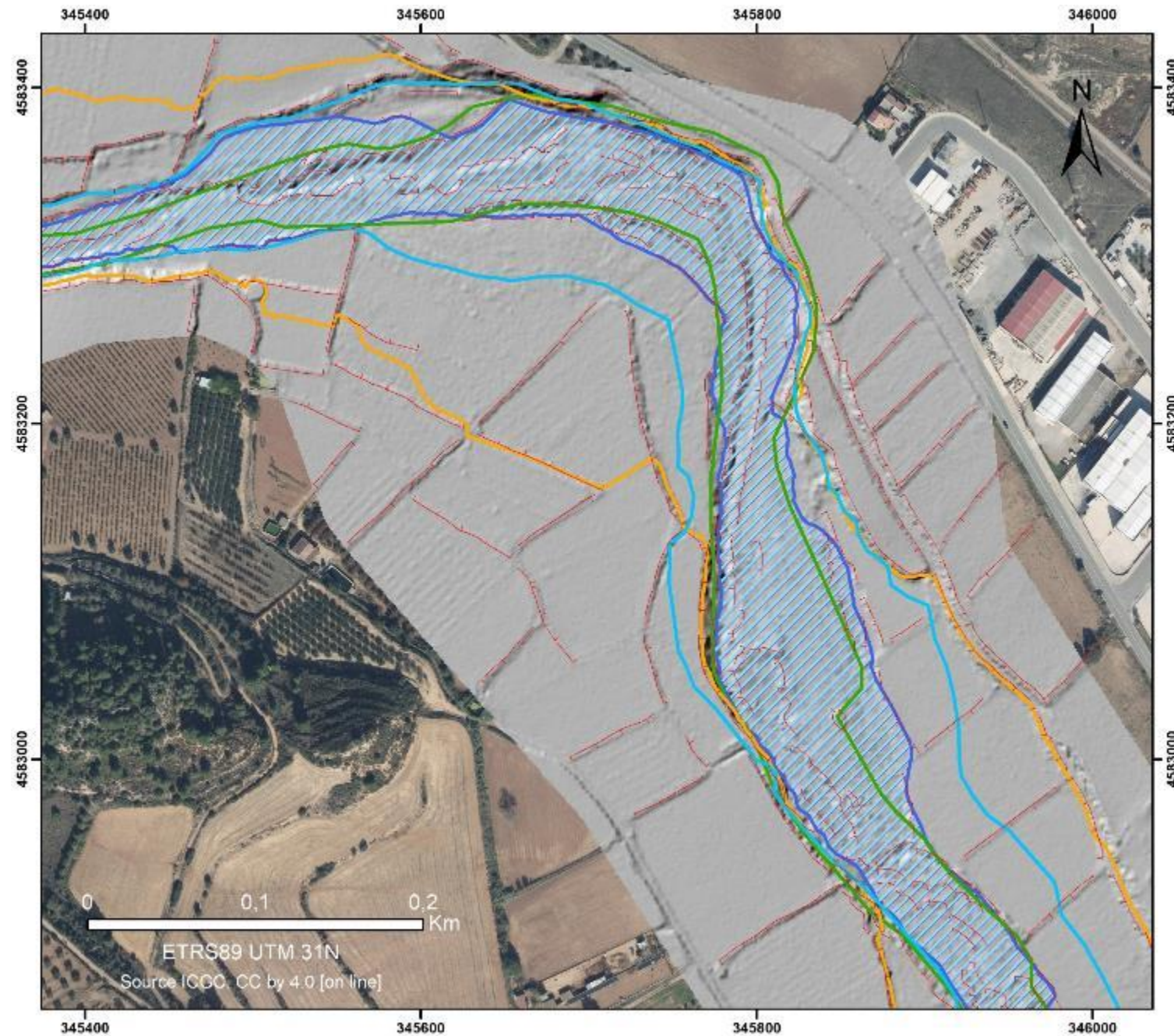


MINIMUM AREA
FLOODED IN 1994



1947 RIVERBED

RESULTS AND COMPARISON



RESULTS AND COMPARISON

2019 FLOODED AREA:
ACTIVE BAND

2019 HIGH ENERGY
FLOW AREA

SCARPS 2003

2019
ORTOPHOTO
POST FLOOD



RESULTS AND COMPARISON

2019 FLOODED AREA:
ACTIVE BAND

2019 HIGH ENERGY
FLOW AREA

SCARPS 2003

2003
DTM 1X1
SCARPS ANALYSIS



RESULTS AND COMPARISON



MINIMUM AREA
FLOODED IN 1994



SCARPS 2003

1995

ORTOPHOTO
(POST 1994 FLOOD)



