Imperial College London

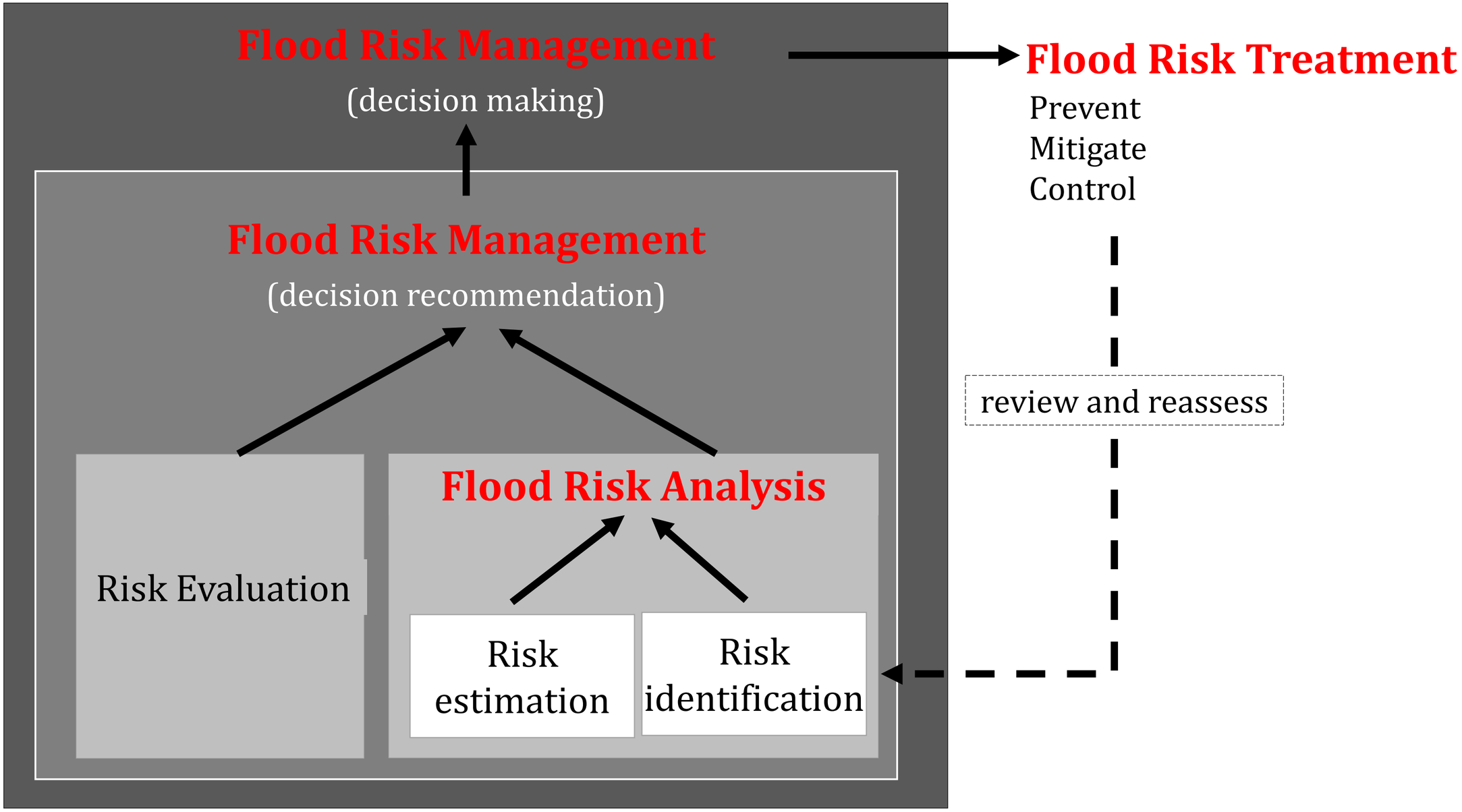
Detecting Flood Embankment Deterioration and Future Projection

Ahmad Agus Widodo
PhD Student in Geotechnics Sections

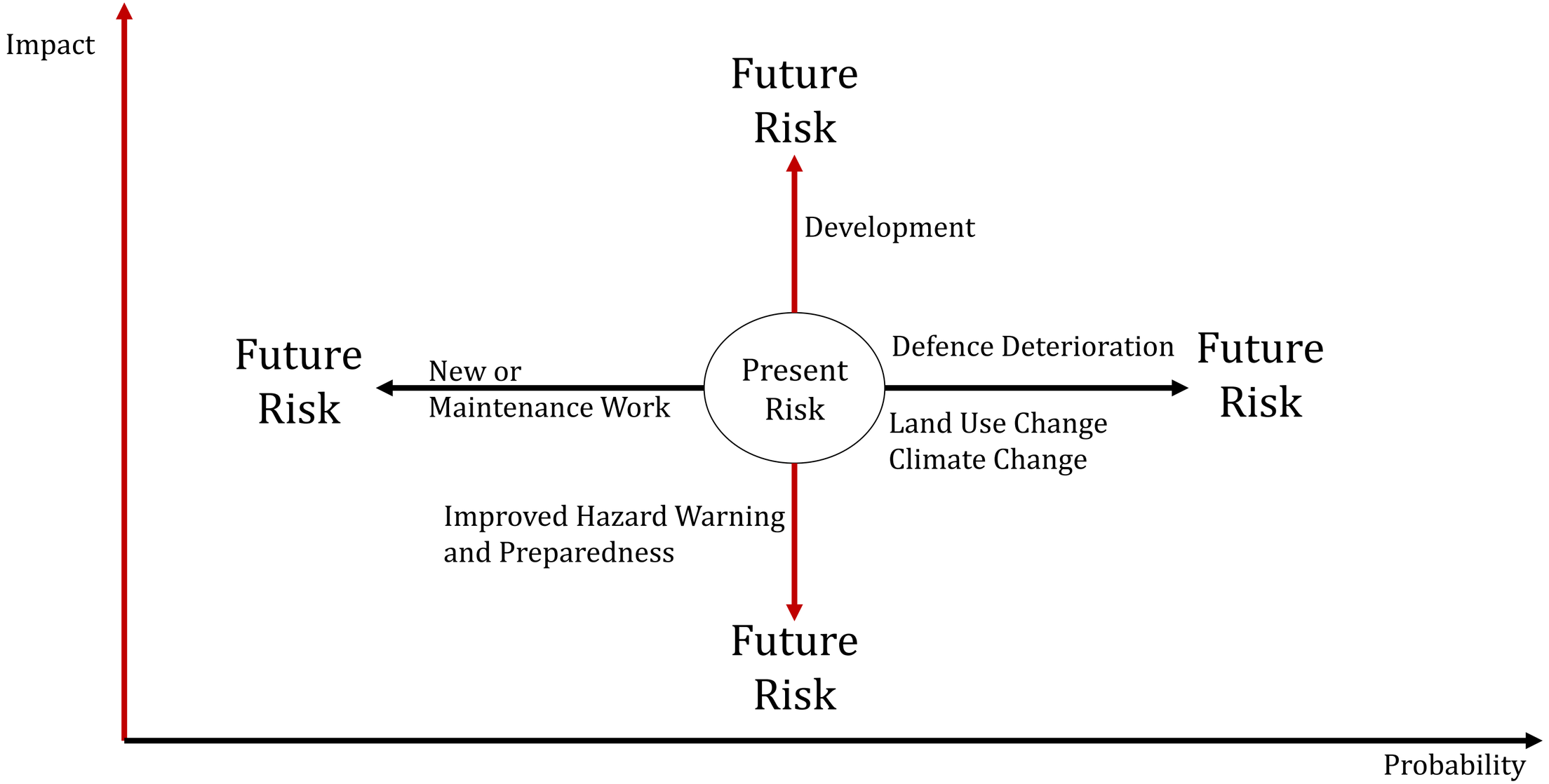
Supervisors:
1. Dr Truong Le (Geotechnic Sections)
2. Dr Philippa J Mason (Royal School of Mines)

This PhD is funded by Indonesian Endowment Funds for Education (LPDP)

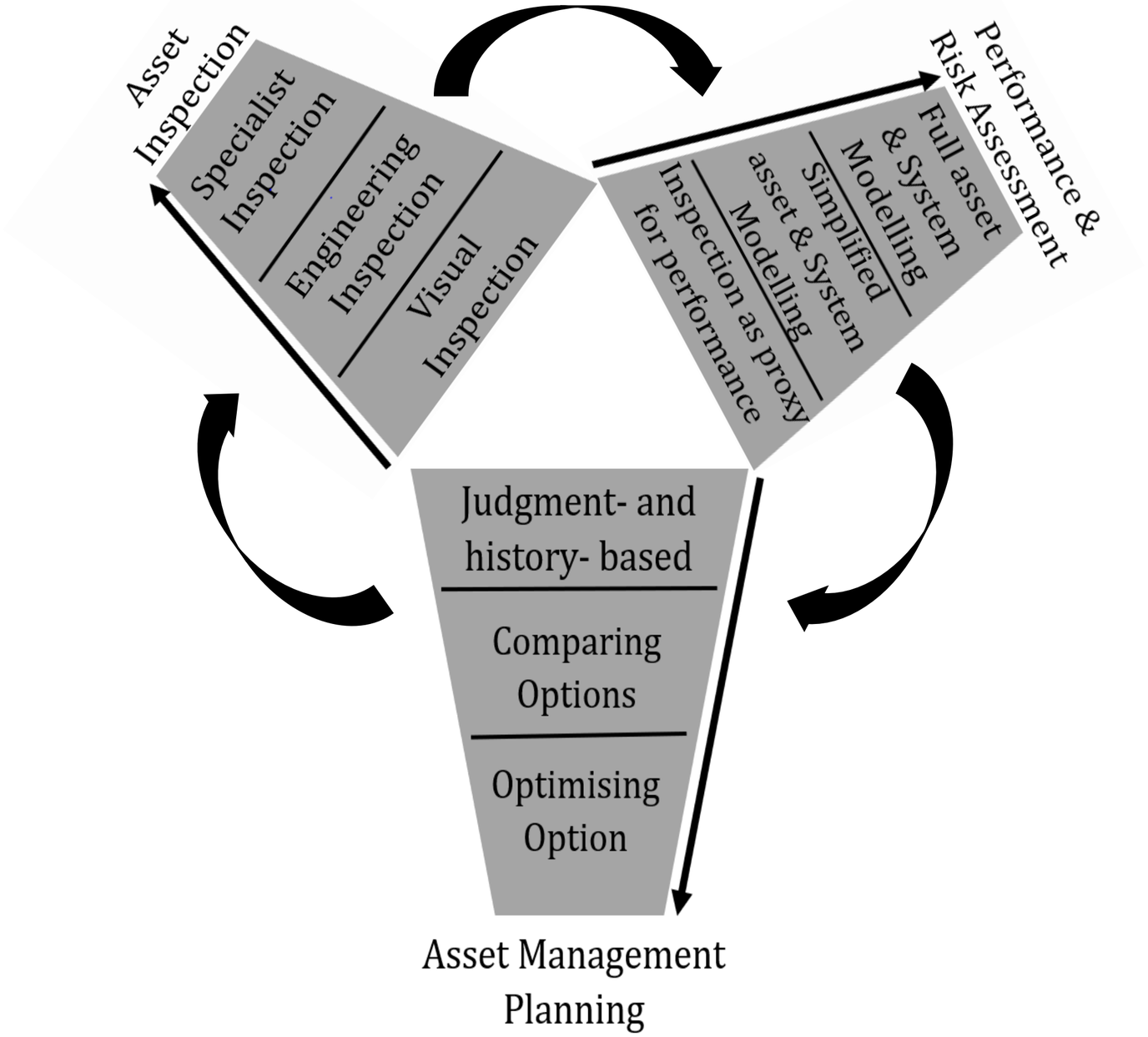
Outline


Flood Risk Management
(decision making)
Flood Risk Management
(decision recommendation)
Risk Evaluation
Flood Risk Analysis
Risk estimation
Risk identification
Flood Risk Treatment
Prevent
Mitigate
Control
review and reassess

Outline


Impact
Future Risk
Development
Future Risk
New or Maintenance Work
Present Risk
Defence Deterioration
Land Use Change
Climate Change
Future Risk
Improved Hazard Warning and Preparedness
Future Risk
Probability

Example approach of flood defense asset management



Flood Disaster

Flooding is defined as the temporary presence of surface water, on or near an embankment, and as the most frequent and widespread natural disaster in the world and typically destructive (1).

Key Point

*"Globally, during 2000 – 2019, **rapid urbanisation** increased potential of disaster susceptibility, and extreme weather events have caused thousands reported disasters, **many of fatalities**, and continue to cause billions of dollars of direct **economic loss**. And under the background of global warming, such losses will continue to increase in the future."*

Flood Data (2000 – 2019) compared to other types of disasters

1st Floods are the most common type of disasters, accounted for around 3254 (44%) of total events.

1st The type of disasters that affecting 1.6 billion people worldwide or around 41% of total affected population.

3rd It accounted around 636 billion US$ (21%) economic losses.

4th One of the deadliest disasters with at around 104.614 fatalities.

