RESTORATION OF FLUVIAL ECOSYSTEMS – Course ATHENS

Tools for Fluvial Landscape Management and Restoration: Remote Sensing and Geographical Information Systems (GIS)

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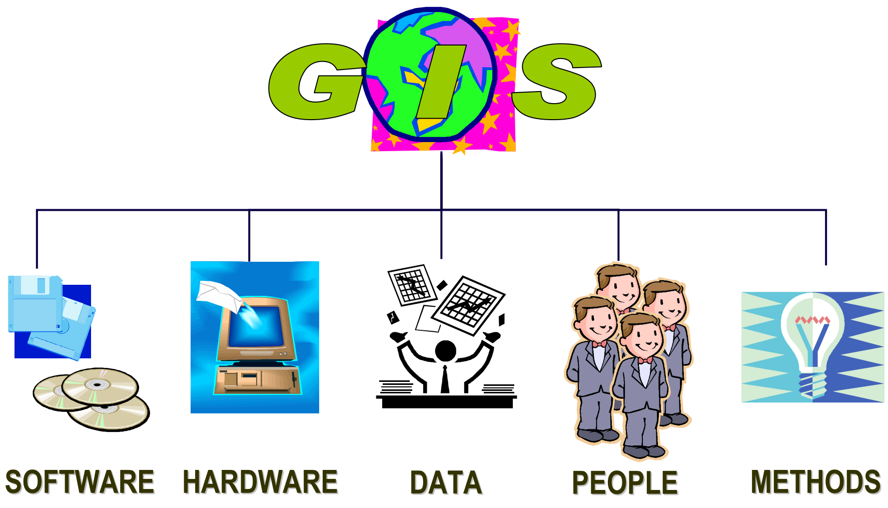
CONTENTS:

1.1. Principles of GIS: Definition

- A GIS is 'a computer system for collecting, checking, integrating and analyzing information related to the surface of the earth' (Rhind, 1988)
- GISs are 'tools that allow for the processing of spatial data into information and used to make decisions about some portion of the earth' (DeMers, 1999). The GIS has the following sub-systems (DeMers, 1999):
  - A **data input subsystem** that collects and pre-process spatial data from various sources.
  - A **data storage and retrieval subsystem** that organizes the spatial data in a manner that allows retrieval, updating and editing.
  - A **data manipulation and analysis subsystem** that performs tasks on the data, estimates parameters and performs modelling functions.
  - A **reporting subsystem** that displays data in tabular, graphic or map form.
- A GIS is neither a CAD (computer assisted drafting) nor a CAC (computer assisted cartography) system.

1.1. Principles of GIS: Components



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1.1. Principles of GIS: Data

- Data are a simplified representation of real world characteristics and phenomena
- There are two possibilities:
  - *Using existing data*:
    - Format (vector *vs* raster; coverage *vs* shapefile, etc.)
    - Precision, accuracy, scale
    - Date
  - *Producing our own data*:
    - Field trip, library trip…
    - Typing, scanning, digitalization…
- Data collection and pre-processing may consume up to 75% of time and budget.

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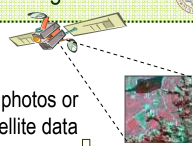
1.1. Principles of GIS: Data

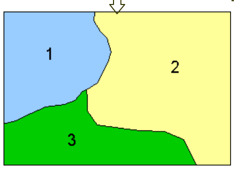


Field data, land surveys, etc.

TRACT	POP1990	AREA
0056	3433	5205890
0057	1775	17330714
001102	1331	13391034
001202	3245	10129278
001302	2839	8228478

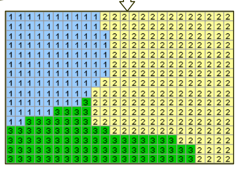
TABLE

Maps (in paper or digital format)



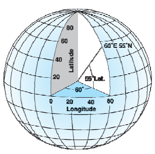
VECTOR LAYER

Air photos or satellite data



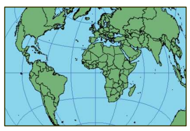
GRID or RASTER LAYER

DATA EDITION AND CORRECTION



GEO-REFERENCE DATA

TRANSFORMATION INTO A COMMON CO-ORDINATE SYSTEM



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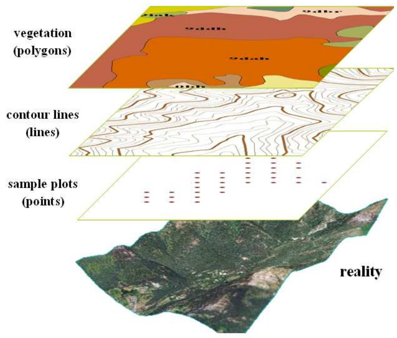
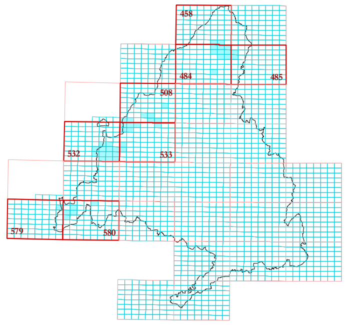
1.1. Principles of GIS: Data

LAYERS



- Each layer represents only one attribute of the territory
- Analyses may be performed on one or more layers

SHEETS



- As traditional maps
- Optimizes data processing
- Requires extra data pre-processing (merge and dissolve processes)

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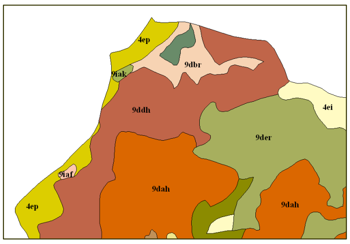
1.1. Principles of GIS: Data structure

- Each data layer contains:
  - **Graphic information** (graphic file or map file)
  - **Alphanumeric information** (table file)
- Both files are linked together: any spatial object within the graphic file is linked to a record in the table file and vice-versa.
- Thanks to this relationship, a GIS can answer questions like '**WHAT?**' or '**WHERE?**'