RESULTS AND COMPARISON

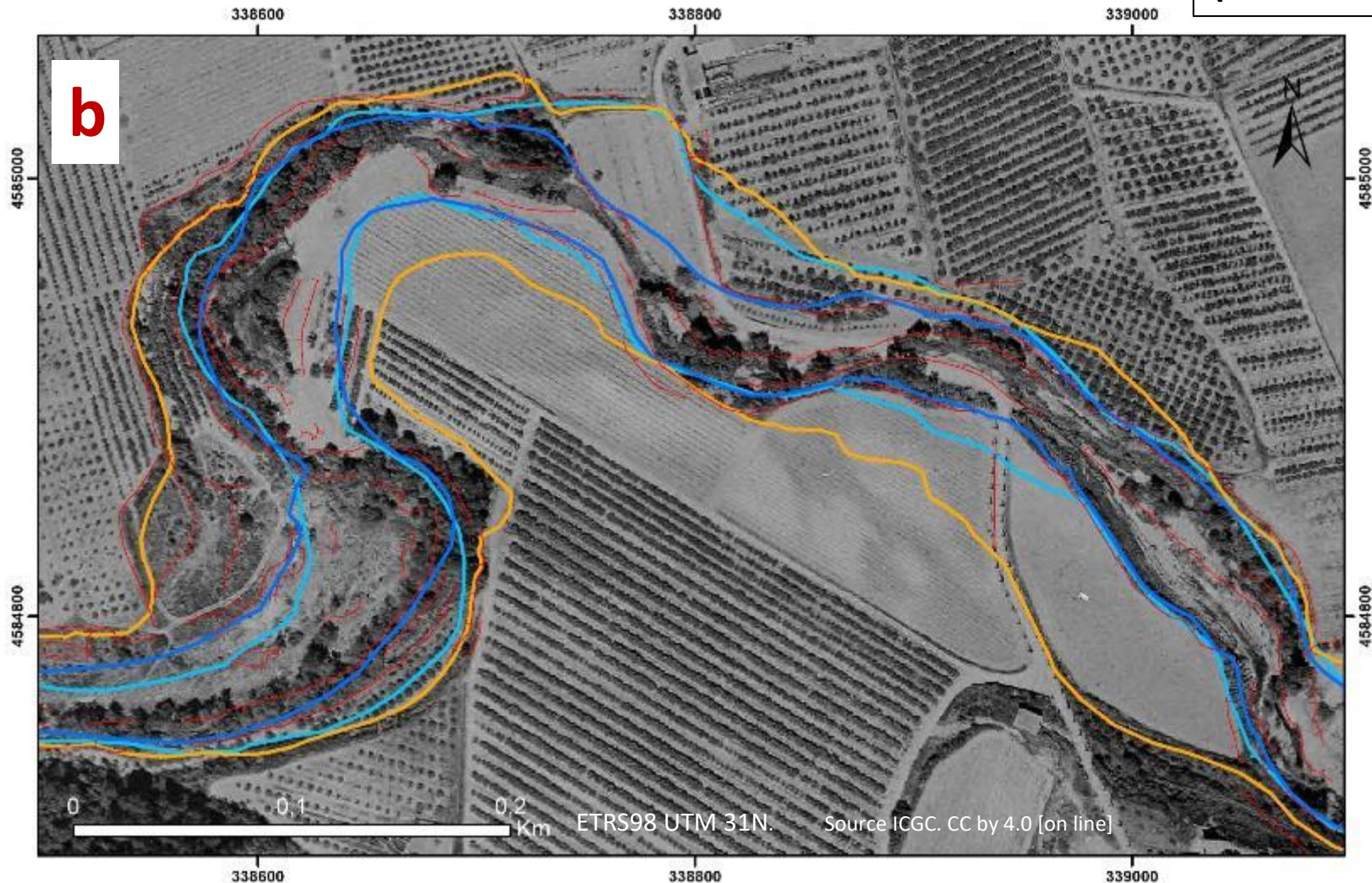
2019 FLOODED AREA:
ACTIVE BAND

2019 HIGH ENERGY
FLOW AREA

SCARPS 2003

MINIMUM AREA
FLOODED IN 1994

1995
ORTOPHOTO
(POST 1994 FLOOD)

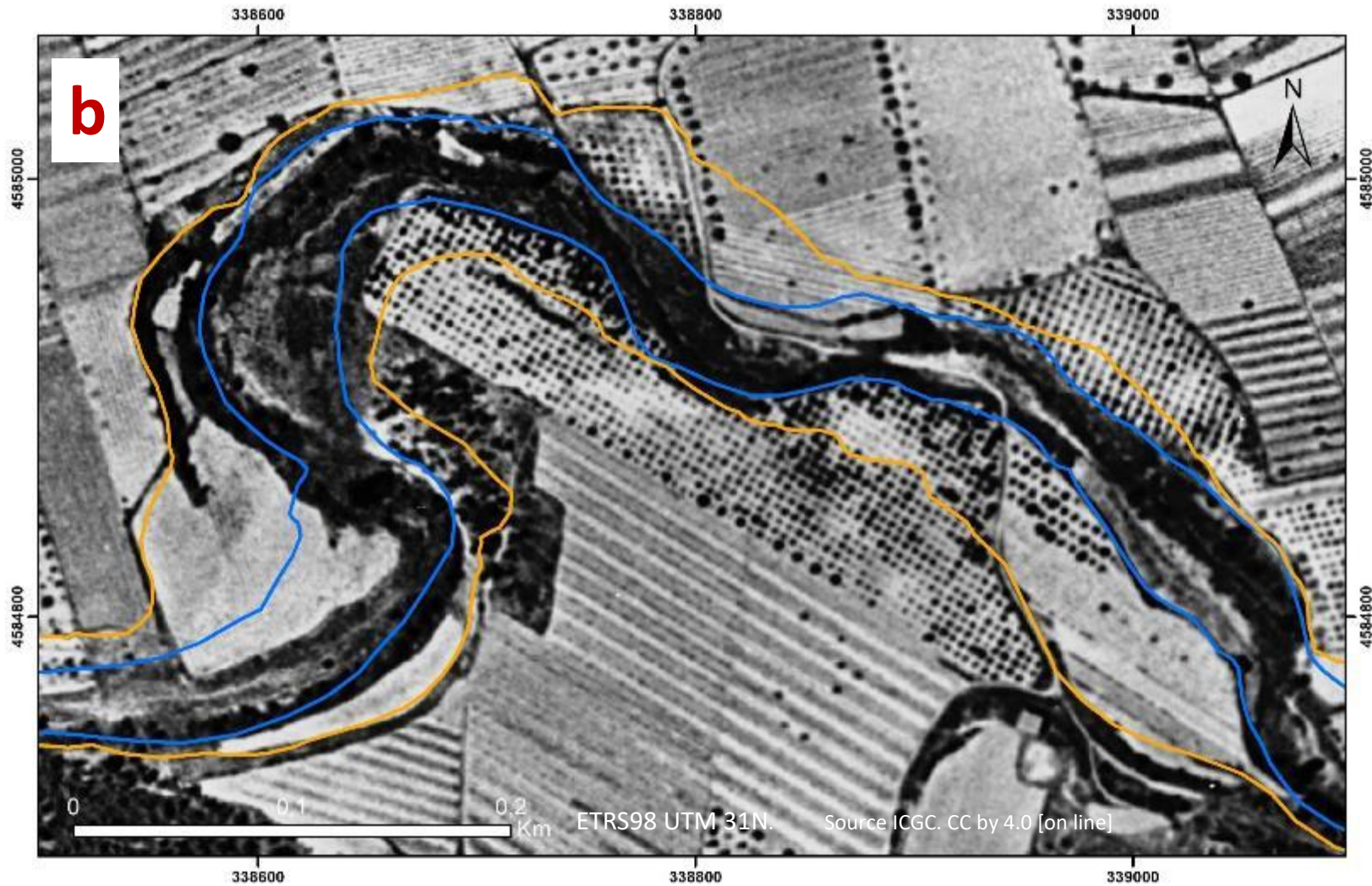


RESULTS AND COMPARISON

2019 FLOODED AREA:
ACTIVE BAND

2019 HIGH ENERGY
FLOW AREA

1956



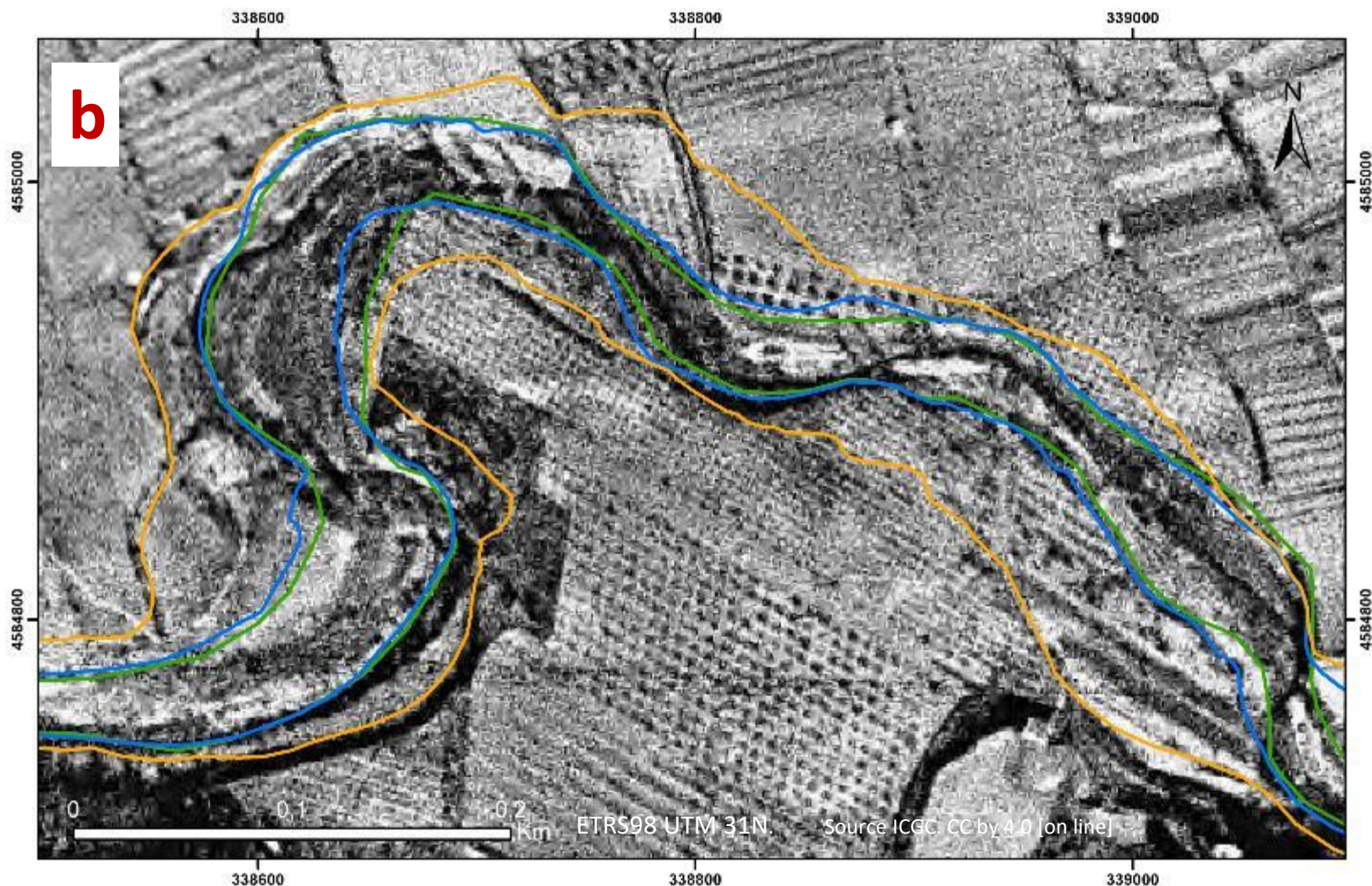