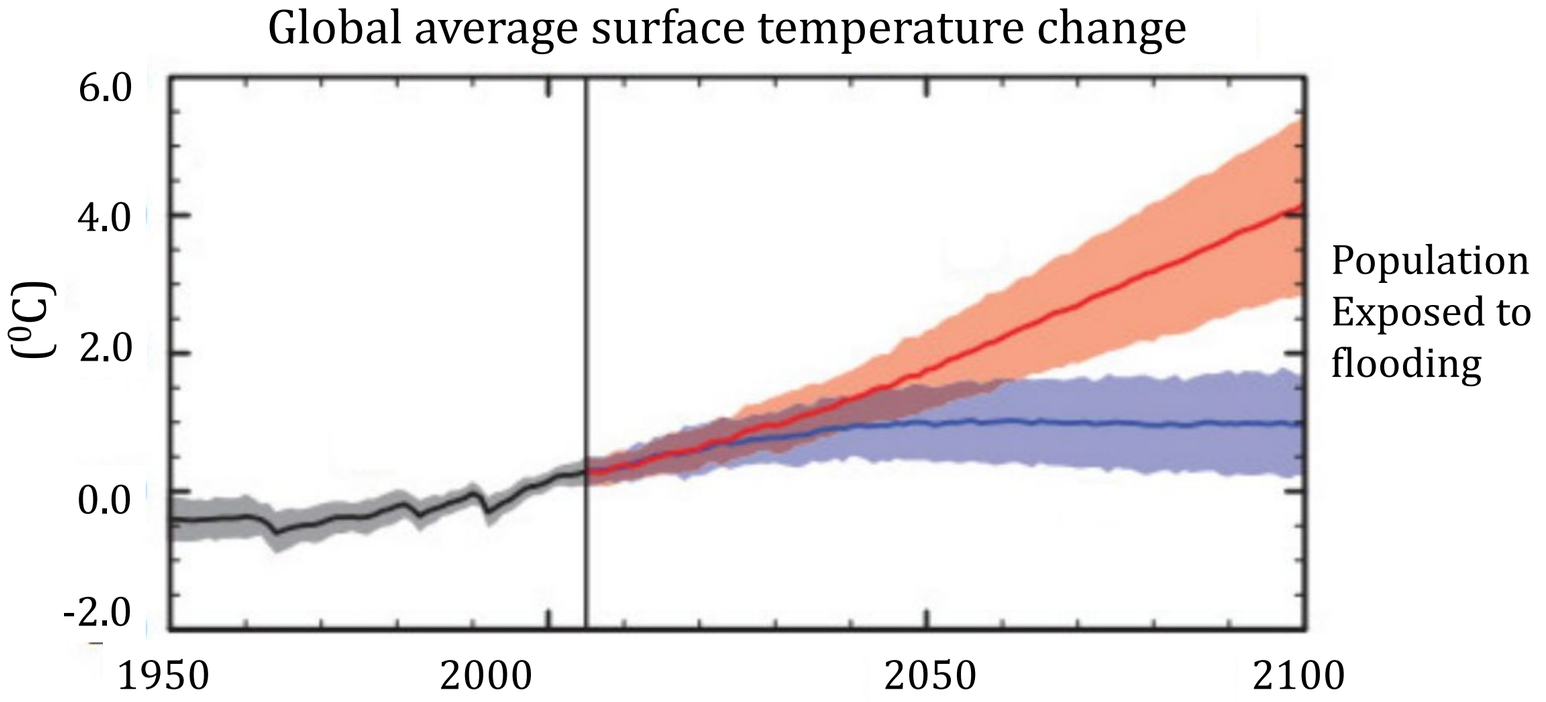
Source:

[1] Iqbal et al. (2021), [2] Centre for Research on the Epidemiology of Disasters (CRED), United Nations Office for Disaster Risk Reduction

Flood under Climate Scenario

Key Point

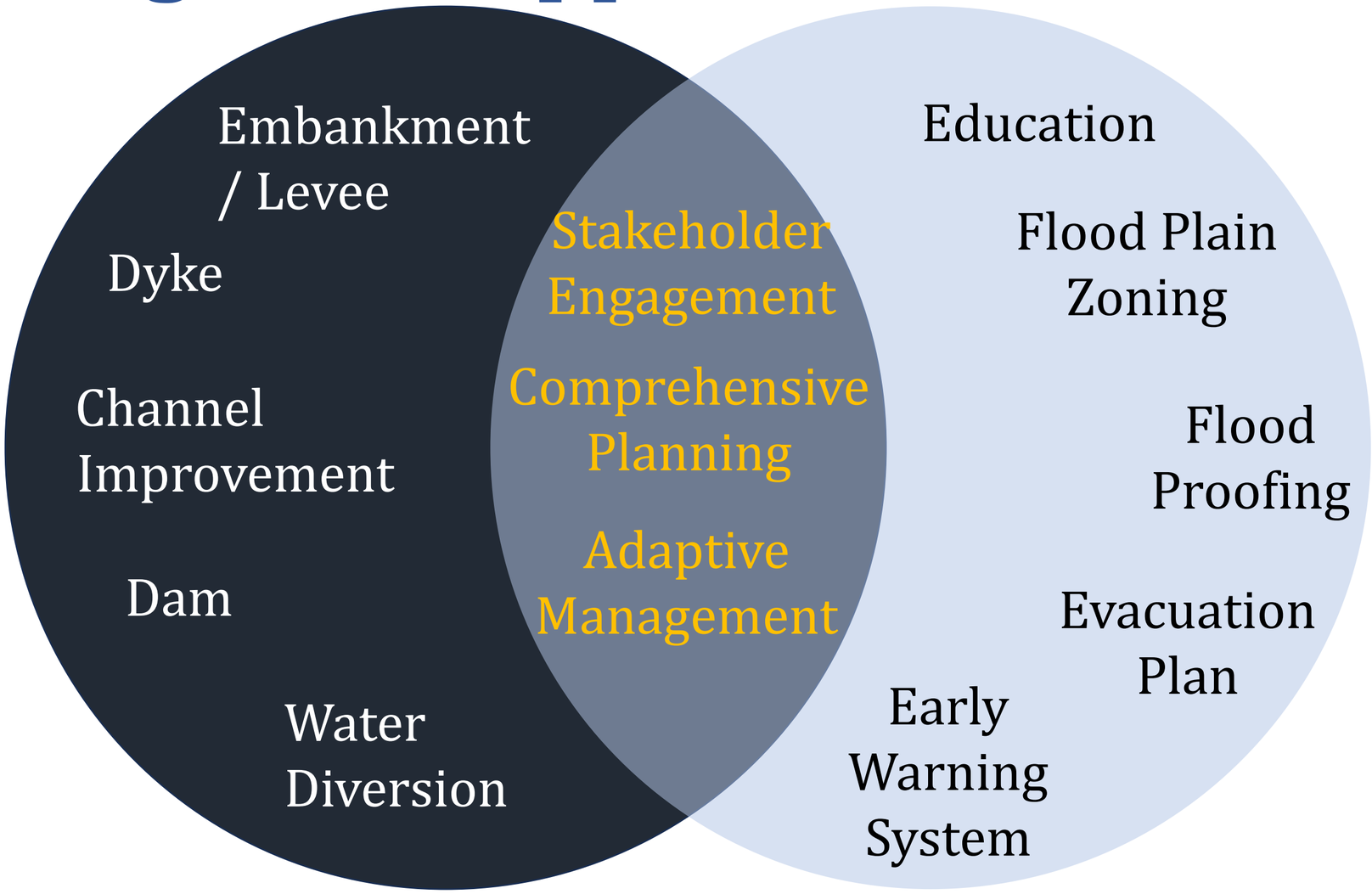
Better flood control, including prediction and monitoring, *is one of the possible solutions in DRR policy terms since affordable and effective technologies already exist.*
The priority should be given to ***cost-effective measures*** *in poor regions at high risk of recurrent flooding.*



- People living in **coastal cities and riverine areas** are considered among the most vulnerable to sea level rise, storm surges, and coastal flooding.
- **Global warming** is estimated to increase the frequency of potentially high impact natural hazard events across the world.

Source: Centre for Research on the Epidemiology of Disasters (CRED), United Nations Office for Disaster Risk Reduction

Flood Management Approach



Structural Approach

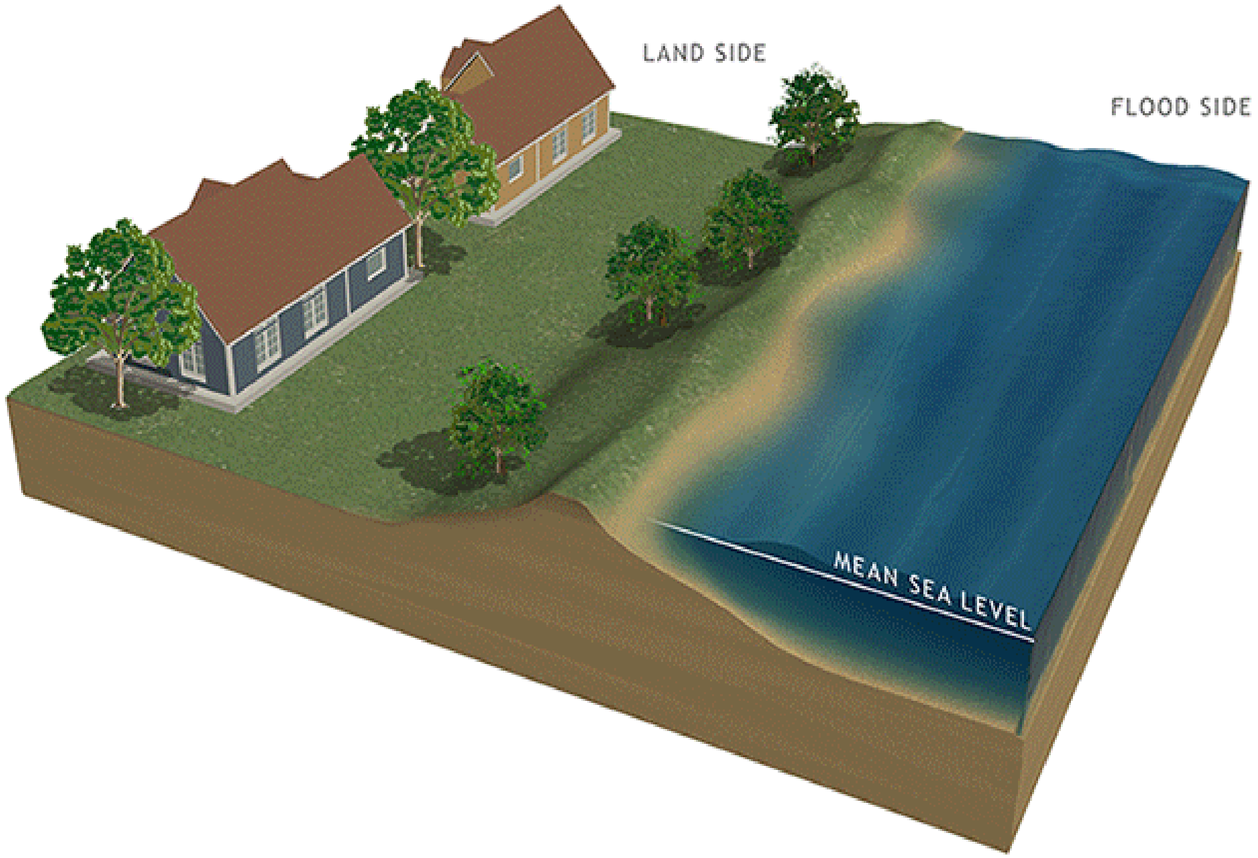
Non-structural Approach

Integrated Flood Management

Source: Allsop et al. (2009)

Structural Approach : Levee / Embankment

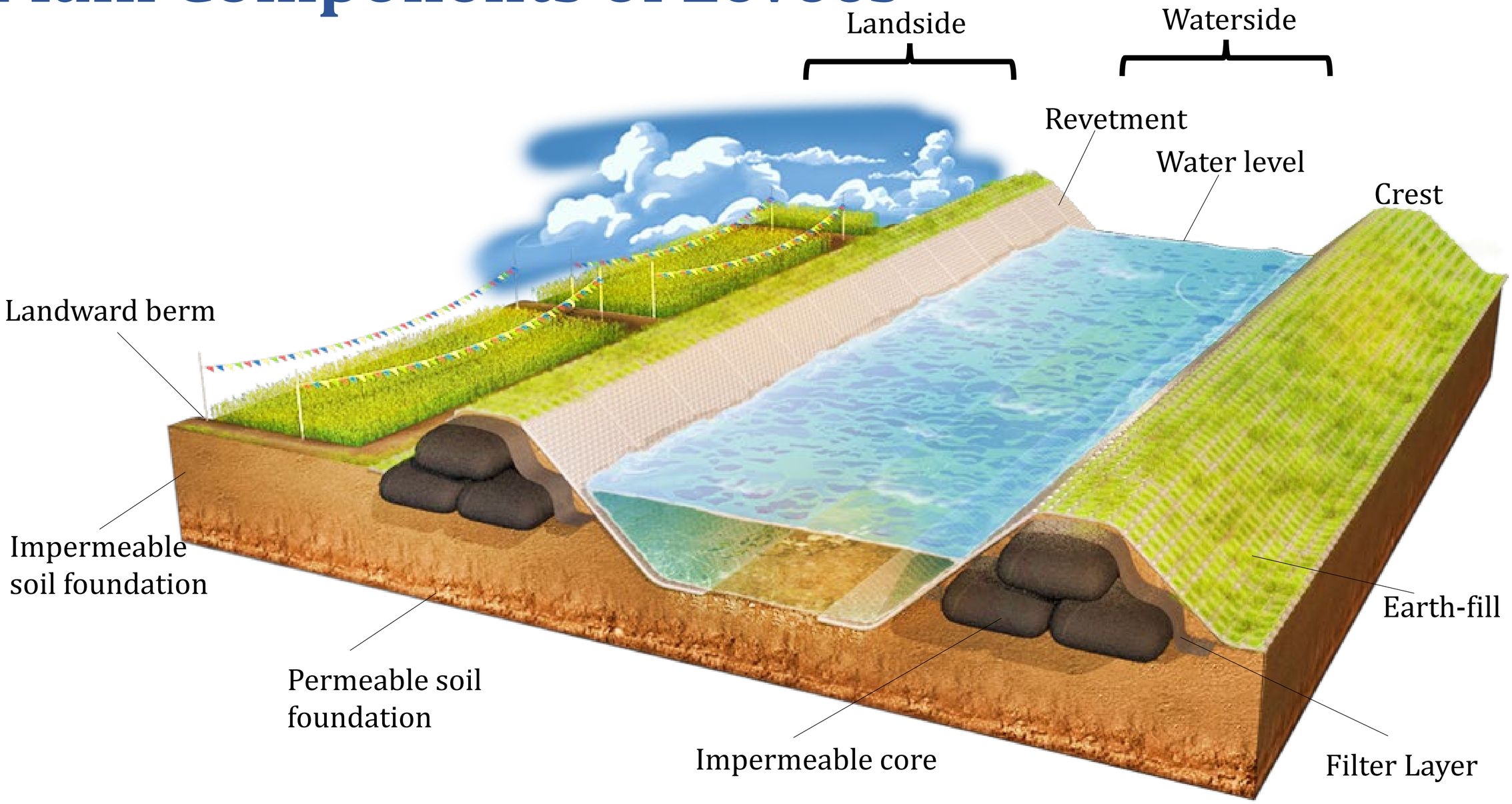
- Levees are raised, predominantly earth, structures that are not reshaped under normal conditions by the action of waves and currents.
- Primary objective is to provide **protection** against fluvial and coastal flood events along coasts, rivers and artificial waterways.
- Unlike engineered structures, levees can be **irregular in the standard** and nature of their construction and **can deteriorate** markedly over time if they are not well maintained.