área (m^2)	perímetro (m)	código vegetación nivel 3	código vegetación nivel 2	código vegetación nivel 1
460150.77	4656.1	4ep	4e	4
748859.21	8187.4	9dbr	9d	9
167127.84	2039.3	9dRf	9d	9
6053815.11	23329.0	9ddh	9d	9
8230568.78	29321.2	9dah	9d	9
51751.30	952.2	9iak	9i	9
624262.93	5067.8	4ei	4e	4
3124381.57	10828.2	9der	9d	9
683817.85	6321.0	4ep	4e	4
3936723.82	14434.3	9dah	9d	9
44259.69	909.2	9iaf	9i	9

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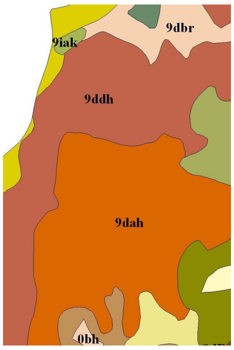
1.1. Principles of GIS: Data models

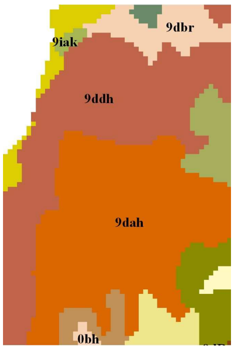
- There are two data models:
  - **Vector data model**: it is made of 'entities' (points, lines, polygons) which are described by their attributes or properties, and whose position is well defined.
  - **Raster data model**: it is the continuous field approach and it is used when the variation of an attribute over the space follows a mathematical function.



Vector data model:

Real world is mapped using three drawing 'entities':

- Points
- Lines
- Polygons



Raster data model:

- real world is divided into homogeneous parcels, usually squared, called 'pixels'
- map scale is related to pixel size
- boundaries or limits are not neatly defined

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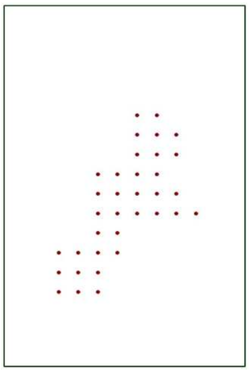
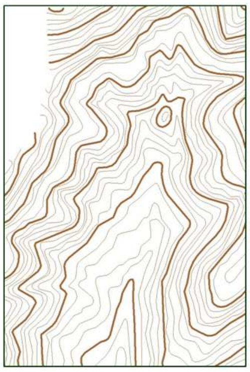
1.1. Principles of GIS: Data models

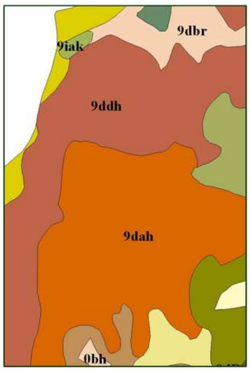
Vector data model: it is made of 'entities' (points, lines, polygons) which are described by their attributes or properties, and whose position is well defined.



Points



Lines



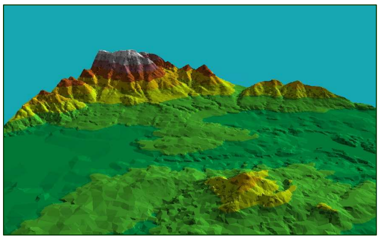
Polygons

1.1. Principles of GIS: Data models

- Opting for a vector or raster/grid data models depends on several factors:
  - Information sources
  - Scientific or technical discipline of the work
  - Phenomenon of interest
    - Most natural phenomena (altitude, temperature, precipitation, etc.) are best defined using the **raster/grid data model**.
    - Most anthropogenic phenomena (houses, land parcels, administrative units, roads, etc.) are best defined using the **vector data model**.
  - Most GISs can process both data models and allow conversions from one into the other.

1.1. Principles of GIS: Digital elevation models

- Digital elevation or digital terrain models (DEM, DTM) represent terrain surface (altitude)
- A x,y,z cloud of points is needed…



3-D view of a digital terrain model

- **In-field methodologies:**
  - Field surveying (total station; terrain laser)
  - Field surveying with **GPS**
  - Airplane laser (**LiDAR**)
  - ✓ **Advantages**: high accuracy
  - × **Disadvantages**: field surveys are expensive and time-consuming
- **Not direct methodologies**:
  - Photogrametric flight (automatic correlation)
  - Satellite images: SPOT, SAR.
  - Existing contour line maps
  - ✓ **Advantages**: not field work is needed → cheaper and faster
  - × **Disadvantages** : less accurate (except for restitution)

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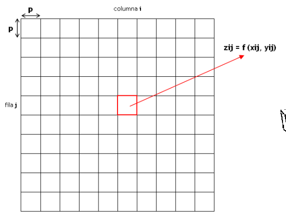
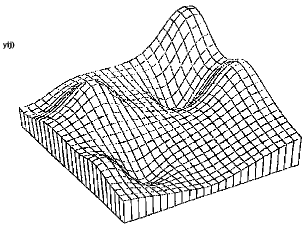
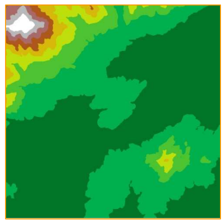
1.1. Principles of GIS: Digital elevation models

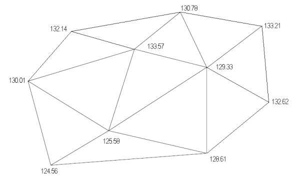
- Digital elevation or digital terrain models (DEM, DTM) represent terrain surface (altitude)



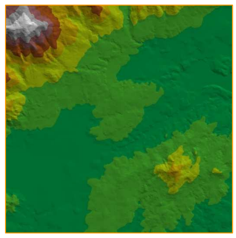
Regular grid







TIN (triangulated irregular network)



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1.1. Principles of GIS: Applications

- What kind of questions can be solved using a GIS?:
  - **IDENTIFICATION**: what is this…?
  - **CONDITION**: where does it happen that…?
  - **CHANGE DETECTION**: what have it changed…?
  - **PATH**: what is the best route…?
  - **PATTERNS**: what is the spatial pattern…?
  - **MODELING**: what would it happen if…?