RESULTS AND COMPARISON

2019 FLOODED AREA:
ACTIVE BAND

2019 HIGH ENERGY
FLOW AREA

1947 RIVERBED

1946
ORTOPHOTO



RESULTS AND COMPARISON



SCARPS 2003

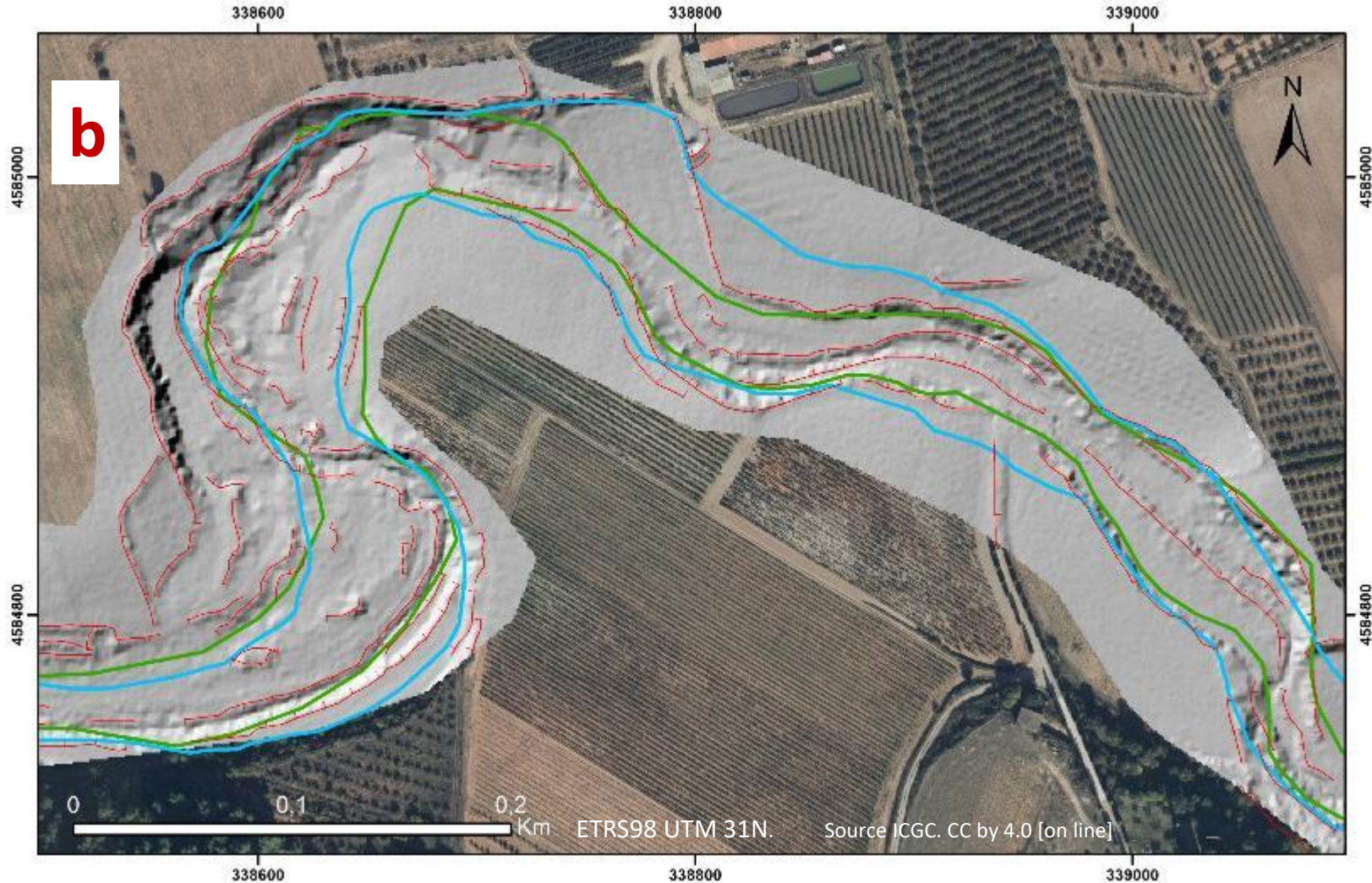


MINIMUM AREA
FLOODED IN 1994



1947 RIVERBED

Elements mapped: previous to the 2019 flood.
Is it possible to delineate the High Energy Flow
area of 2019?