Source: The International Levee Handbook

Source: adapted from nad.usace.army.mil

Main Components of Levees

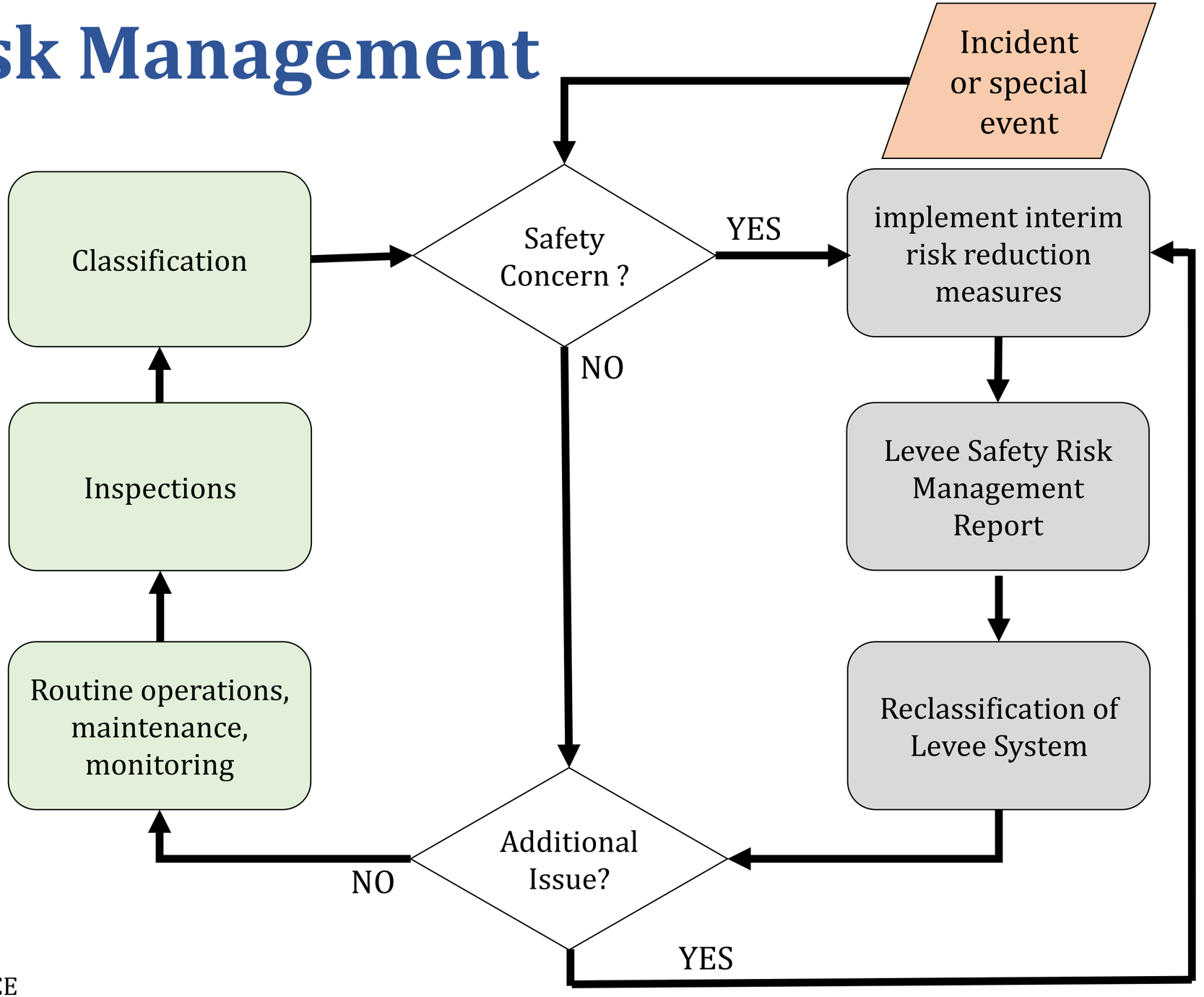


Source: adapted from https://www.geoace.com/app/Riverbank-and-Channel-Protection/Levees-and-Dikes

Levee Safety Risk Management

Key Point

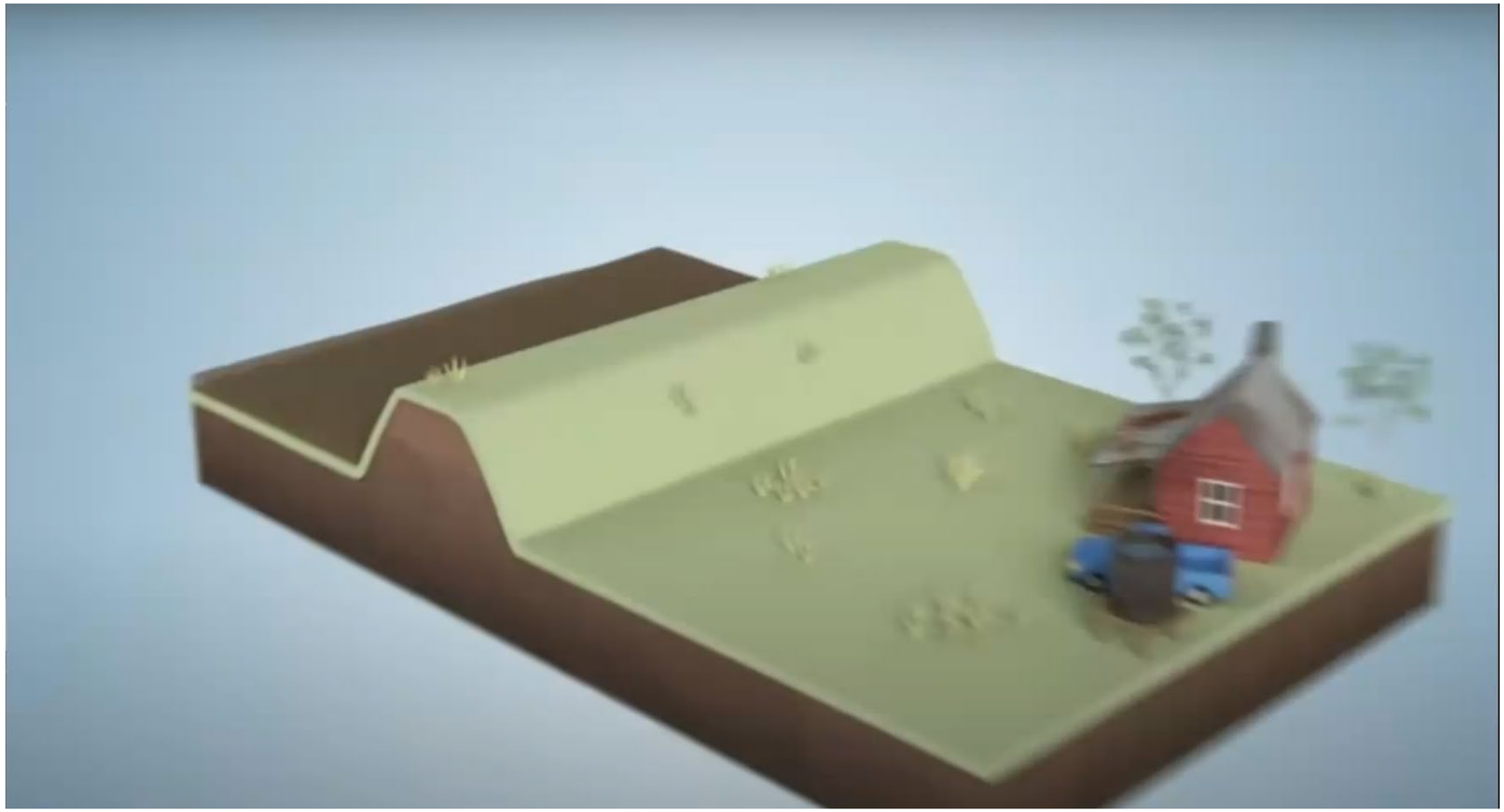
*Typical routine activities are combination between **field inspections** and **screenings**. It must be remembered that although **flood risk may be reduced** by such an approach, **it can never be removed completely**.*



Source: Recommended framework adapted from USACE (The International Levee Handbook)

Disaster Potential of Embankment System

1. Overtopping
2. Cracking
3. Piping, Tree, Weather, and Animal/Human Activities



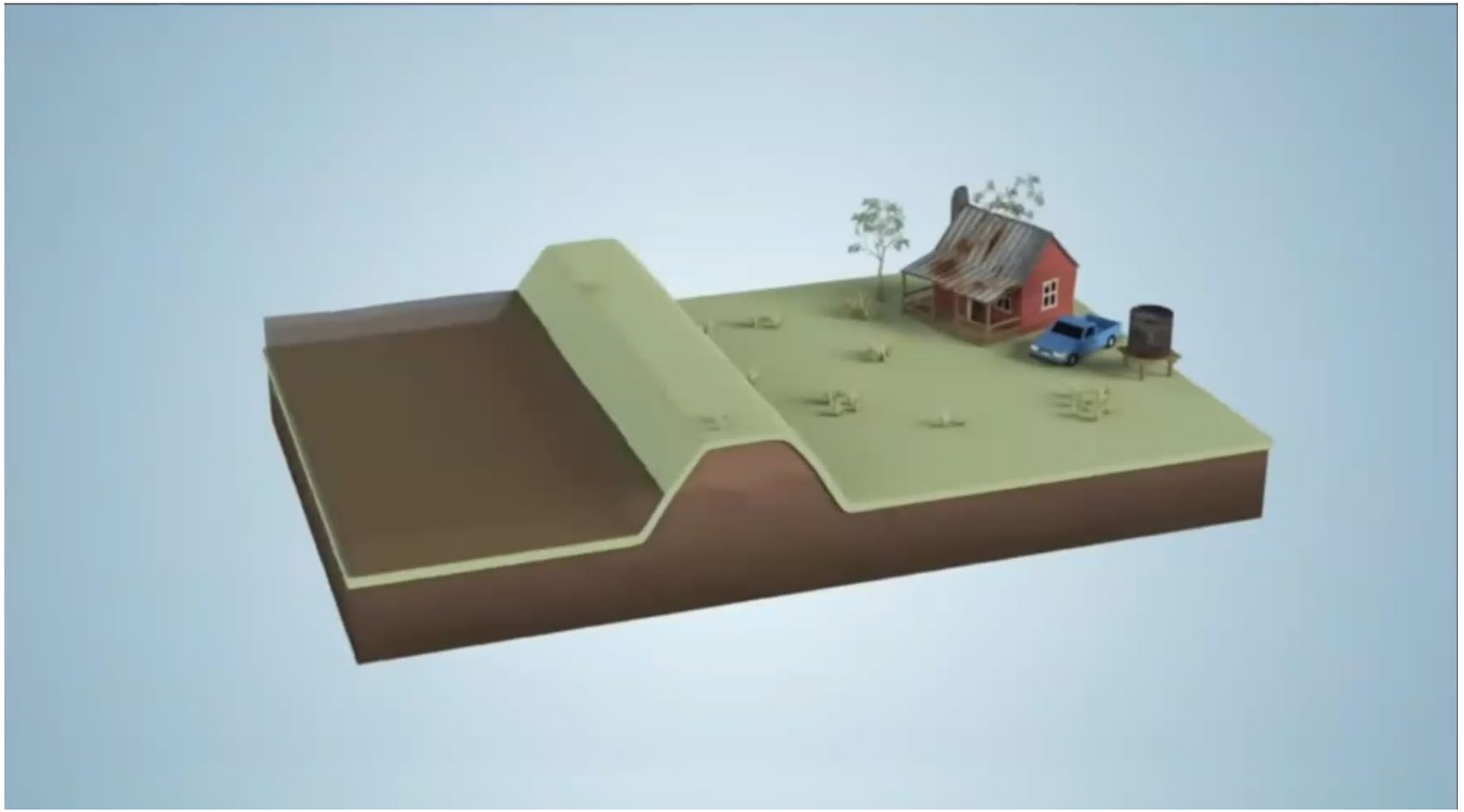
Courtesy : YouTube NSW SES accessed at 14/03/2023