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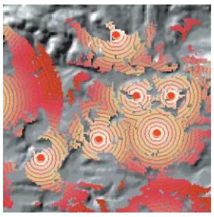
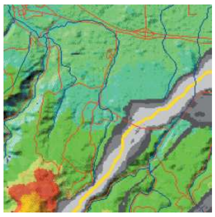
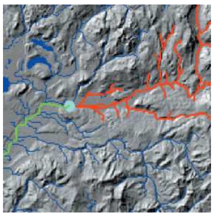
1.1. Principles of GIS: Applications



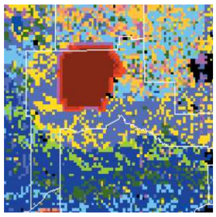
A telecommunication company is finding new locations for mobile phone antennae



A pipeline company is finding the least cost path for a new pipeline



A water resources manager traces upstream to find possible sources of contaminants



A fire fighting team predicts the spread of a forest fire using terrain and weather data

An environmental study analyzes the impact of a new infrastructure (road)

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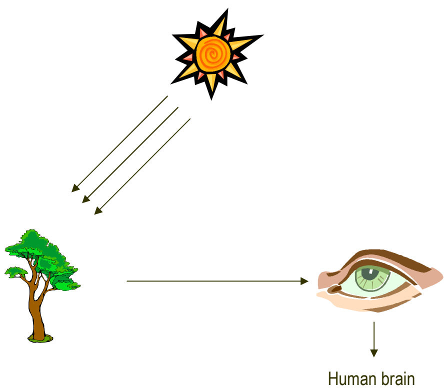
1.2. Principles of Remote Sensing: Definition

- Remote sensing is the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation (Lillesand & Kiefer, 1999).



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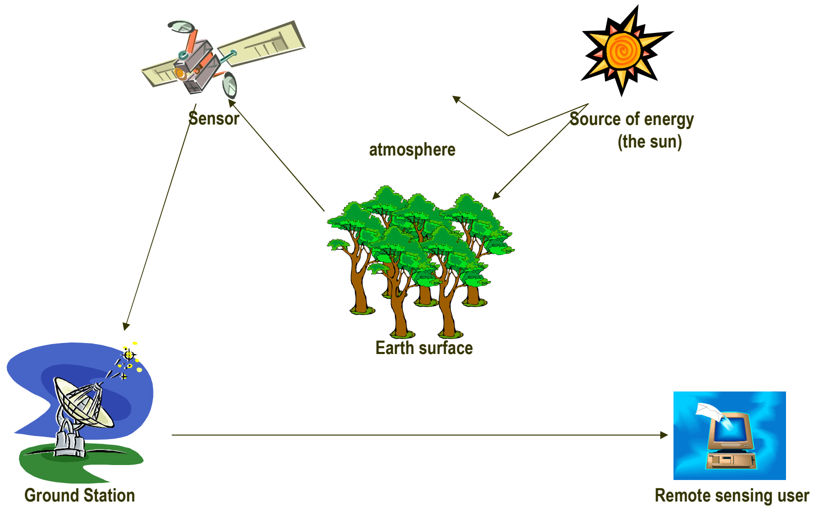
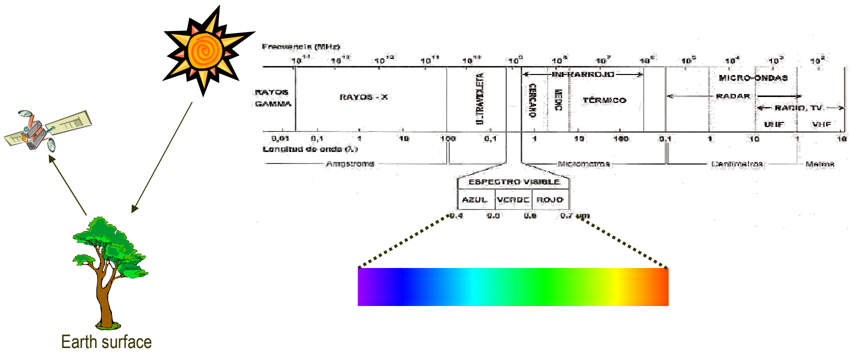
1.2. Principles of Remote Sensing: Components



1.2. Principles of Remote Sensing: Energy & the Electromagnetic spectrum

- Energy (emitted by the sun or recorded by the sensor) is always characterized by its **wavelength** or by its **frequency**. Used energy in remote sensing systems:
  - **Visible** range: 0.4 to 0.7μm
  - **Infrared** range (near, shortwave, thermal): 0.7 to >100 μm
  - **Microwave** or **RADAR** range: 0.1cm to 1m



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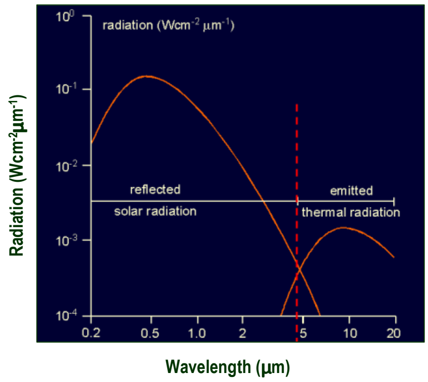
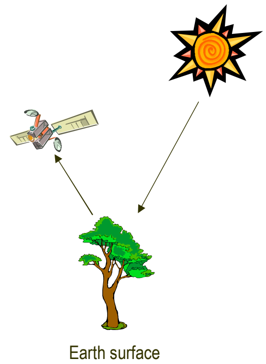
1.2. Principles of Remote Sensing: more about Energy…

- The **amount of energy** coming from an object (e.g. the sun, the earth… or myself!) depends on its **temperature** and it may be expressed as a function of its **wavelength**.
- Energy coming from the earth surface (and recorded at sensor level) is either 'reflected solar radiation' or 'emitted thermal radiation'.