RESULTS AND COMPARISON



SCARPS 2003



MINIMUM AREA
FLOODED IN 1994



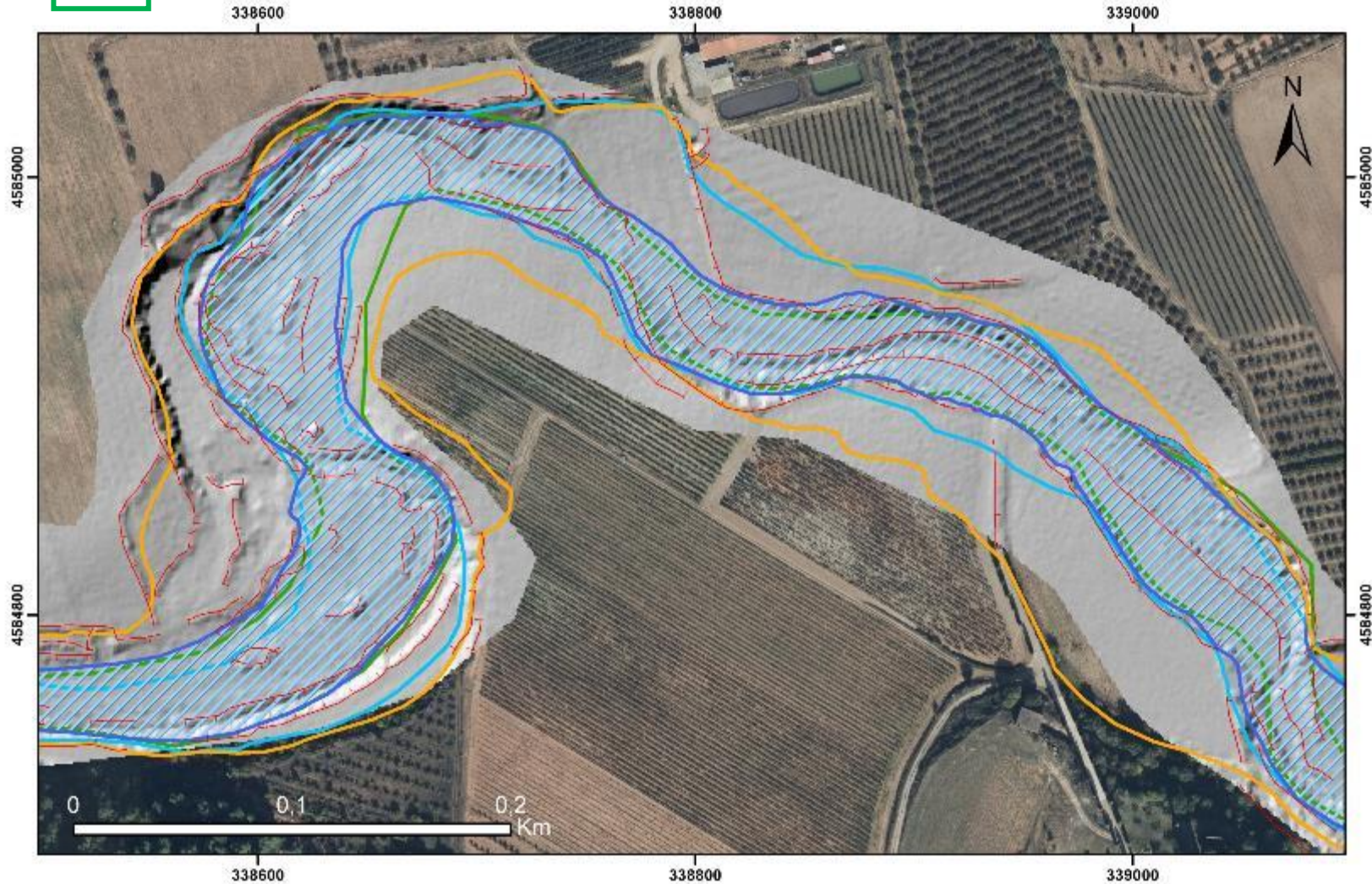
1947 RIVERBED



2019 FLOODED AREA:
ACTIVE BAND

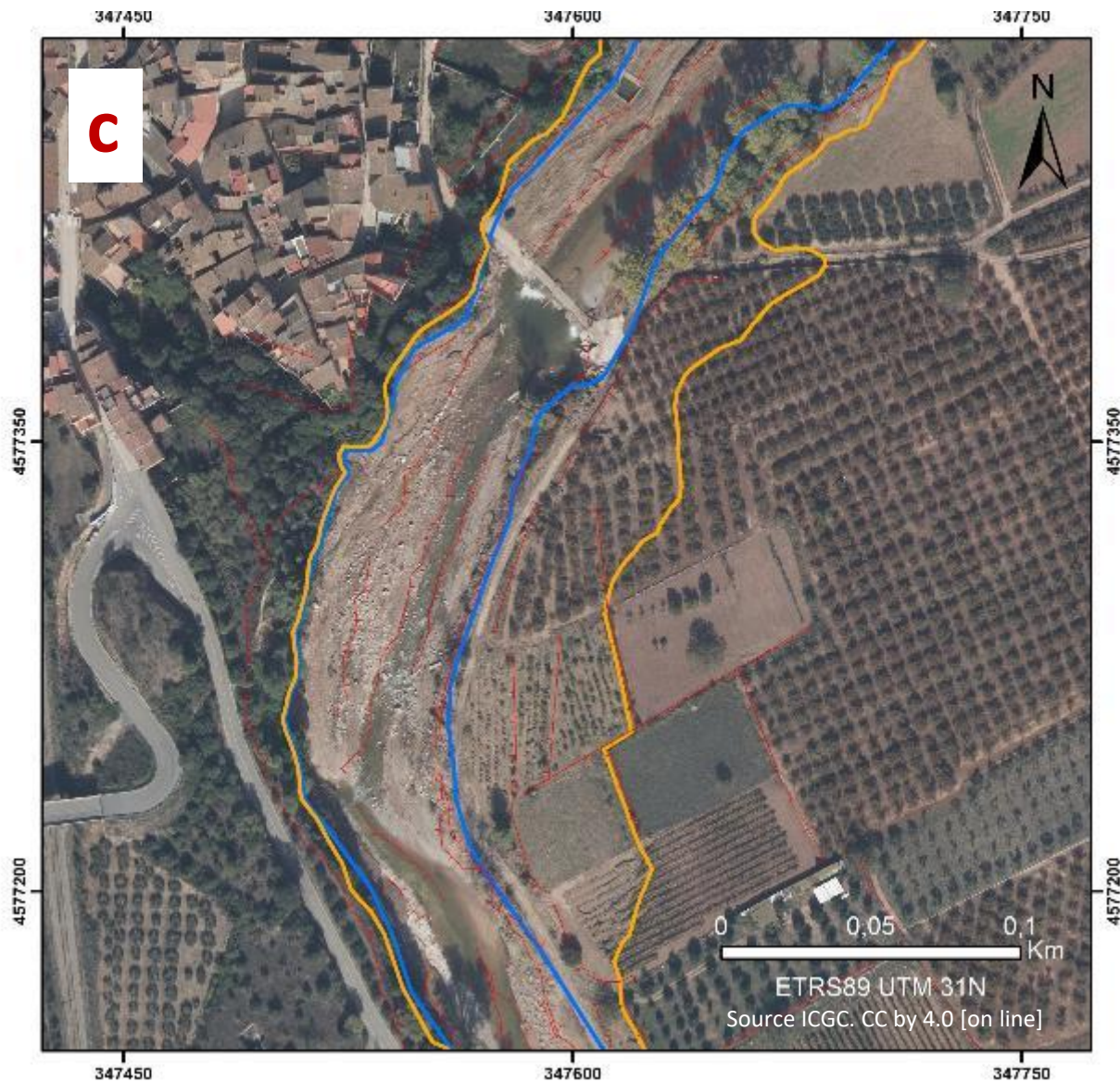


2019 HIGH ENERGY
FLOW AREA



RESULTS AND COMPARISON

2019
ORTOPHOTO
POST FLOOD