Disaster Potential of Embankment System

1. Overtopping

2. Cracking

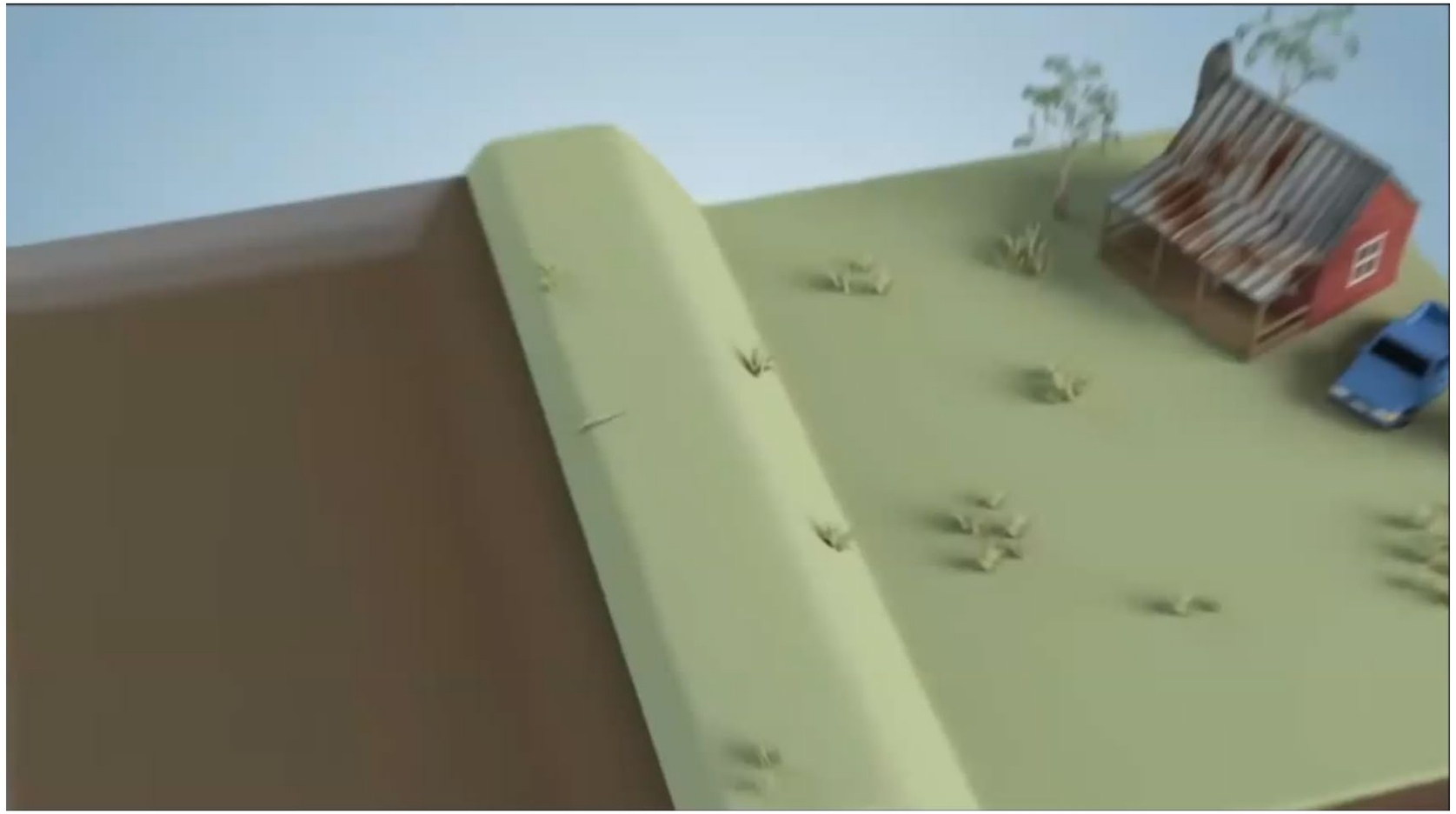
3. Piping, Tree, Weather, and Animal/Human Activities



Courtesy : YouTube NSW SES accessed at 14/03/2023

Disaster Potential of Embankment System

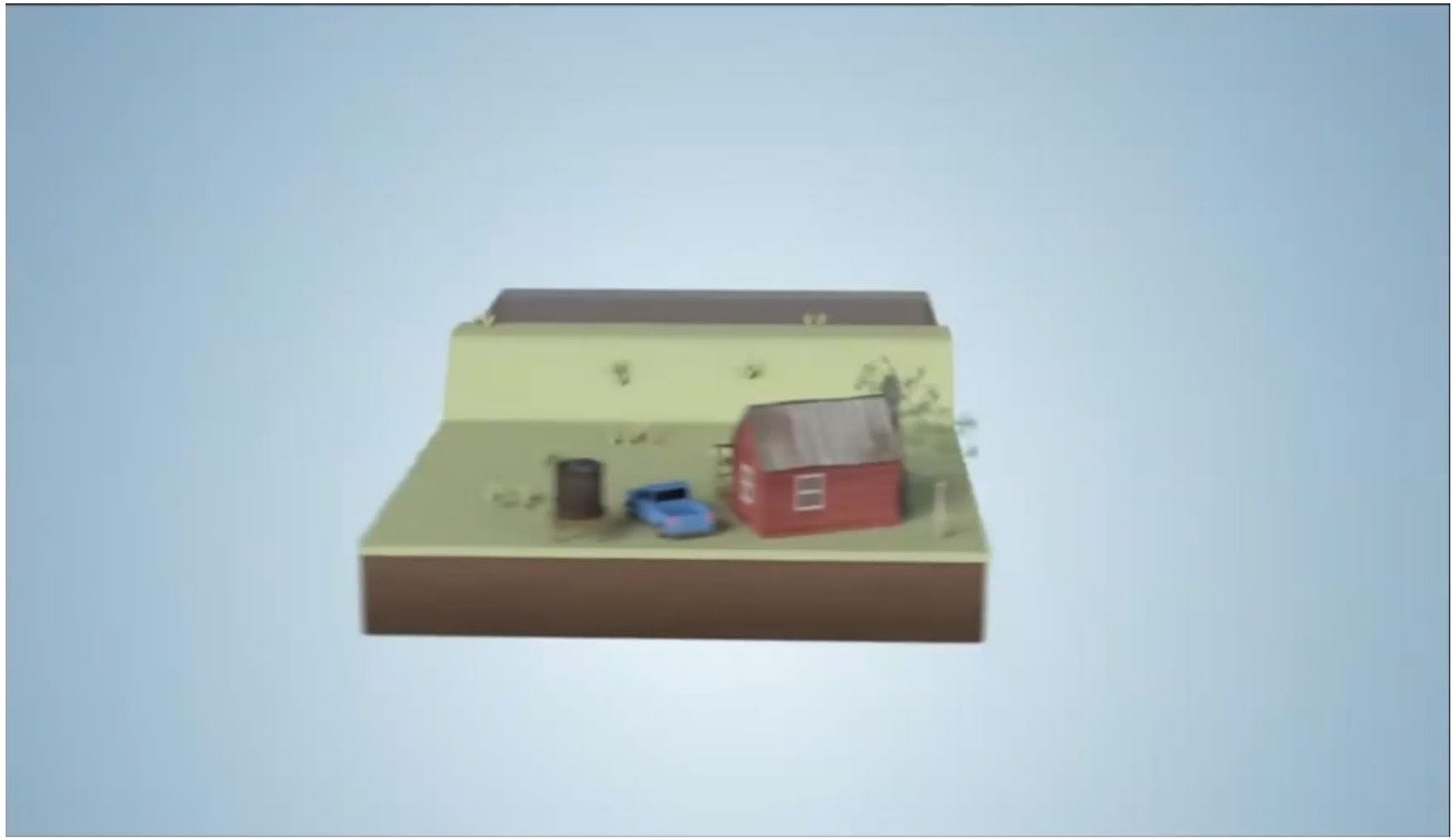
1. Overtopping
2. **Cracking**
3. Piping, Tree, Weather, and Animal/Human Activities



Courtesy : YouTube NSW SES accessed at 14/03/2023

Disaster Potential of Embankment System

1. Overtopping
2. Cracking
3. **Piping, Tree, Weather, and Animal/Human Activities**

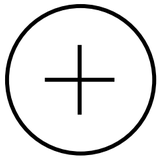


Courtesy : YouTube NSW SES accessed at 14/03/2023

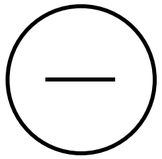
Main Challenge in the Embankment System

Key Point

It is essential for mitigating flood embankment before extreme flood events and ensuring sustainable flood and coastal defence [1].



The rate of deterioration can be detected in high accuracy through long-term observation and inspection.



The traditional inspection methods by visual monitoring are inefficient and inaccurate.

The use of algorithms and techniques based on remote sensing can help local government to identify vulnerable levee sections and repair them rapidly with lower costs [2].

Source: Morris et al., 2007 (1), Mahrooghy et al., 2015 (2)

Goal and Objective

Key Point

"The structure and components of the embankment should be in a ***sustainable design****, consider the effect of* ***water loading****, and understanding* ***climate variability****."*

Goal

This research aims to calculate the robust deterioration rate of soil embankment, particularly along the Thames and Humber Rivers, and predict future potential failure.

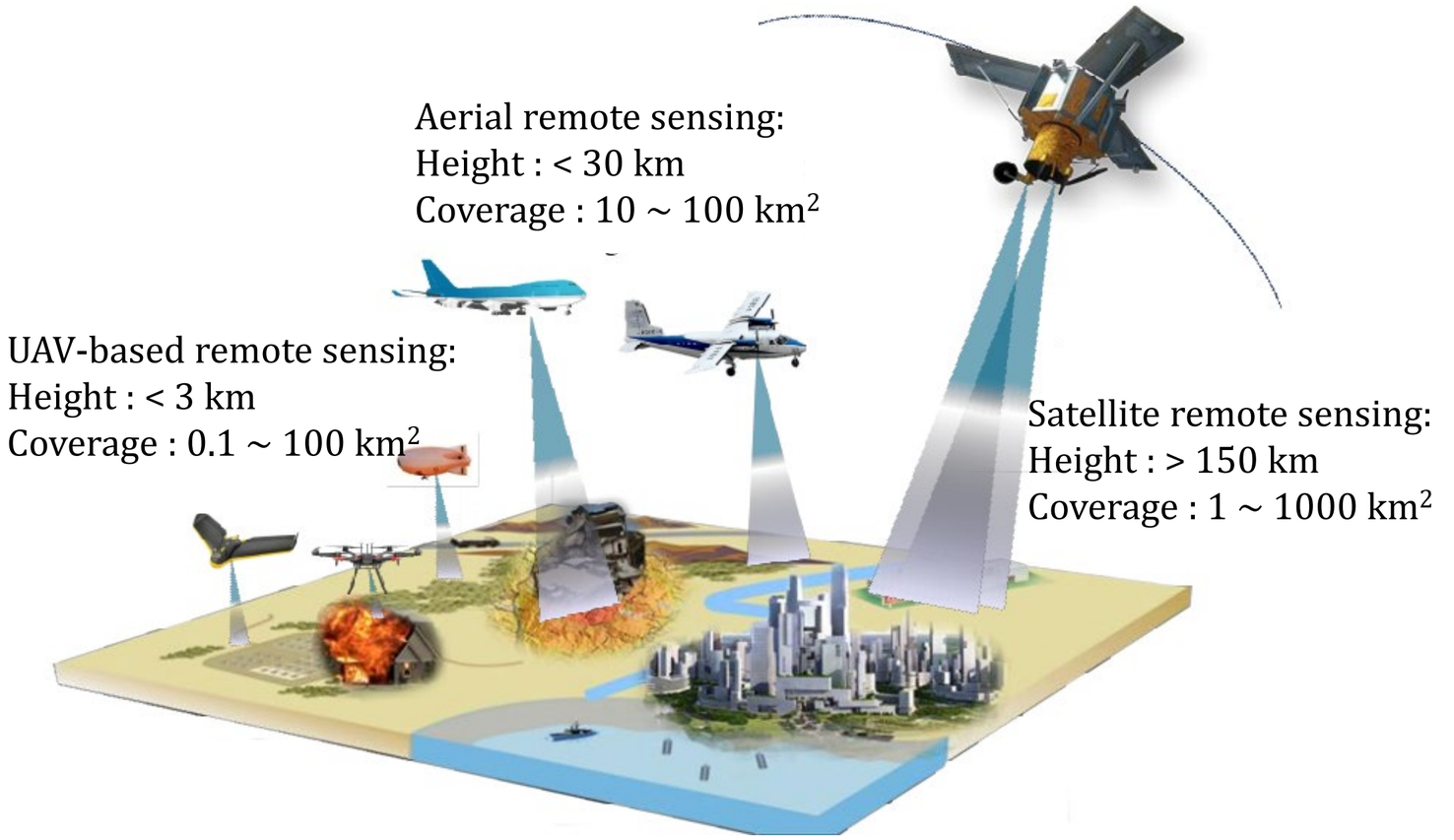
Objective

- To calculate deterioration rate of the embankment by identifying the sign of failure (subsidence, crack, or others)
- To project future potential of the embankment structure considering climate change approach

Unmanned Aerial Vehicle (UAV)

Advancements in sensor and UAV technologies have facilitated :