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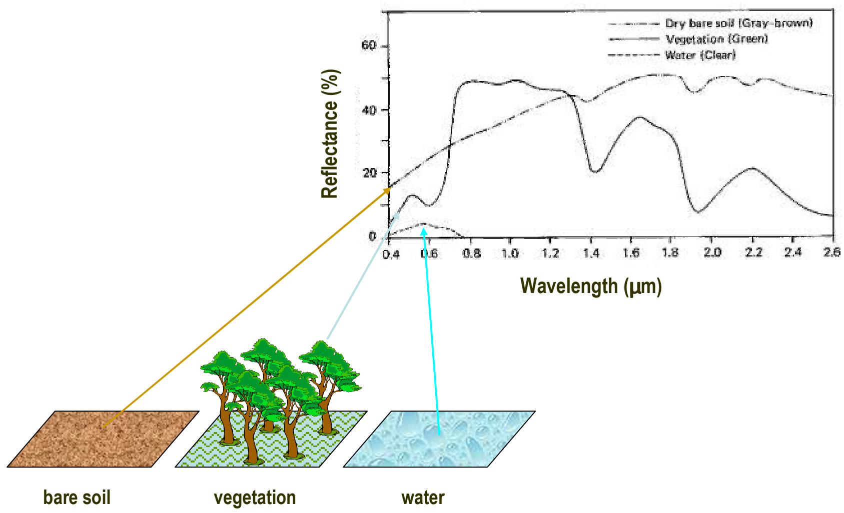
1.2. Principles of Remote Sensing: more about Energy…

- Energy coming from different objects presents different patterns: **spectral signature**



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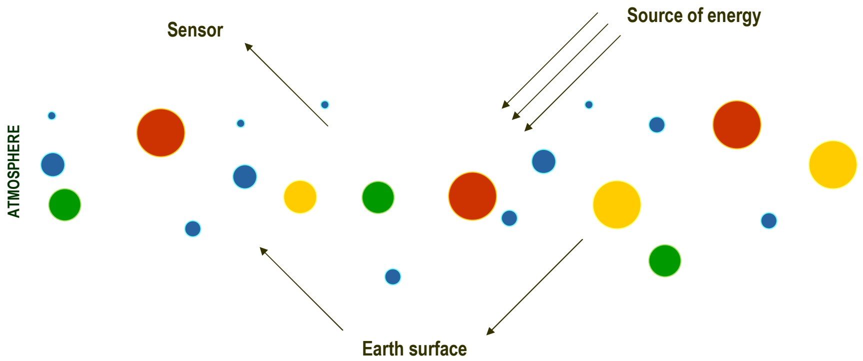
1.2. Principles of Remote Sensing: more about Energy…

- Energy traveling from the sun to the earth surface and then, from the earth surface to the sensor, goes through the atmosphere suffering from different phenomenon: **dispersion**, **absorption** and **emission**.
- Such phenomenon are rather complex and highly variable in time and space. In some cases we will have to correct images from these effects.



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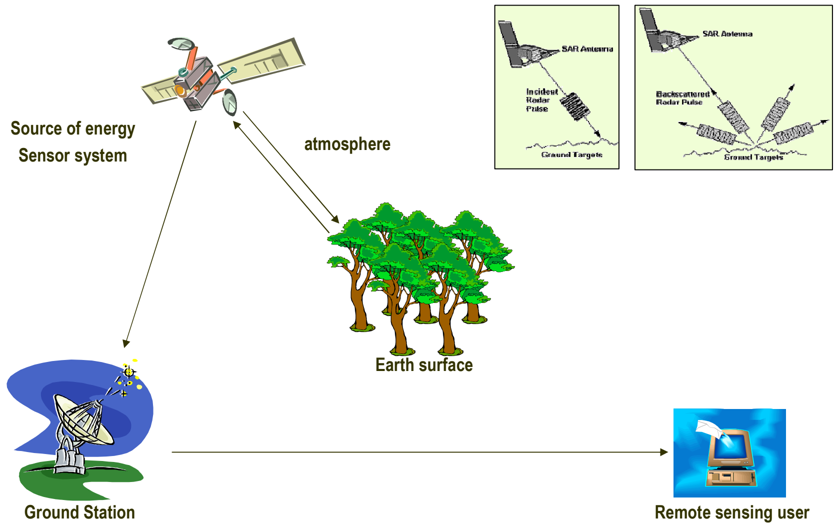
1.2. Principles of Remote Sensing: Active Remote Sensing Systems



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1.2. Principles of Remote Sensing: Active Remote Sensing Systems

- **RADAR**: Radio Detection and Ranging
- RADAR systems for image production: SLAR and SAR
- Main characteristics:
    - RADAR systems are active systems:
        - RADAR systems are day-night independent
        - RADAR systems are used defined
    - Energy in RADAR wavelengths is un-correlated with energy in other parts of the spectrum
    - RADAR energy may go through cloud cover (It is almost weather independent), canopy cover or even soil.
    - Image processing is very complex.
    - SAR data is used for high-quality Digital Terrain Model (DTM) development using different techniques (SAR, InSAR, DInSAR).

Gibraltar (between Spain and Africa)

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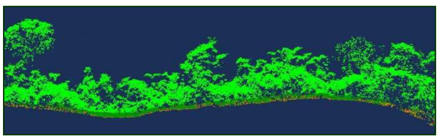
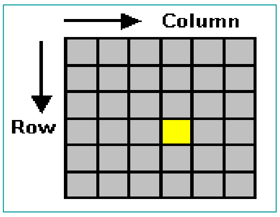
1.2. Principles of Remote Sensing: Active Remote Sensing Systems

- **LiDAR**: Light Detection and Ranging
- Uses variable wavelengths (shorter than RADAR)
- Main characteristics:
    - Laser pulses:
        - Sub-meter planimetric resolution
        - Centimeter altimetric resolution
    - LiDAR data is mainly used for Digital Terrain Model (DTM) development.
    - LiDAR data is highly adequate for morphologic applications (e.g. geo-morphologic applications).
    - LiDAR data processing is quite complex.