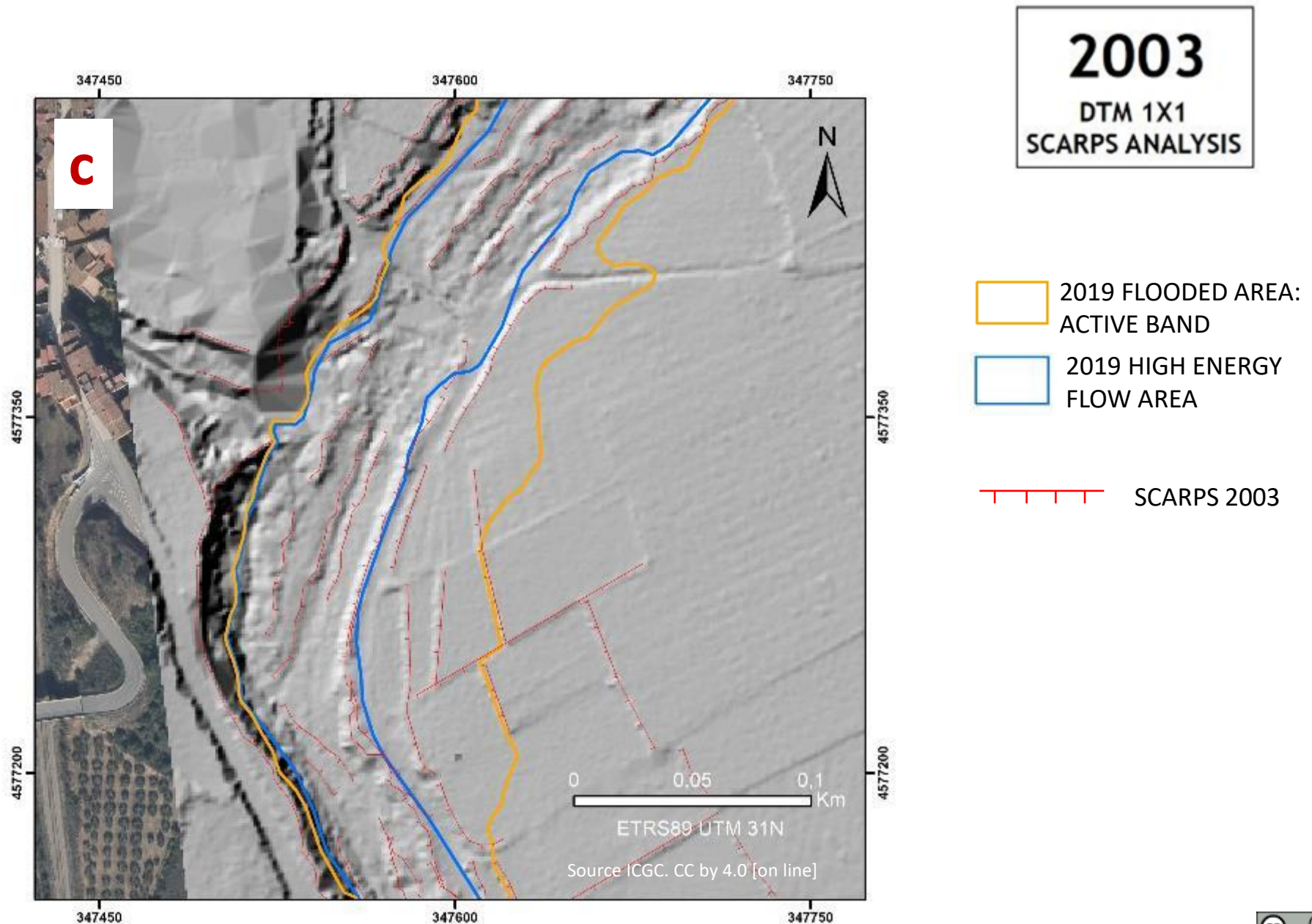


 2019 FLOODED AREA:
ACTIVE BAND

 2019 HIGH ENERGY
FLOW AREA

 SCARPS 2003

RESULTS AND COMPARISON



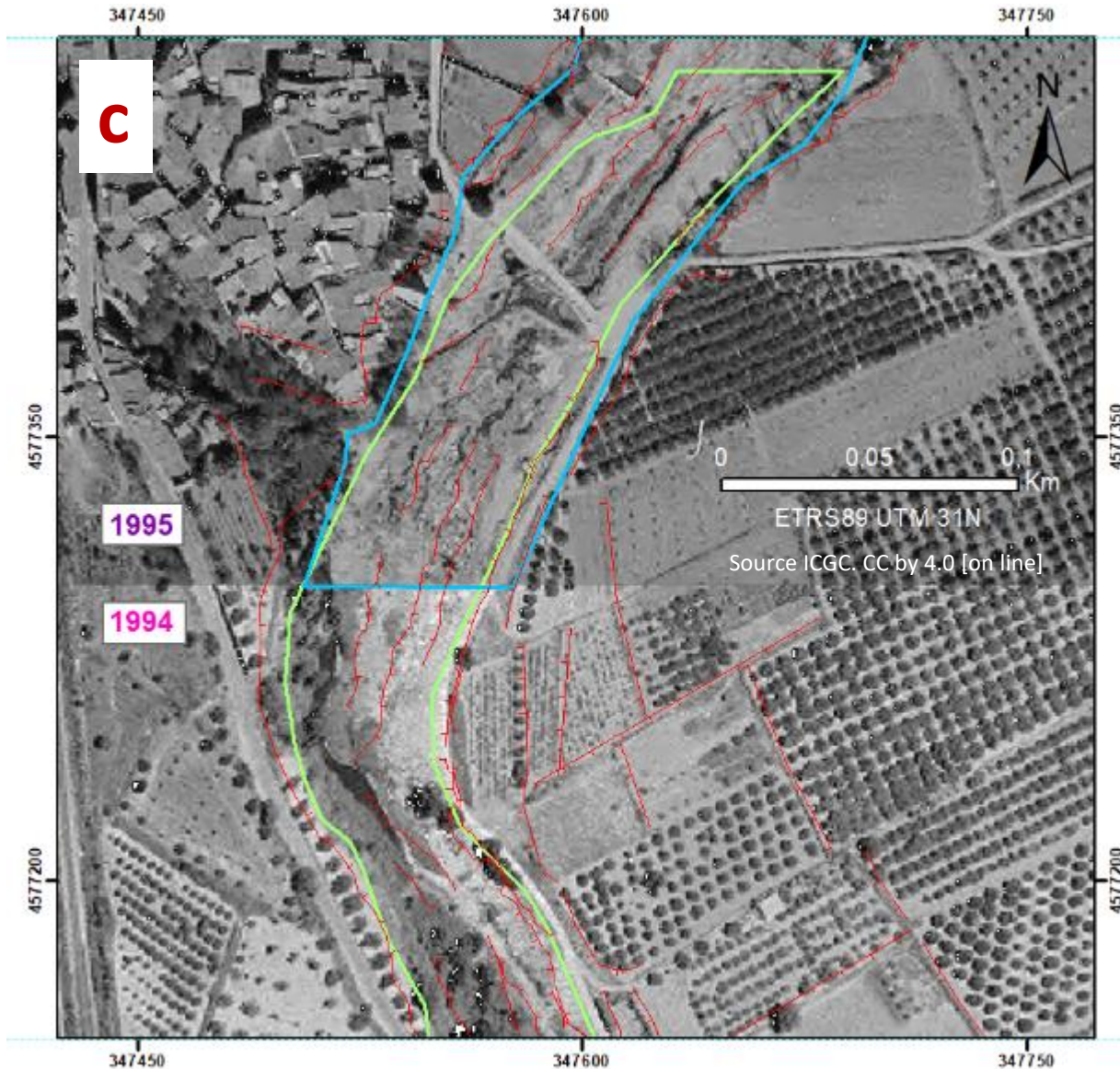
RESULTS AND COMPARISON

1995

ORTOPHOTO
(POST 1994 FLOOD)

1994

ORTOPHOTO
(PRE 1994 FLOOD)