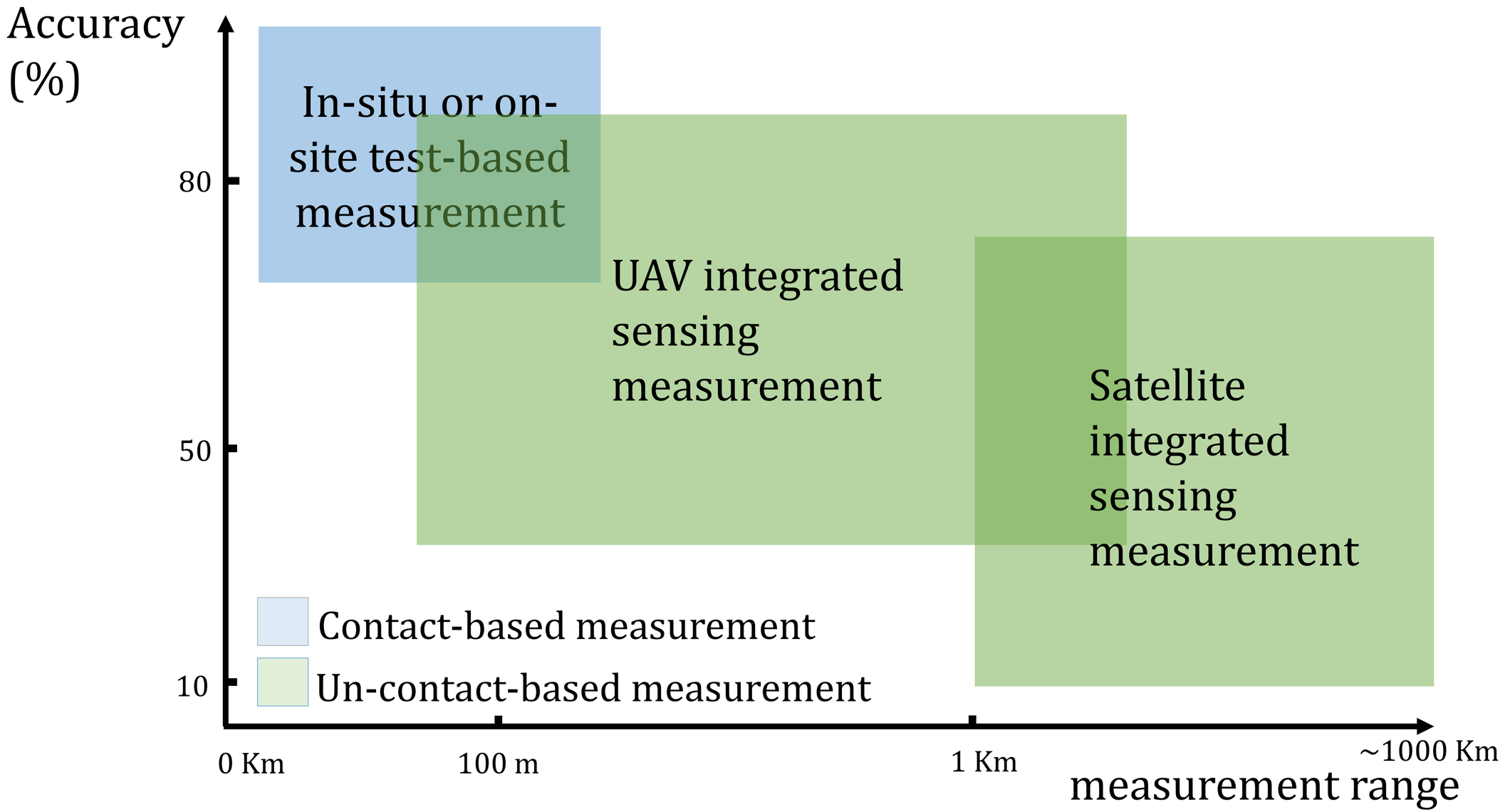
- more **intelligent monitoring** and inspection of sites prone to failure.
- provide both **in situ and satellite measurements** with sufficient accuracy.
- **fewer spatiotemporal constraints** and **offer superior resolution** with reduced data gaps compared to satellite-based measurements.



Source: Mahrooghy et al., 2015

Source: Xiang et al., 2018

Comparison of UAVs Sensing Measurement



Source: Kim et al., 2023, Colomina et al., 2014 (UAV), Lillesand et al., 2015 (On-site Test), Congalton et al., 2009 (Satellite)

Previous Research

3D point cloud data derived from LiDAR is widely used in the sector of autonomous driving, satellite remote sensing, and spatial mapping

Key Point

LiDAR output will contain noise and non-target information due to the complex and changeable environment (weather, interference, other types of obstacles)

Note

Airborne/spaceborne LiDAR commonly uses scanning or array detection to obtain 3D point information. It is commonly resulting in low density and poor-quality point cloud data acquisition after scanning due to volume and weight data.

Solution

A variety of pre-processing processes after acquisition is important, such as point cloud segmentation, denoising, background point cloud removal, sparse/ missing point cloud completion.

Source: Zhao et al., 2023 (1)

Previous Research

LiDAR can be used to monitor landslides, rockfalls, and debris flows by generating an accurate slope map [2], calculating instability signs of landslide [3], and understanding the landslide processes and reducing related losses [4]

Key Point

LiDAR Enable 3D landslide analysis by using a narrow laser beam to scan a certain object [1]

Note

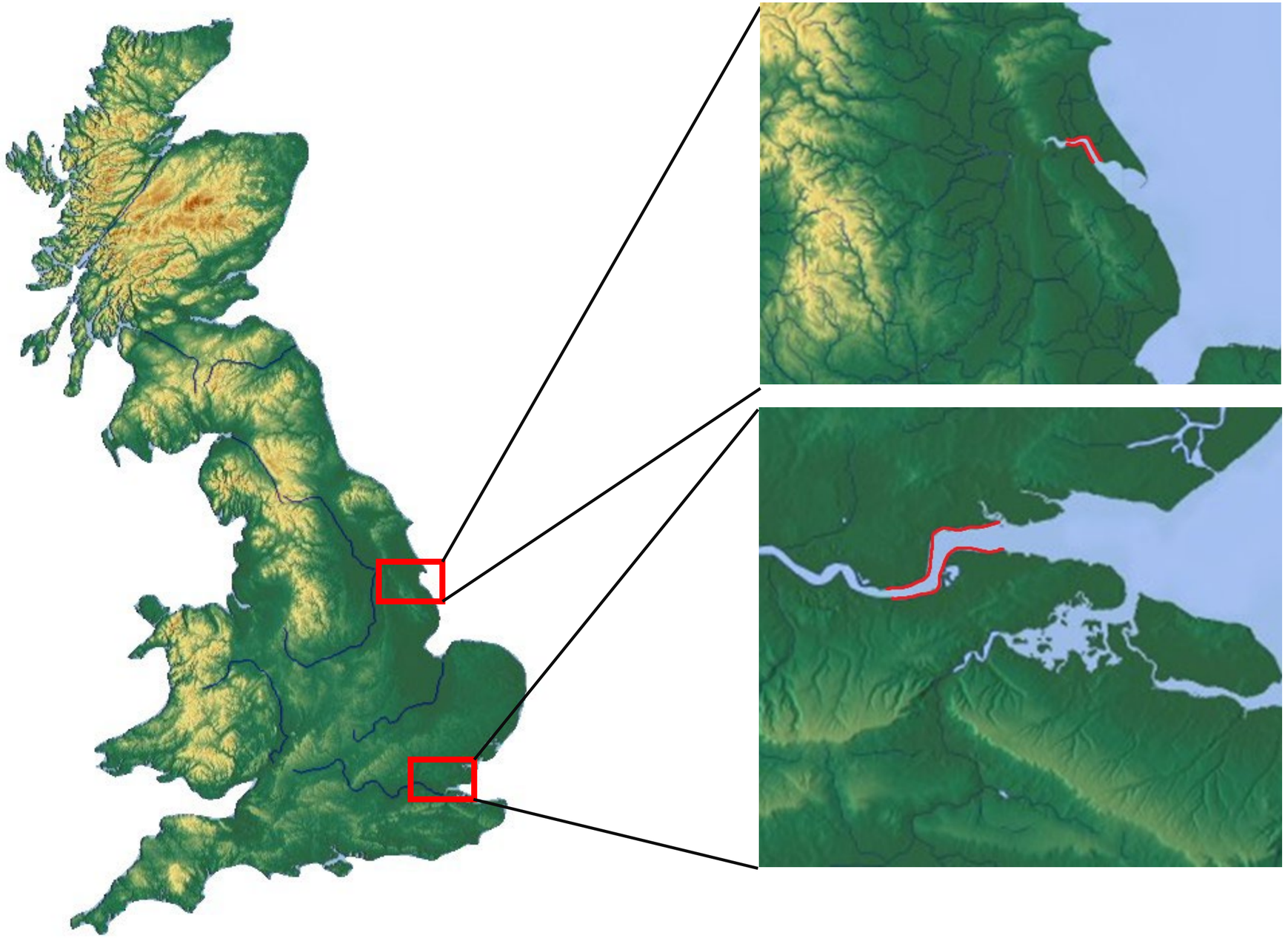
Main factor of the quality of the application results of the LiDAR is **spatial resolution**, including sensor equipment performance, measurement distance, vegetation canopy density, and the **filtering algorithm** effect of the point cloud.

Solution

- Develop mathematical calculation as an input in computational methods that enable to identify potential failure on embankment system
- Develop a statistical approach to project future potential disaster under climate change consideration

Source: Casagli et al., 2023 (4)

Study Area



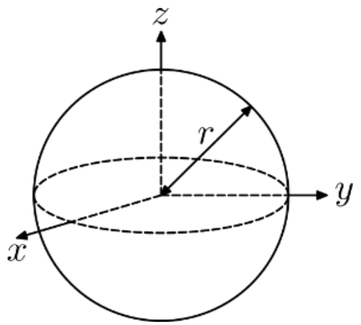
River Humber

The Humber is about 64 km long, the River is lined by the major ports of Kingston upon Hull, Grimsby, and Immingham.

River Thames

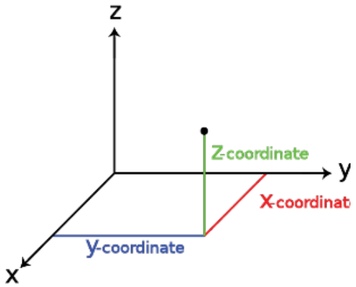
The Thames is the largest river in England, with a total length of 354km, housing a fifth of the UK population, including London.

LiDAR



The IMU (inertial measurement unit) gives the precise orientation of the scanner

Drone equipped with LiDAR unit



The GPS gives the precise location of the scanner

Key Point

LiDAR excels in capturing data with both **high spatial** and **spectral resolutions**, facilitating the generation of **precise classifications**, detection of surface alterations, environmental monitoring, and various other applications.

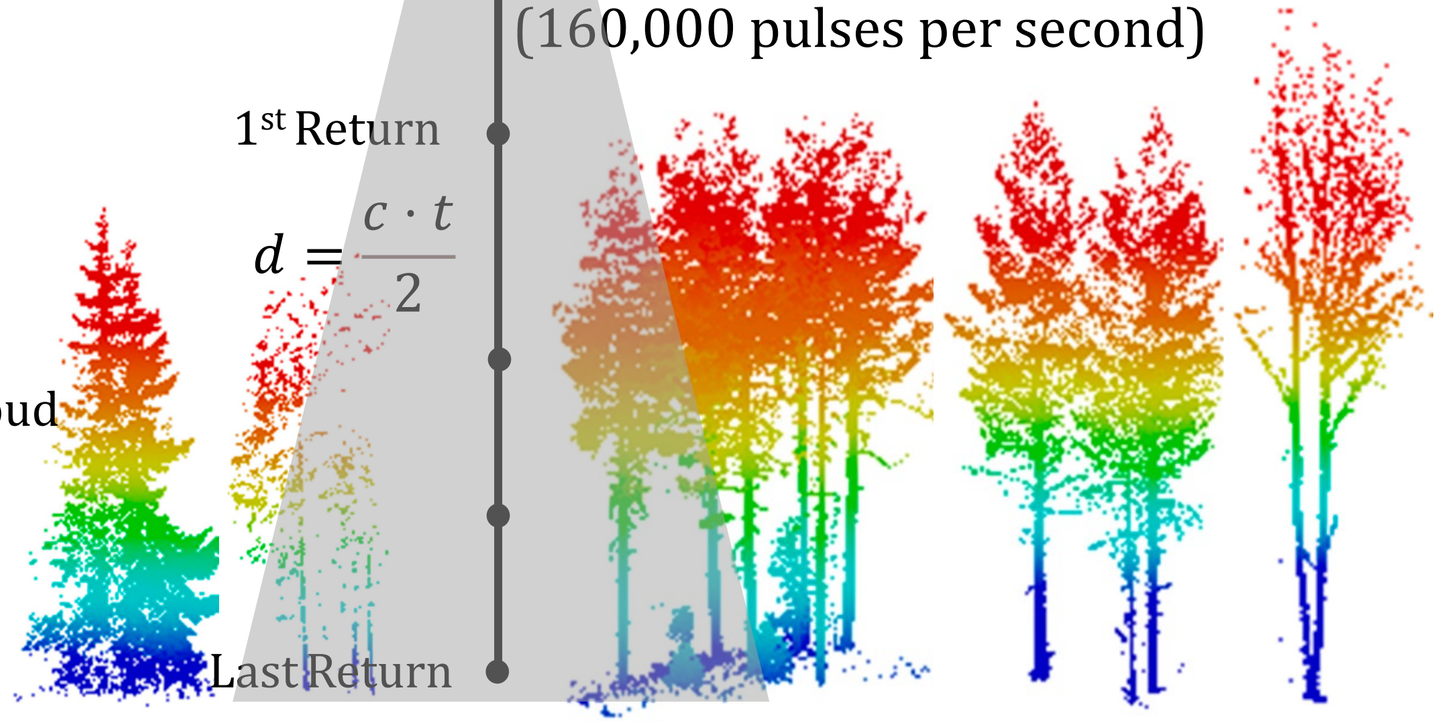
Laser Pulse
(160,000 pulses per second)