1.2. Principles of Remote Sensing: Digital image

- The **digital image** is the way to store most of the remotely-sensed data:
  - It is a matrix of pixels
  - Each pixel is filled with a value which represents energy
  - Each pixel is located in space (column-row system)
- The **digital image** is characterized by its **resolution**. Image resolution involved four aspects:
  - Spatial resolution
  - Spectral resolution
  - Temporal resolution
  - Radiometric resolution



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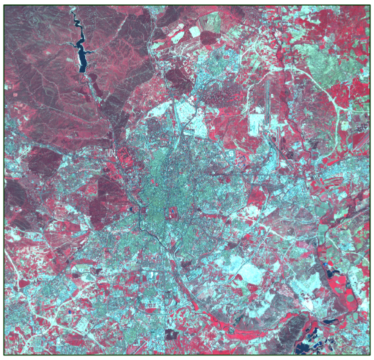
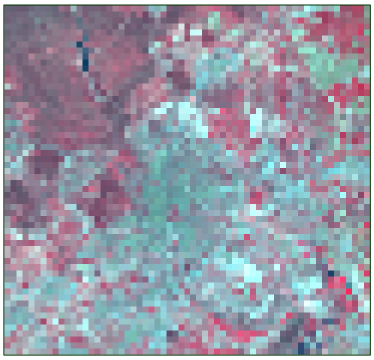
1.2. Principles of Remote Sensing: Digital image

- **Spatial resolution** is related to the minimum detail that one can see in an image. It may also be defined as 'pixel size'.



Landsat - TM
30m spatial resolution



Terra - MODIS
500m spatial resolution

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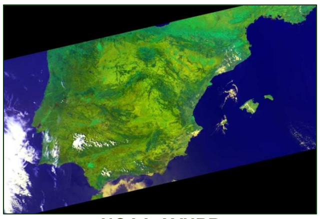
1.2. Principles of Remote Sensing: Digital image

- **Spatial resolution** classifies sensors:

- low spatial resolution sensors:	NOAA-AVHRR → 1.1km
- medium spatial resolution sensors:	Terra/Aqua-MODIS* → 250, 500,1 000m
	Envisat-MERIS* → 300, 1200m
- high spatial resolution sensors:	Landsat-TM/ETM+ → 30, 15m
	SPOT-HRG → 5, 10m
- very high spatial resolution sensors:	IKONOS → 1, 4m
	QuickBird → 0.70, 2.80m
- variable spatial resolution sensors:	on board planes



NOAA-AVHRR

QuickBird

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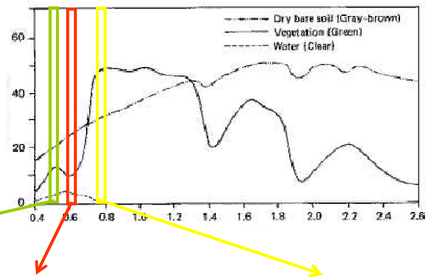
1.2. Principles of Remote Sensing: Digital image

- **Spectral resolution** is related to the number, situation and width of the available bands.



Green band

Red band

Near-infrared band

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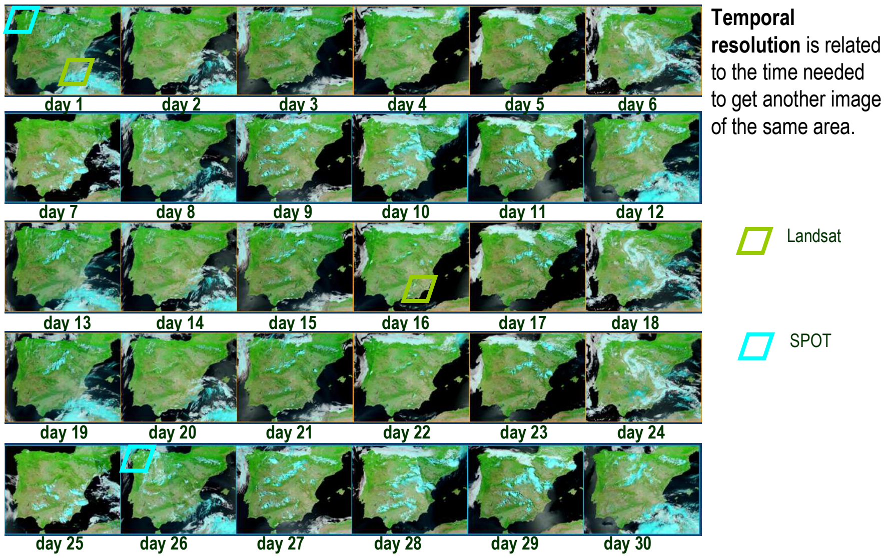
1.2. Principles of Remote Sensing: Digital image



Temporal resolution is related to the time needed to get another image of the same area.

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1.2. Principles of Remote Sensing: Digital image

- **Image resolution** is trade-off between its different resolutions… no system can produce an image with high spatial, spectral and temporal resolutions at the same time.

Source: NASA

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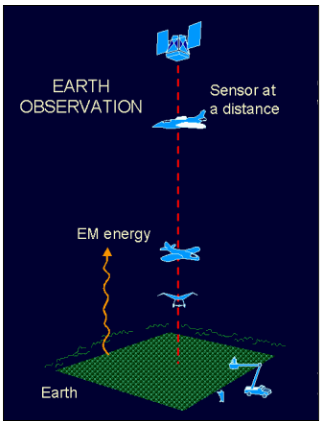
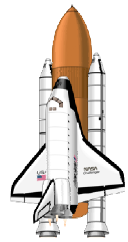
1.2. Principles of Remote Sensing: Sensors and Systems

- **Remote sensing** is carried out using different types of sensors (passive or active). Sensors go onboard different types of systems:
  - Satellites
  - Space shuttles
  - Airplanes
  - Terrestrial systems





Space shuttle (NASA)

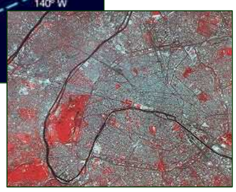
Avioncar (INTA-Spain)

RESTORATION OF FLUVIAL ECOSYSTEMS – Course ATHENS

1.2. Principles of Remote Sensing: Sensors and Systems

- **Satellites** are classified into two groups: **geo-stationary** (orbits are 35.000km above earth surface) and **polar** (orbits are 600-900km above earth surface).