SCARPS 2003

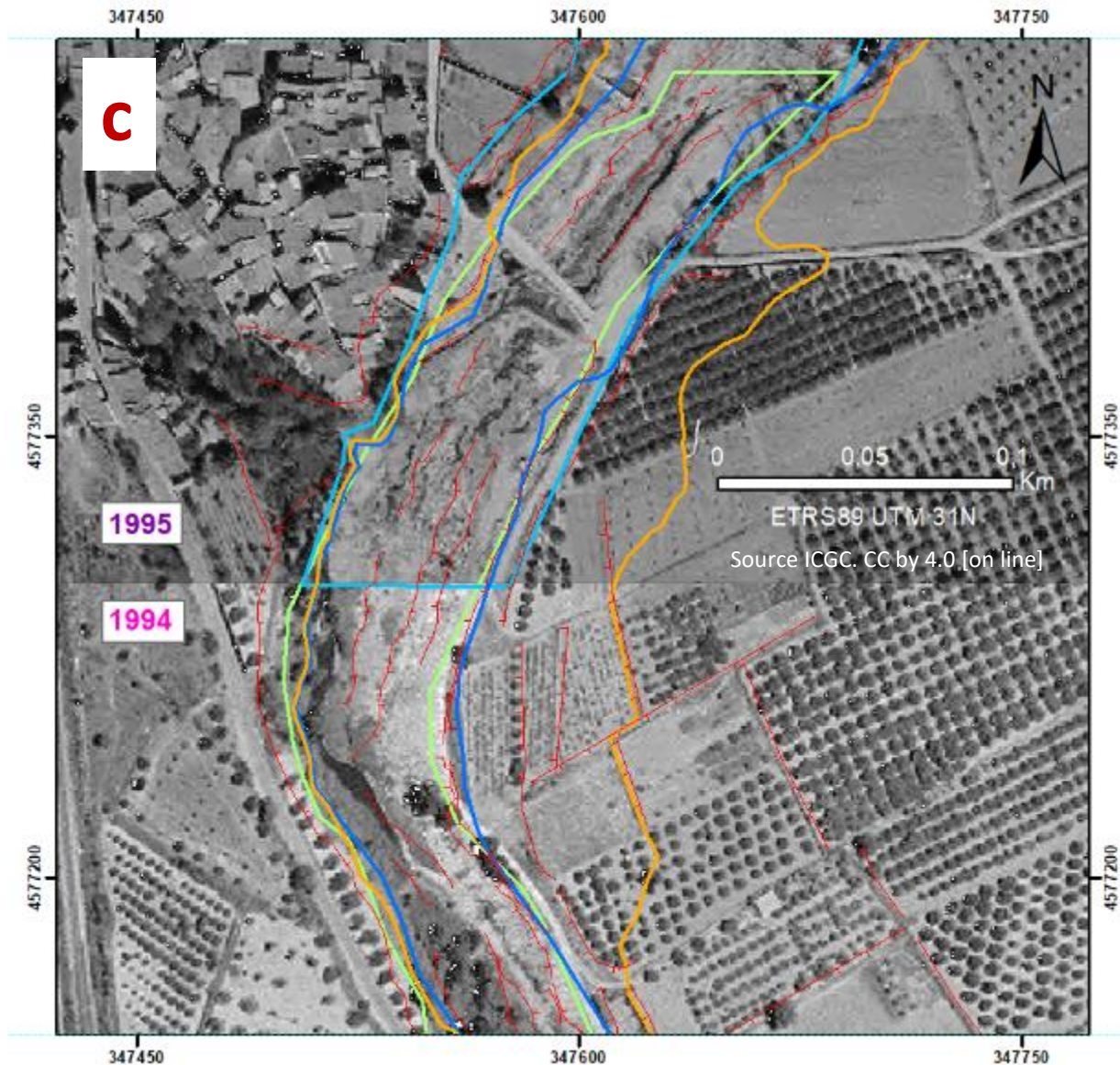


MINIMUM AREA
FLOODED IN 1994



RIVERBED 1994

RESULTS AND COMPARISON



1995
ORTOPHOTO
(POST 1994 FLOOD)

1994
ORTOPHOTO
(PRE 1994 FLOOD)

2019 FLOODED AREA:
ACTIVE BAND

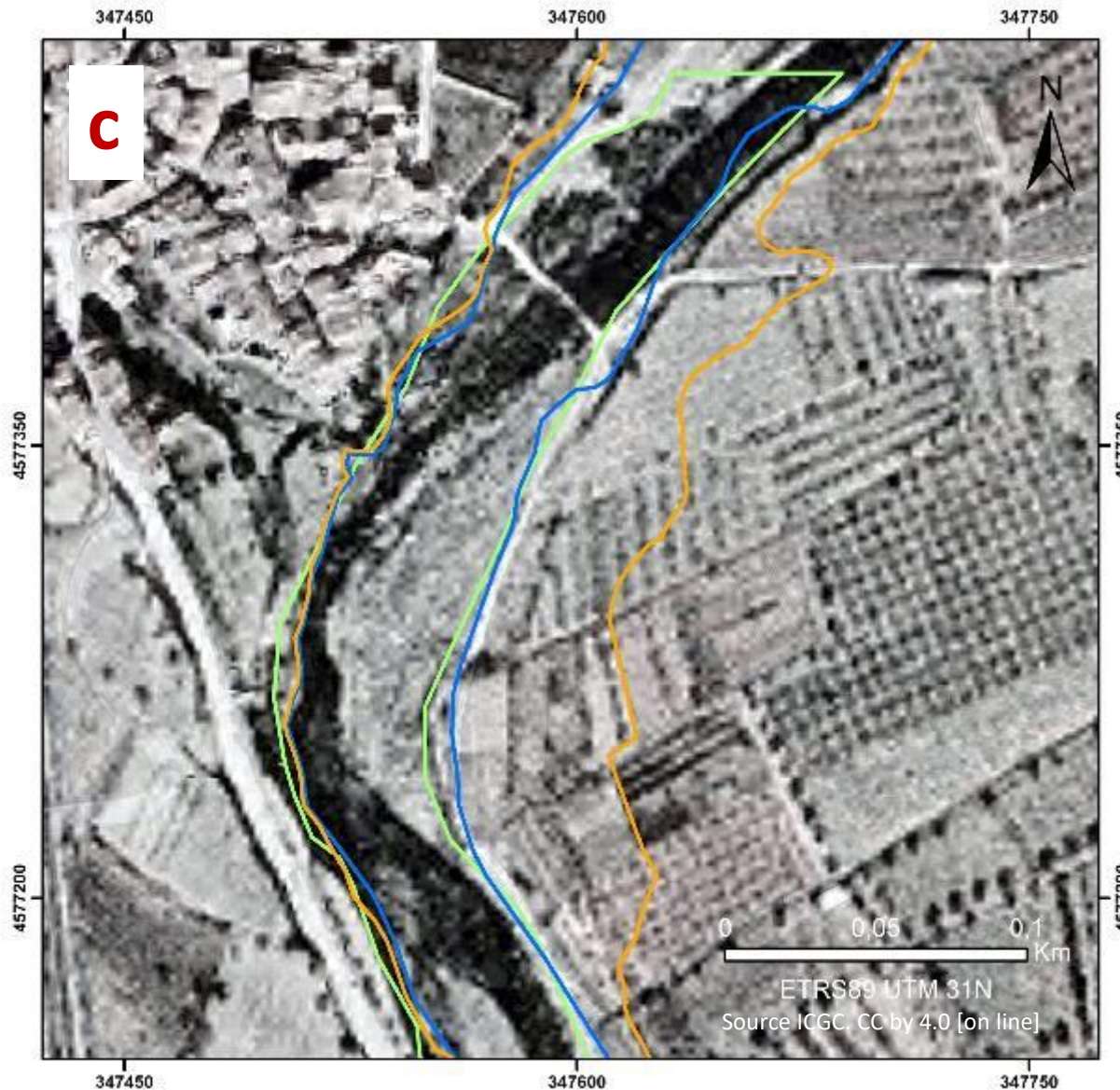
2019 HIGH ENERGY
FLOW AREA

SCARPS 2003

MINIMUM AREA
FLOODED IN 1994

RIVERBED 1994

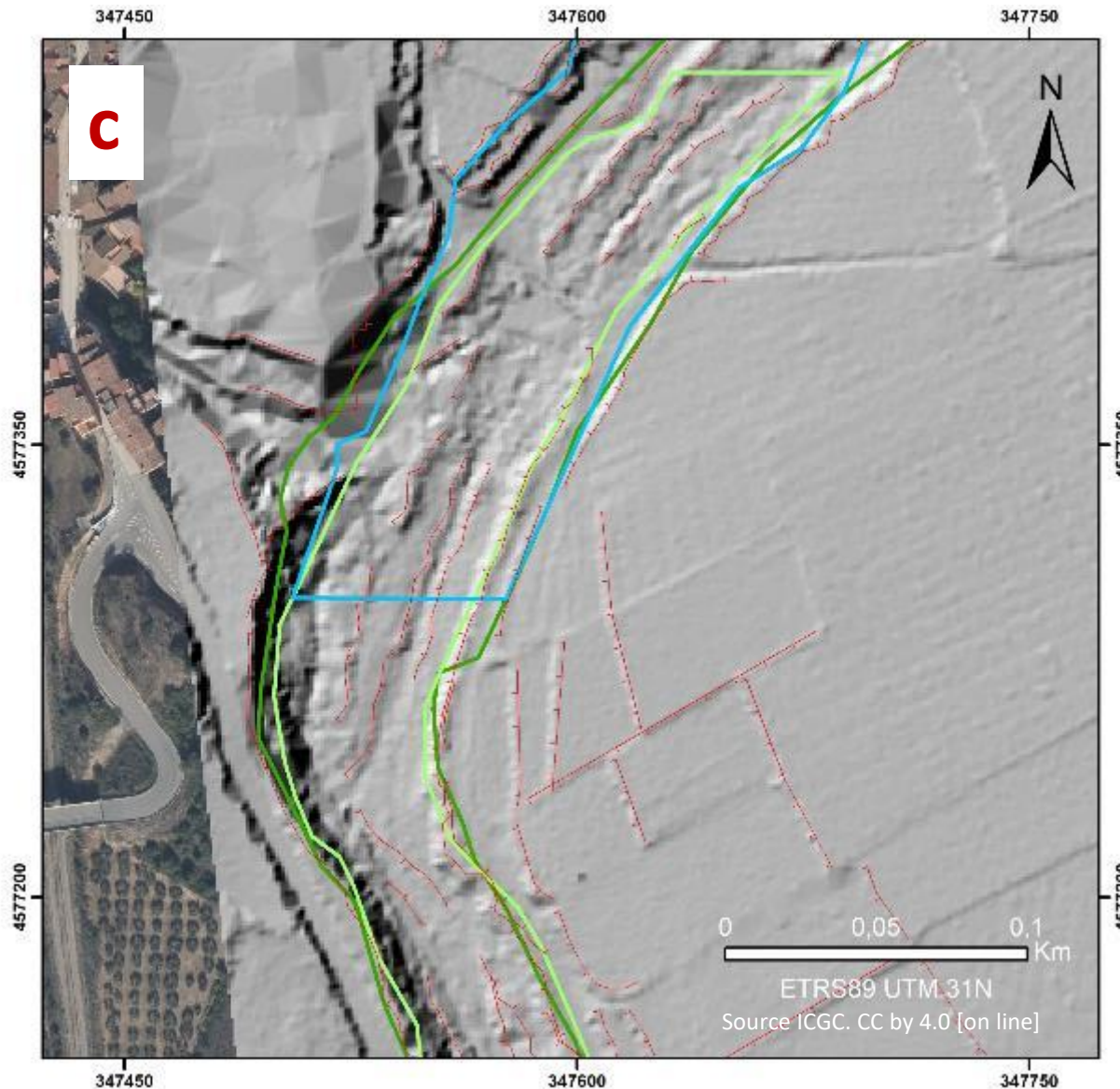
RESULTS AND COMPARISON



1946
ORTOPHOTO

- 2019 FLOODED AREA:
ACTIVE BAND
- 2019 HIGH ENERGY
FLOW AREA
- 1947 RIVERBED

RESULTS AND COMPARISON



Elements mapped:
previous to the 2019 flood.

Is it possible to delineate
the High Energy Flow area
of 2019?

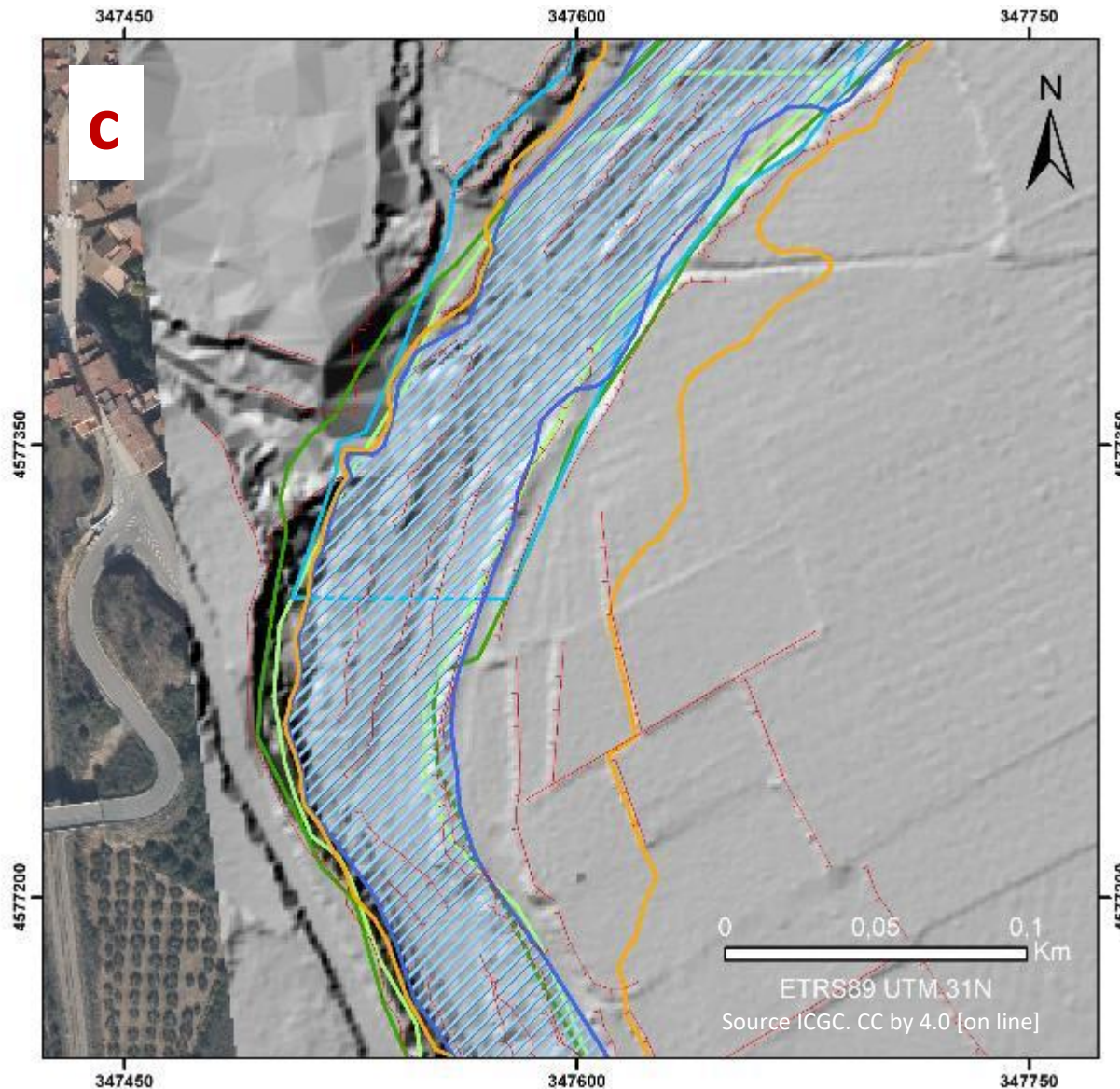