1st Return

$$d = \frac{c \cdot t}{2}$$

3D Point Cloud

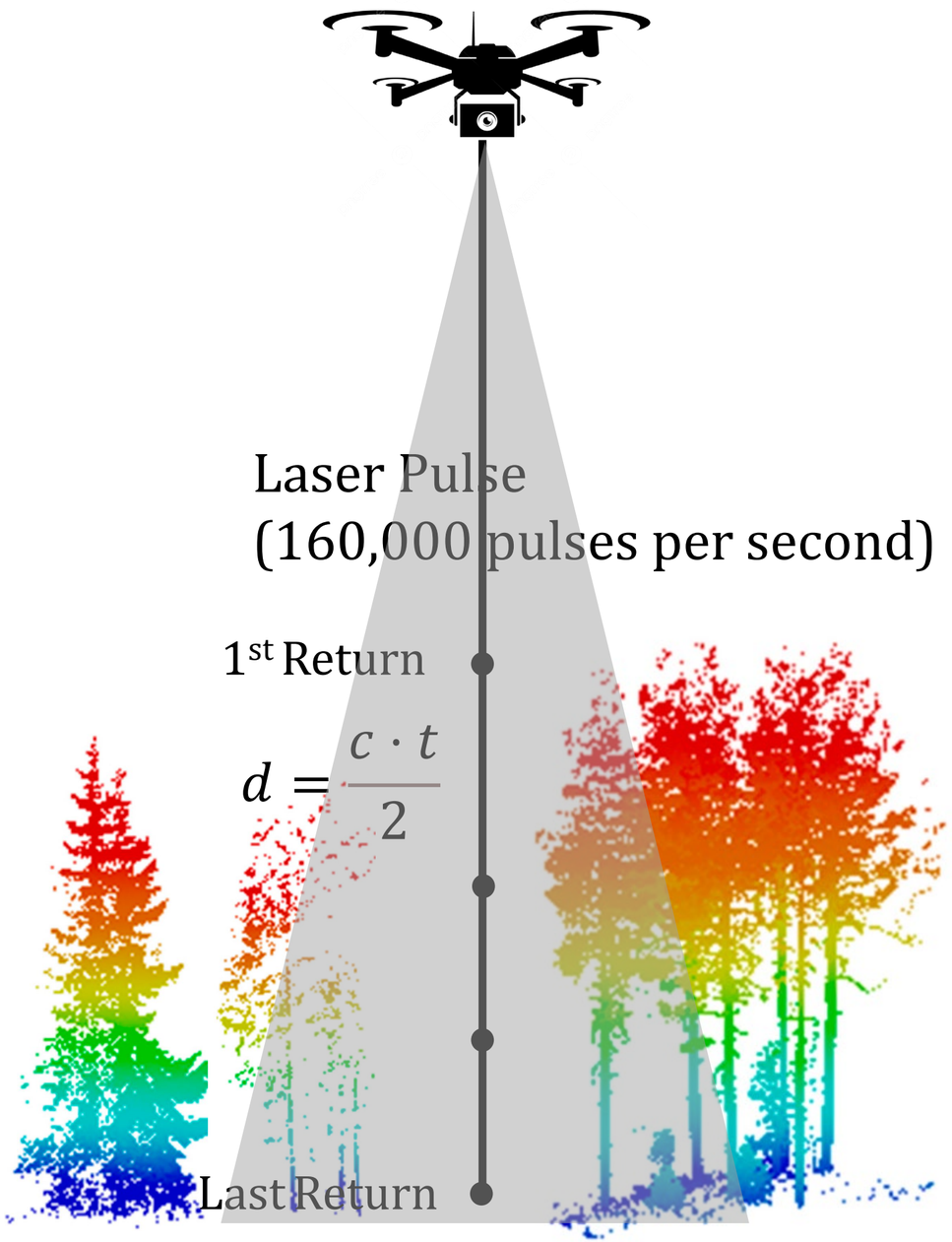
Last Return



Source: Kahraman et al., 2021

LiDAR

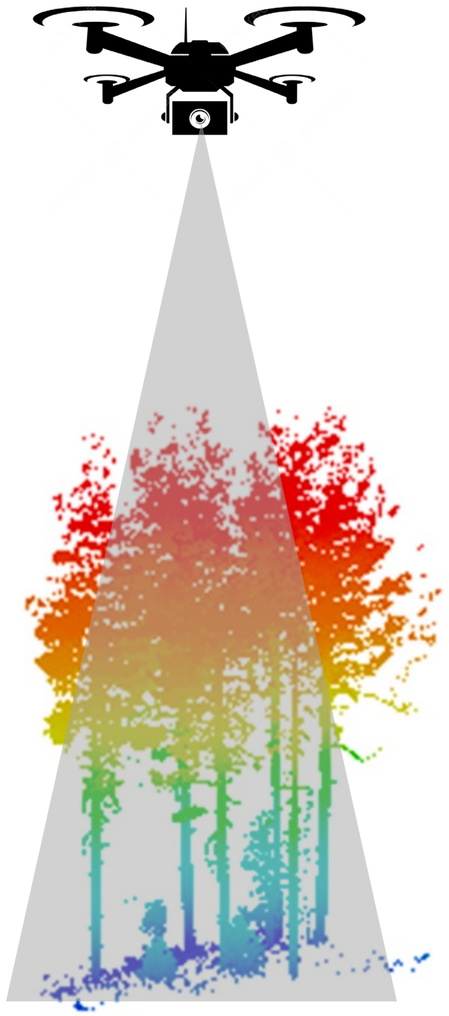
- One pulse may record 1-5 return pulses
- The returned pulses is classified into one or more discrete returns X, Y, Z intensity
- Optical frequency is between Green and near Infra-Red (wavelengths from 532 to 1064 nm)
- Spatial resolution is a function of the altitude and flight speed ranging from a few cm for altitudes of about 250 m to a few decimetres for higher than 1000m
- Can operate both day and night, some limitations may occur