METEOSAT - MSG
- High temporal resolution
- Low spatial resolution

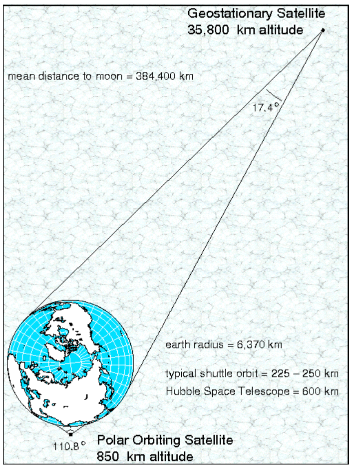


SPOT - HRG
- Low temporal resolution
- High spatial resolution

RESTORATION OF FLUVIAL ECOSYSTEMS – Course ATHENS

1.2. Principles of Remote Sensing: Sensors and Systems

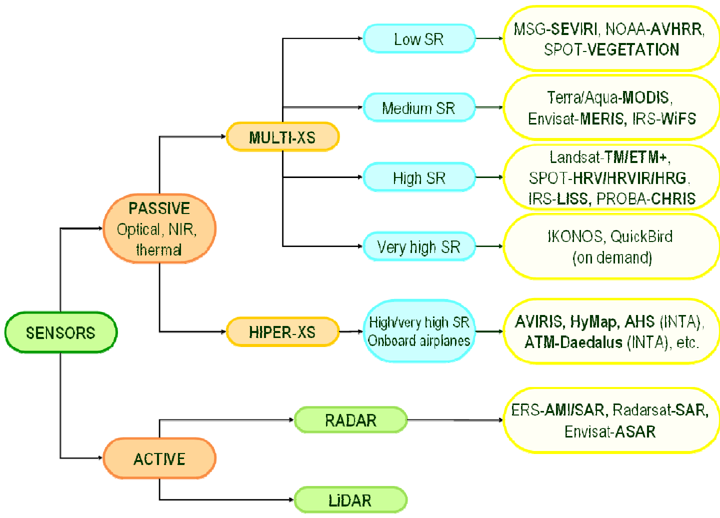
- **Satellites** are classified into two groups: **geo-stationary** (orbits are 35.000km above earth surface) and **polar** (orbits are 600-900km above earth surface).



RESTORATION OF FLUVIAL ECOSYSTEMS – Course ATHENS

1.2. Principles of Remote Sensing: Sensors and Systems

- **Sensors** may be classified as a function of their spatial resolution and spectral resolution



1.2. Principles of Remote Sensing: Remote Sensing advantages

- Wide, global and periodic coverage of earth surface.
- Quantitative measurement of any object or phenomena being studied.
- Digital format that allows automatic (or semi-automatic) pre-processing, processing and analysis.
- Information on non-visible regions of the spectrum (infrared, microwave).
- Low cost per unit area.
- Updated information about the earth surface properties or phenomena (real time or near-real time).

1.2. Principles of Remote Sensing: Remote Sensing and Hydrology

- There are some of the variables or fluvial properties that may estimated or studied using remote sensing data and techniques:
  - River geo-morphology (shape, thalweg profile, etc.).
  - Soil moisture.
  - Surface run-off.
  - Riparian vegetation (composition, status, delineation, etc.).
  - Wetlands (status, delineation, etc.).
  - Flooding areas (floodplain delineation, erosion and sedimentation mapping).
  - Water quality (reservoirs).
  - **Fluvial Landscape Management and Restoration**.

RESTORATION OF FLUVIAL ECOSYSTEMS – Course ATHENS

2.1. USLE application using remote sensing data and GIS techniques

- USLE (Universal Soil Loss Equation): is a function of several variables that should be managed using a GIS. Some of the variables may be estimated using remote sensing data (updated information):

$$A = R \cdot K \cdot LS \cdot C \cdot P$$

A = annual soil loss (tones per area per year)

R = rainfall and runoff factor (erosion potential term)

K = soil erodibility factor (texture, structure, organic matte, permeability)

LS = slope length gradient factor

C = crop-vegetation and management factor

P = support practice factor

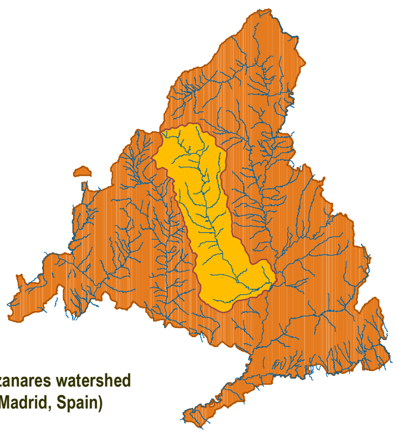
- Case study: River Manzanares (Madrid, Spain)

Tools for Fluvial Landscape Management and Restoration: Remote Sensing and GIS

RESTORATION OF FLUVIAL ECOSYSTEMS – Course ATHENS

2.1. USLE application using remote sensing data and GIS techniques

- Study case: Manzanares watershed (Madrid, Spain)

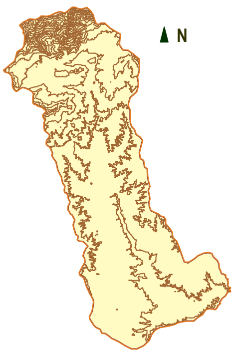


Manzanares watershed (Madrid, Spain)

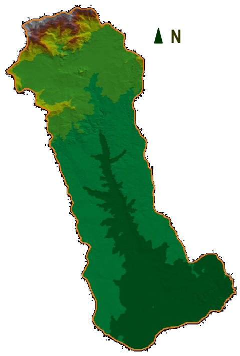
Tools for Fluvial Landscape Management and Restoration: Remote Sensing and GIS

2.1. USLE application using remote sensing data and GIS techniques

- A contour line map may be used for DTM derivation. This is also possible using remote sensing data (SAR images, LiDAR data, optical images).