SCARPS 2003

MINIMUM AREA
FLOODED IN 1994

1994 RIVERBED

1947 RIVERBED

RESULTS AND COMPARISON



-  2019 FLOODED AREA:
ACTIVE BAND
-  2019 HIGH ENERGY
FLOW AREA
-  SCARPS 2003
-  MINIMUM AREA
FLOODED IN 1994
-  1994 RIVERBED
-  1947 RIVERBED

- The HEF zone for the 2019 flood appears to be very similar to the following mapped areas:
 - 2003 DTM: the roughest texture area, probably shaped by the previous floods.
 - 1994 riverbed (when photo exists)
 - 1946 riverbed
- The 2003 scarps show quite well:
 - the main channel, which can migrate and/or avulse during the 2019 flood.
 - some clear boundaries of the roughest textured areas in the 2003 1x1m DTM
- The most severely affected 1994 minimum flooded area (roughest texture in 1995 ortophoto, when it exists) coincides quite well with the 2019 High Energy Flow area.

PRELIMINARY CONCLUSIONS

Multitemporal geomorphological analysis
contributes to determine
the river zones that can be affected by
high energy flow (destructive) during floods.

The ZFP can be reasonably determined for major
floods in this type of Mediterranean rivers.

Good skills on geomorphological mapping are essential to
successfully carry out this kind of analysis

Acknowledgements:

Thanks to Dr. Virginia Ruiz-Villanueva for her valuable comments

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