Source: Kahraman et al., 2021

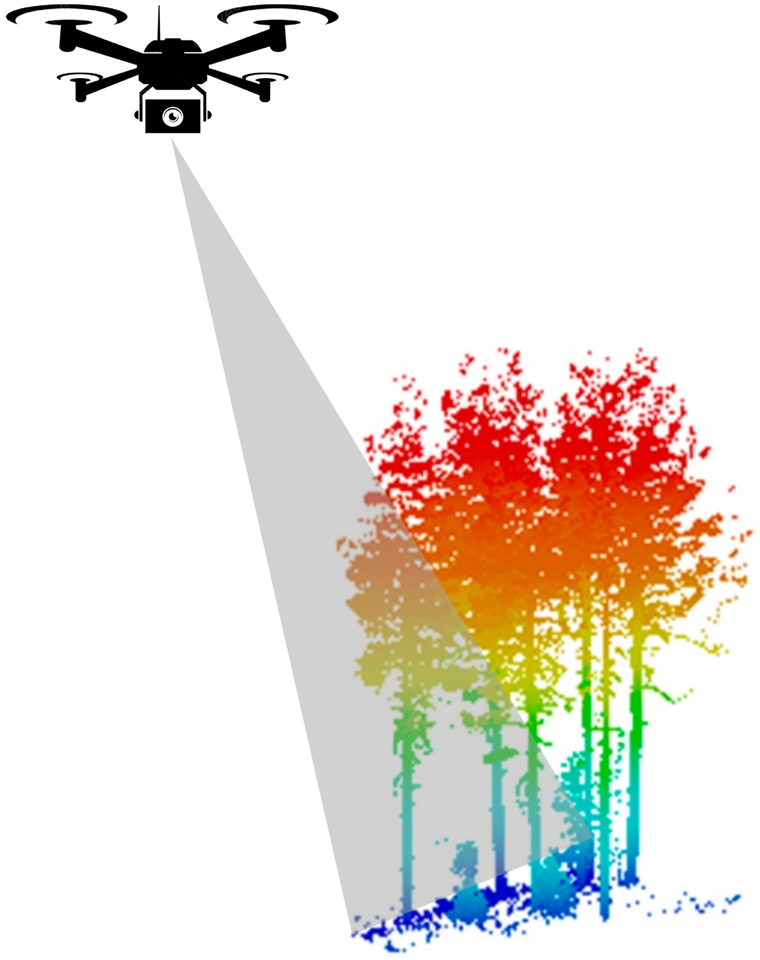
LiDAR Limitation

Obstruction

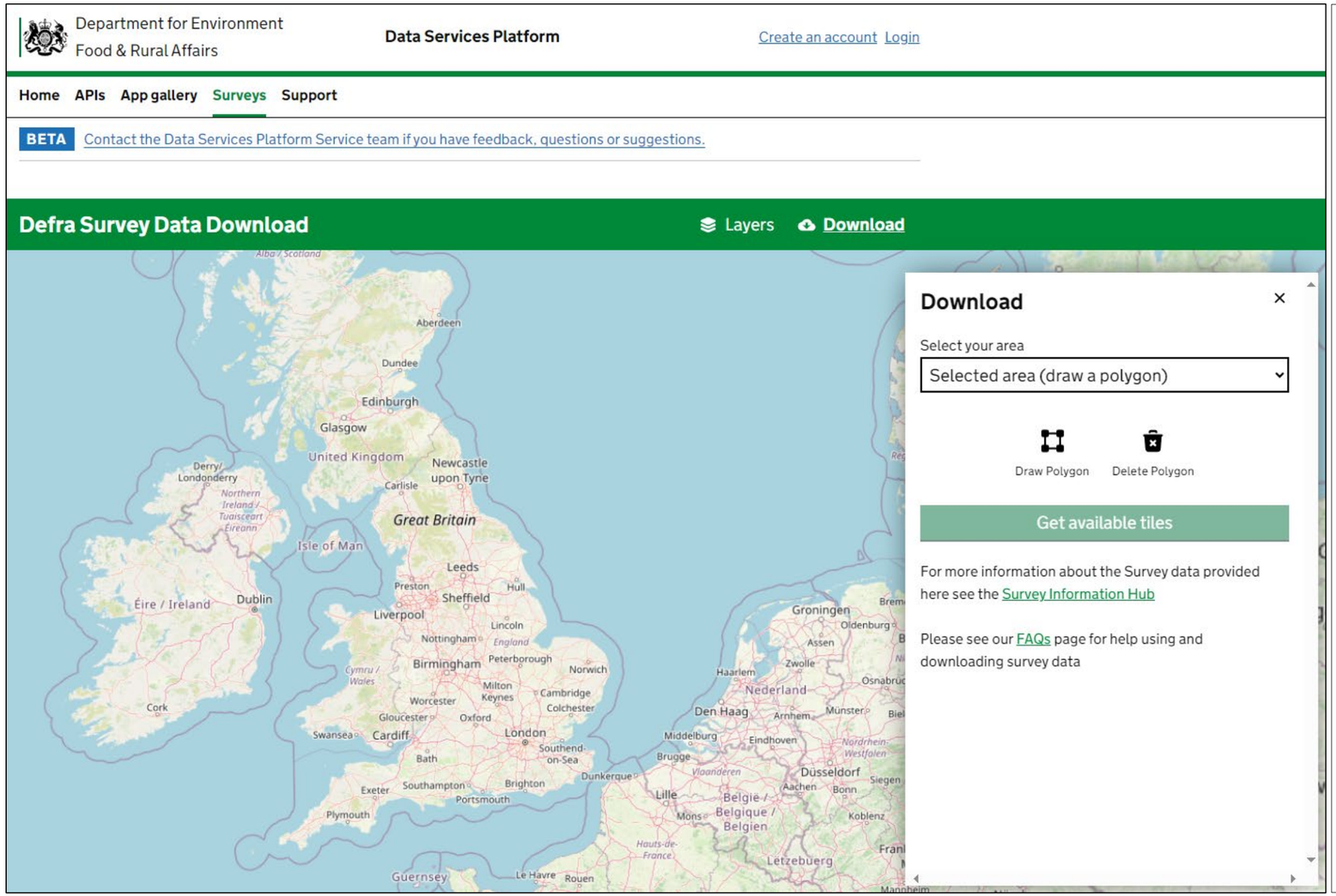


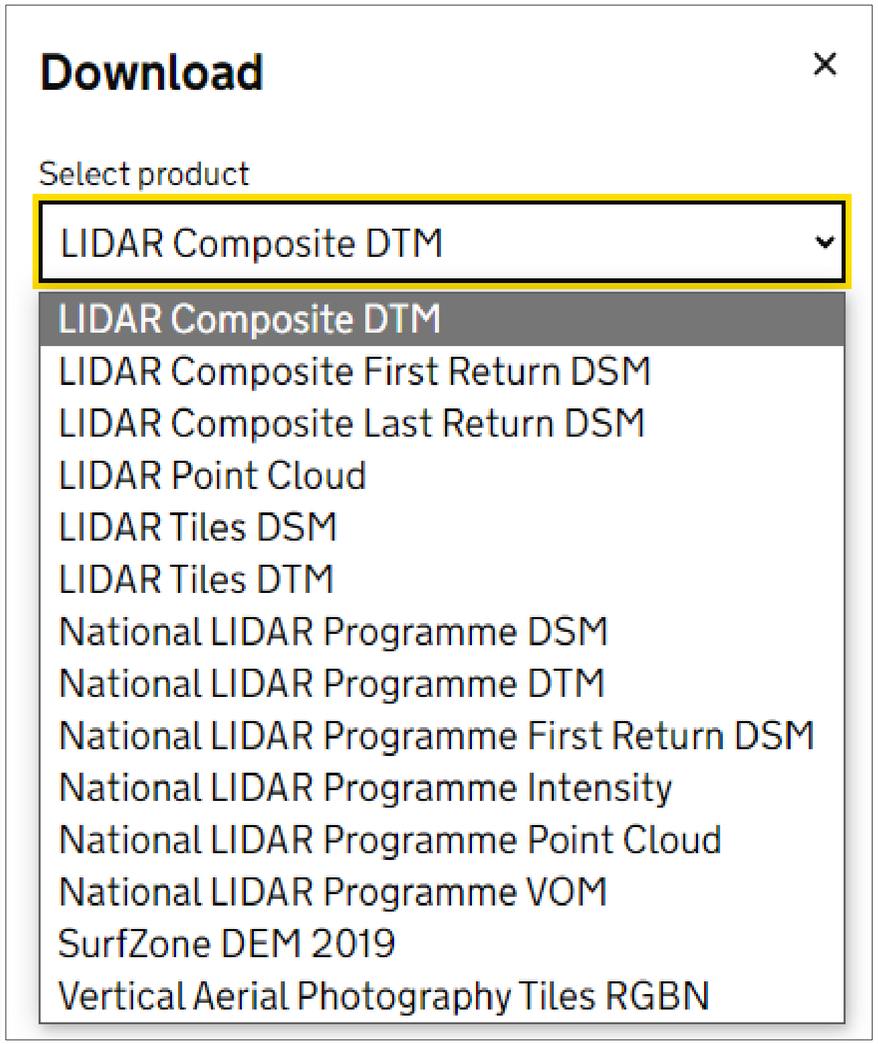
Weather

Angle



Data for Pre-Trained Method





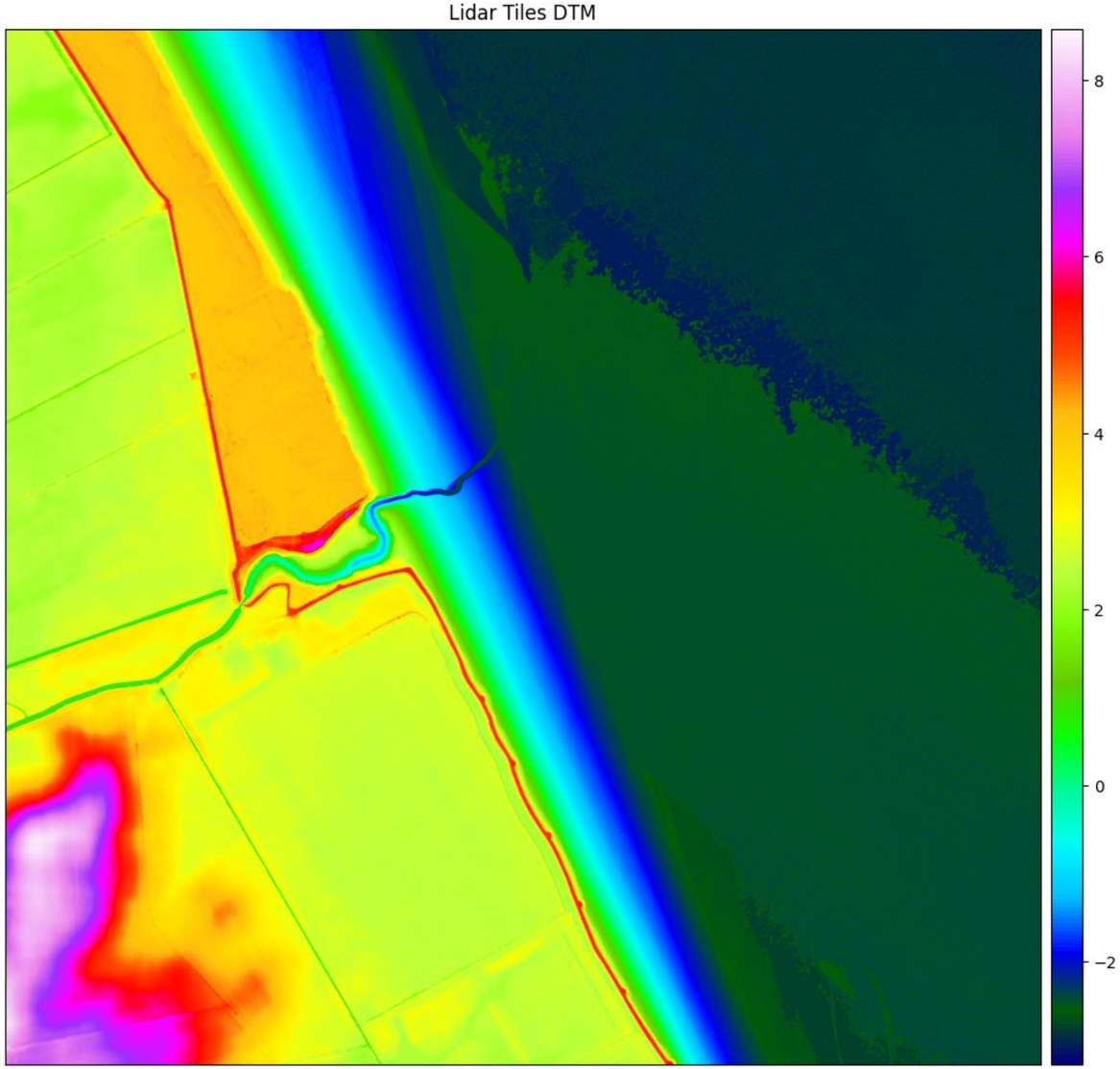
Link : [Defra Survey Data Download]

LiDAR Output

1. LiDAR DTM

2. LiDAR DSM

3. LiDAR Point Cloud



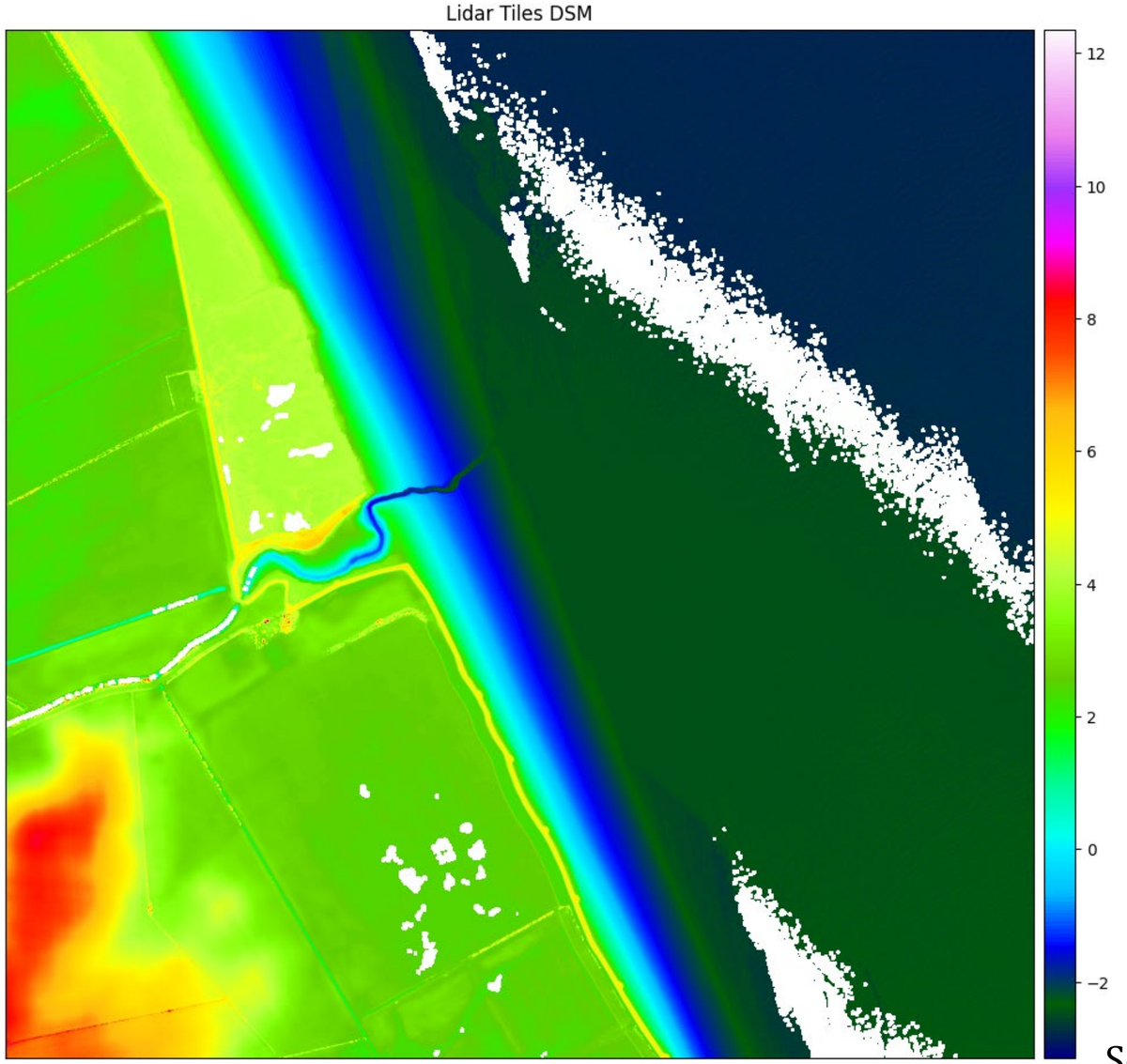
Digital Terrain Model

- Represent the elevation or relief of the Earth's surface, **exclude** human-made features and Trees
- Resolution and accuracy depending on the sensor, but commonly lies between 1 meter to 20 meter.

Source Data : DEFRA
Location : East Halton Skitter - Immingham
Tool : Google Colab - Python

LiDAR Output

1. LiDAR DTM
2. **LiDAR DSM**
3. LiDAR Point Cloud



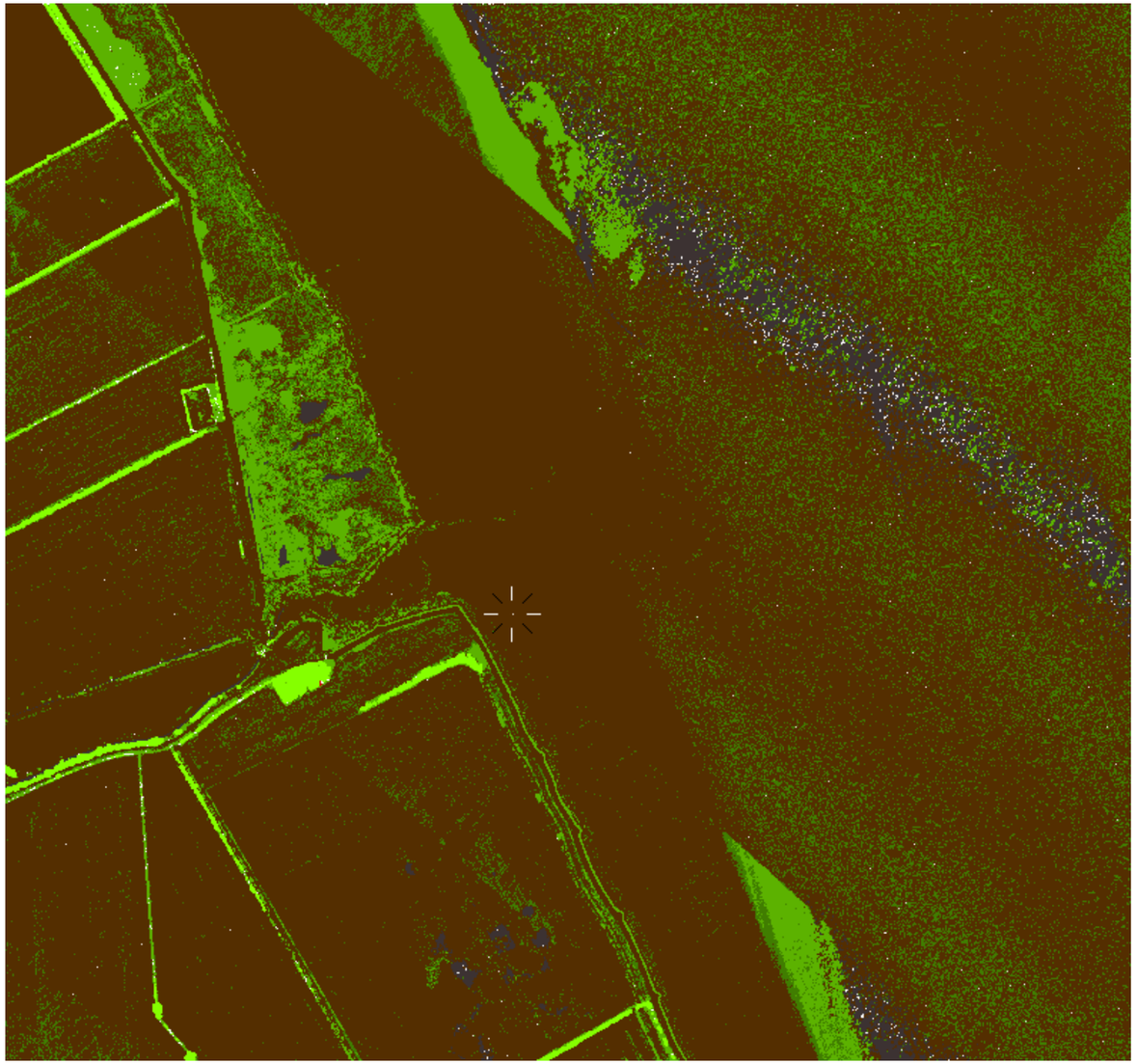
Digital Surface Model

- Represent the elevation or relief of the Earth's surface, **include** human-made features and surface features
- Resolution and accuracy depending on the sensor, but commonly lies between 1 meter to 20 meter

Source Data : DEFRA
Location : East Halton Skitter - Immingham
Tool : Google Colab - Python

LiDAR Output

1. LiDAR DTM
2. LiDAR DSM
3. **LiDAR Point Cloud**



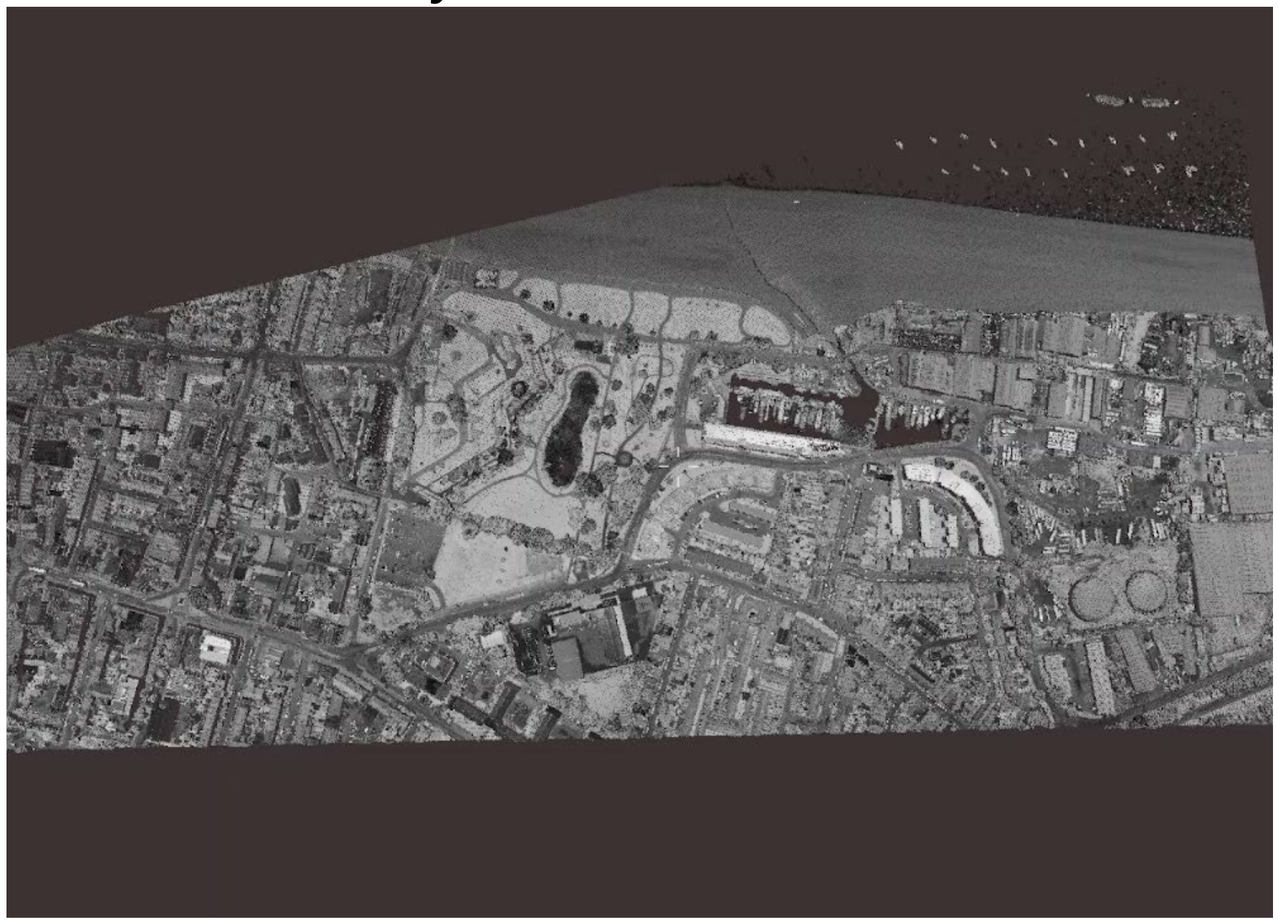
Point Cloud

- Individual points in three-dimensional space
- Accuracy and precision depending on some factors (equipment, sensors, processing algorithm used)
- Can be generated from airborne or terrestrial LiDAR, laser scanning, or structured light scanning)