Contour line map



TIN (triangulated irregular network)

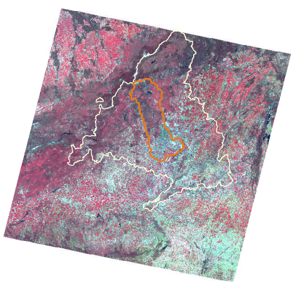
DTM (digital terrain model)

RESTORATION OF FLUVIAL ECOSYSTEMS – Course ATHENS

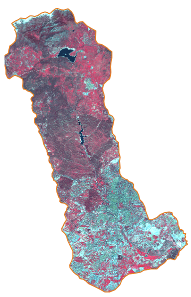
Tools for Fluvial Landscape Management and Restoration: Remote Sensing and GIS

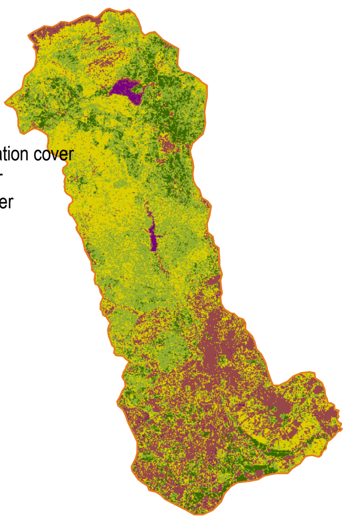
2.1. USLE application using remote sensing data and GIS techniques

- A satellite image may be used for C factor estimation



Landsat TM – 30m spatial resolution





Tools for Fluvial Landscape Management and Restoration: Remote Sensing and GIS

RESTORATION OF FLUVIAL ECOSYSTEMS – Course ATHENS

2.2. Analysis of channel change in a spatial and temporal context – River Oja (La Rioja, Spain)

- Analysis of the different impacts

channel

Hydraulic public domain invasion

16 – 20 March, 2009 silvia.merino@upm.es 41

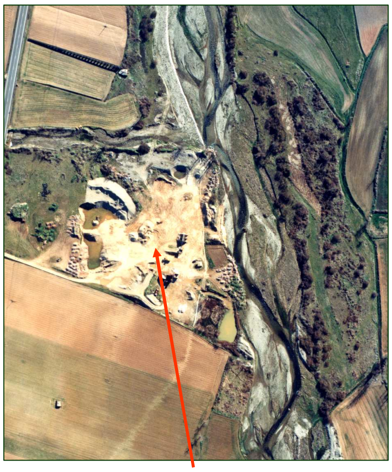
Tools for Fluvial Landscape Management and Restoration: Remote Sensing and GIS

RESTORATION OF FLUVIAL ECOSYSTEMS – Course ATHENS

2.2. Analysis of channel change in a spatial and temporal context – River Oja (La Rioja, Spain)

- Analysis of different impacts

levees



Hydraulic public domain invasion

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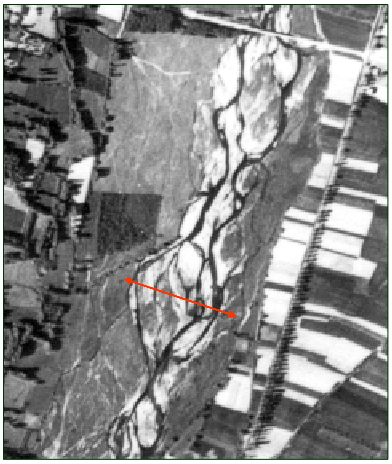
2.2. Analysis of channel change in a spatial and temporal context – River Oja (La Rioja, Spain)

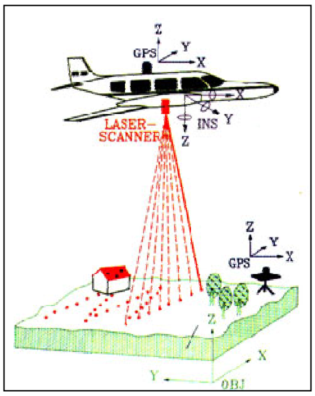
- Comparison 1957 - 1999



Active channel

2.3. LiDAR application in fluvial environments – River Ebro (Aragón, Spain)

- LiDAR systems transmit a series of laser pulses from aerial or terrestrial sensors and record returned signals. A precise measure of the **time** used by the laser pulse in reaching certain object and coming back to the sensor, is used to accurately locate the position corresponding to any single measurement, provided that the position of the sensor in space is well-known. Such technology produces **3-dimensional coordinates** in the same way that land surveying does.
- LiDAR systems are an active remote sensing technology what allows working quite independently of illumination and atmospheric conditions. LiDAR data analysis allows the production of digital terrain models (DTM), digital elevation models (DEM) and other intermediate models.



LiDAR sensor
(Source: NOAA)

Tools for Fluvial Landscape Management and Restoration: Remote Sensing and GIS

RESTORATION OF FLUVIAL ECOSYSTEMS – Course ATHENS

2.3. LiDAR application in fluvial environments – River Ebro (Aragón, Spain)

LiDAR applications in fluvial systems management involved the following:

1.riparian vegetation composition and structure analysis,

2.riverbed geomorphology study (slope, morphometric complexity, roughness, wetted width, thalweg depth, etc.),

3.anthropogenic alterations and disturbances analysis,

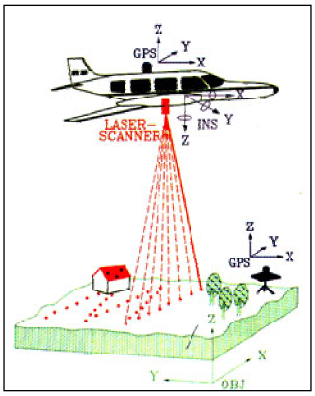
4.channel-riparian interactions analysis,

5.hydrologic and sedimentation modelling,

6.development of indicators for stream ecological state assessment,

7.determination of biological processes in fluvial environments, and

8.drainage network development.



LiDAR sensor
(Source: NOAA)

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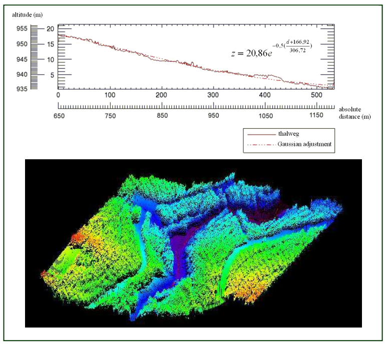
Tools for Fluvial Landscape Management and Restoration: Remote Sensing and GIS

RESTORATION OF FLUVIAL ECOSYSTEMS – Course ATHENS

2.3. LiDAR application in fluvial environments – River Ebro (Aragón, Spain)

- LiDAR applications in the characterization and management of fluvial environments:
  - **Thalweg profile** determination → stream properties such as gradient, hydraulic power and sediment transportation.



Source: Magdaleno & Martínez, 2006. Ingeniería Civil 142: 29-43.

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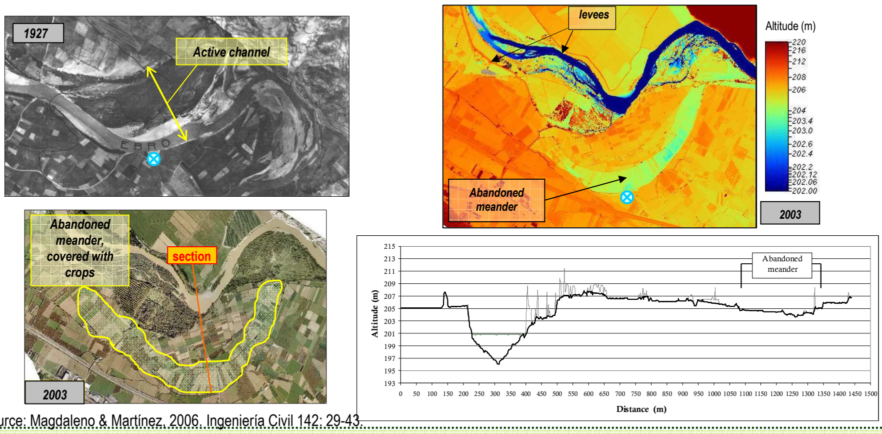
RESTORATION OF FLUVIAL ECOSYSTEMS – Course ATHENS

2.3. LiDAR application in fluvial environments – River Ebro (Aragón, Spain)

- LiDAR applications in the characterization and management of fluvial environments:
  - Fluvial **micro-topography** analysis → influences water balance, riverbed hydromorphologic equilibrium, erosion-sedimentation processes (detailed assessments on the accumulation of sediment bars and islands, deep erosion processes, etc.)



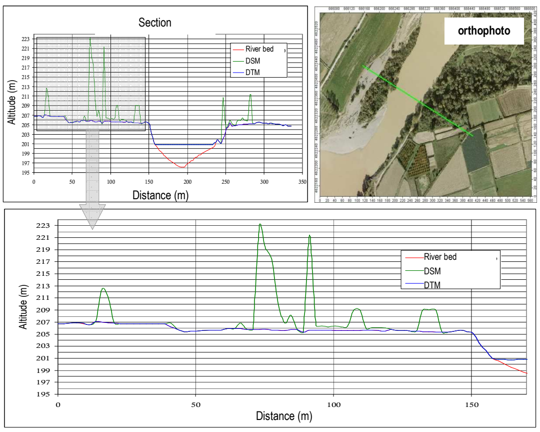
Source: Magdaleno & Martínez, 2006. Ingeniería Civil 142: 29-43.

Tools for Fluvial Landscape Management and Restoration: Remote Sensing and GIS

RESTORATION OF FLUVIAL ECOSYSTEMS – Course ATHENS

2.3. LiDAR application in fluvial environments – River Ebro (Aragón, Spain)

- Riparian vegetation analysis: detailed geomorphology maps (phreatic character), species composition (morphometric criteria), ecological characterization (shading of streams), management of forest plantations in floodplains, etc.



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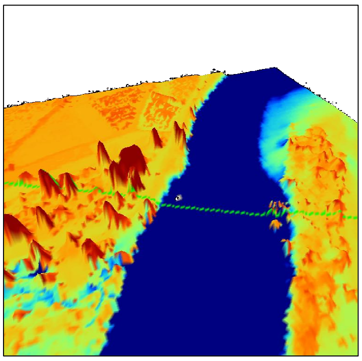
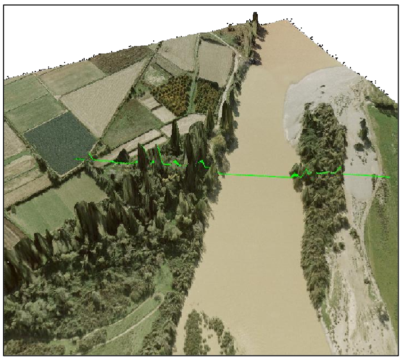


Volumes and shapes

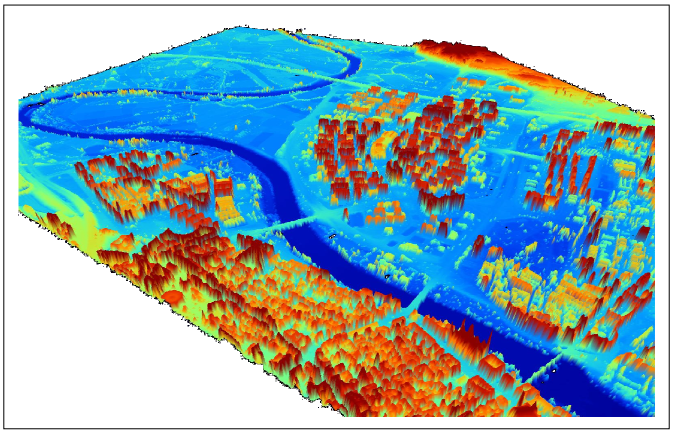


Volumes and shapes + orthophoto

Source: Magdaleno & Martínez, 2006. Ingeniería Civil 142: 29-43.

2.3. LiDAR application in fluvial environments – River Ebro (Aragón, Spain)

- Urban fluvial areas and human infrastructures



Digital terrain model for the Ebro River in Zaragoza (Spain)

Source: Magdaleno & Martínez, 2006. Ingeniería Civil 142: 29-43.