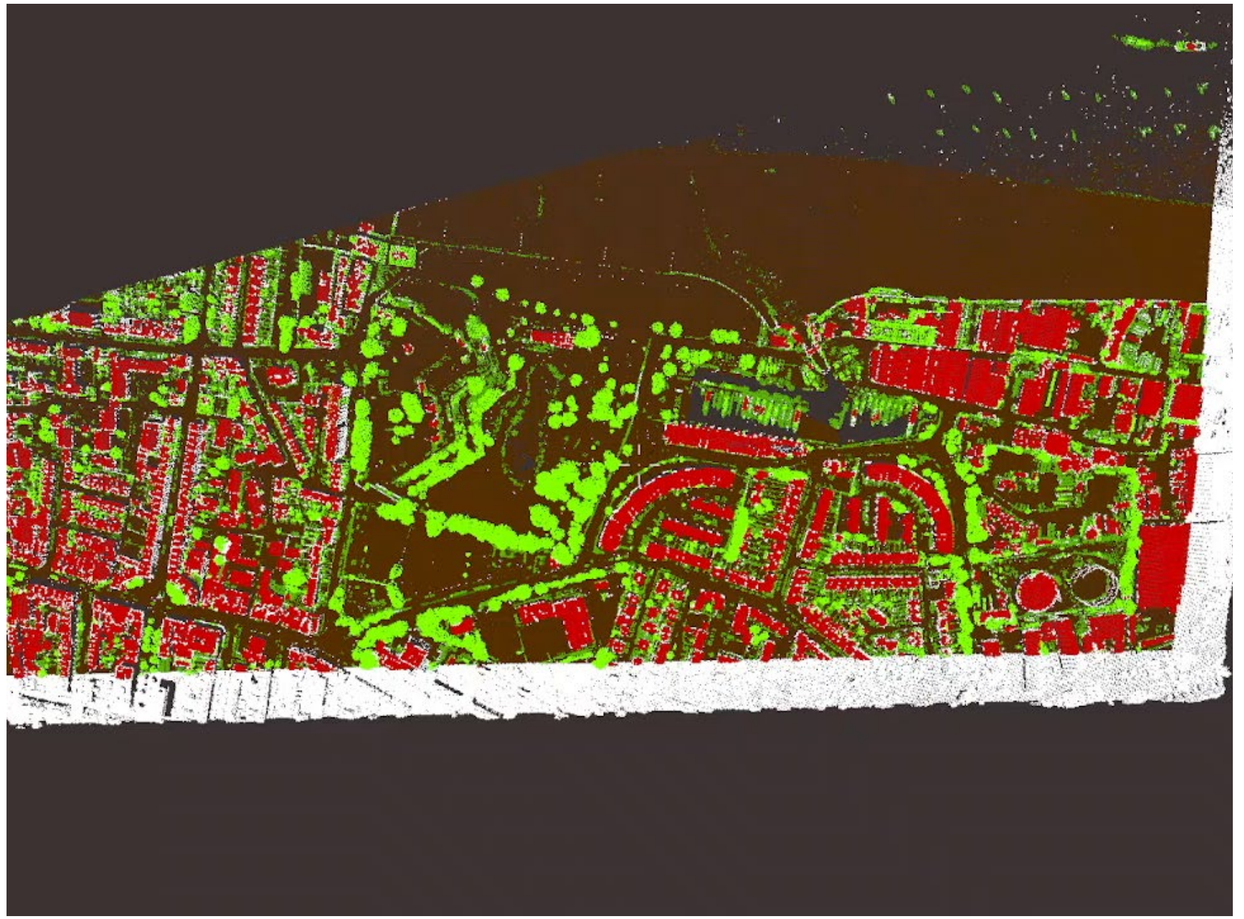
Source Data : DEFRA
Location : East Halton Skitter - Immingham
Tool : Displaz

LiDAR 3D Visualization

LiDAR Intensity Data



LiDAR Classification



Source Data : DEFRA
Location : Residential Area in East Tilburn
Tool : Displaz, CloudCompare

Milestone of Methodology

Lidar Data Acquisition and Pre-processing

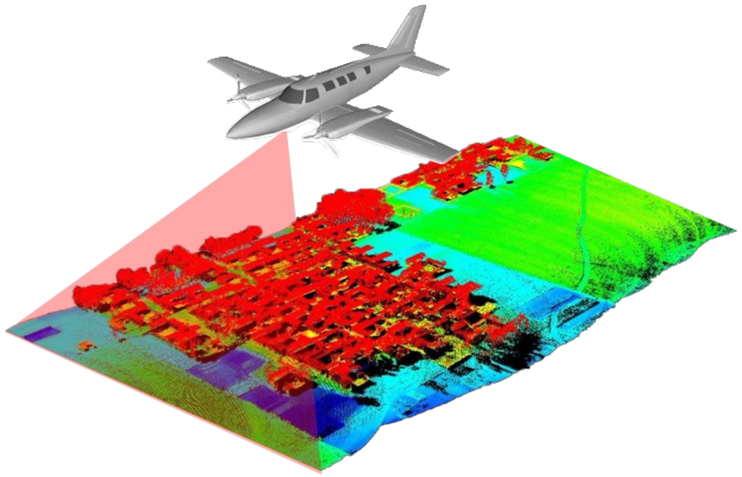
Gathering the data sources and comprehend the data typology.

Segmentation and deterioration analysis

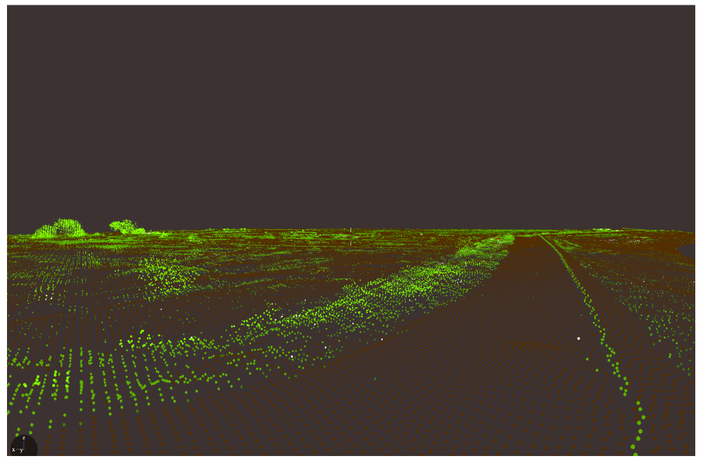
To isolate specific research areas and identify key features from the segmented data relevant to assessing the health and stability of flood embankments.

Predicting and Analysing Future Potential

To project the embankment deterioration rate by applying real-world scenarios to inform decision-making processes in civil engineering.



Source: LIDAR - lidar.co.id



Source : LiDAR Data DEFRA
Tool : Displaz
Location : Lower Hope Point - Rochester

Source : Google Street View
Location : Lower Hope Point - Rochester

Lidar Data Acquisition and Pre-processing

Steps:

1.Project Planning and Preparation

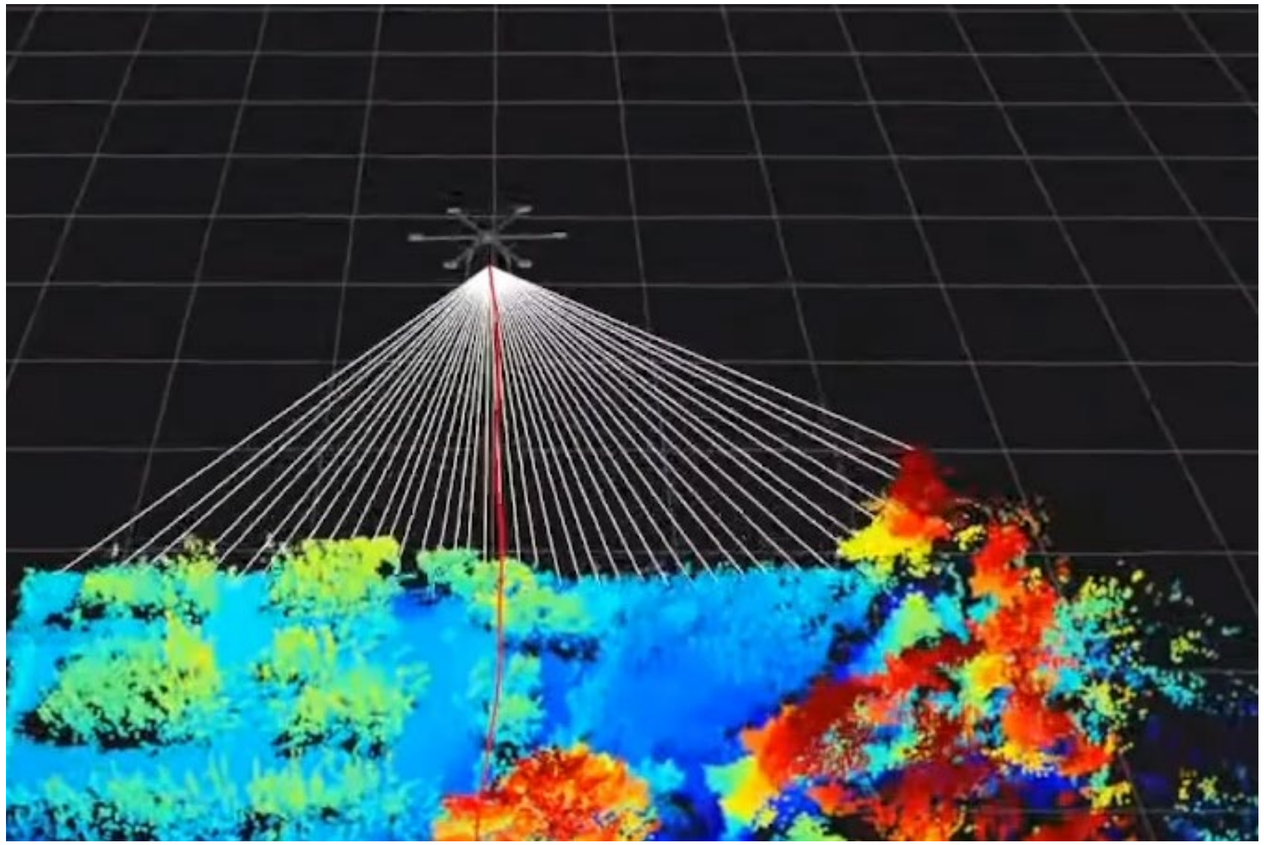
2.Sensor selection and configuration

3.Platform deployment (aircraft / ground vehicle / tripod-mounted, or else)

4.Data acquisition

5.Quality control and assurance

6.Data processing



Source : GNSS-LiDAR: Drone 3D Mapping

Segmentation and Deterioration Analysis

Key Point

A segment-based approach offers a systematic and effective methodology for analysing scalar field data representing surface features to detect embankment cracks

NOTE

Divided into segments or regions of interest based on geometric properties, such as curvature, normal vectors, or point density.

Application

Identifying and analysing specific object recognition, scene understanding, and semantic segmentation.

Advantage

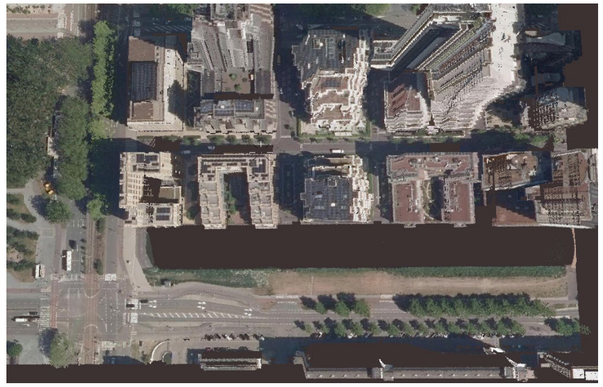
Localised analysis, flexible, and interpretable

Drawback

Segmentation sensitivity, over-segmentation, and computational complexity

Source: Cheng et al., 2018

Segmentation

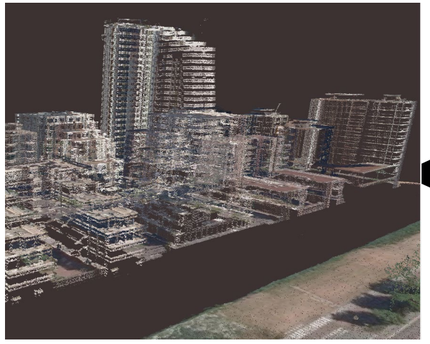


Input point cloud

Surface
Rooftop
Trees
Embankment
River
Etc.

Image
Segmentation

Pixel-Level label



render

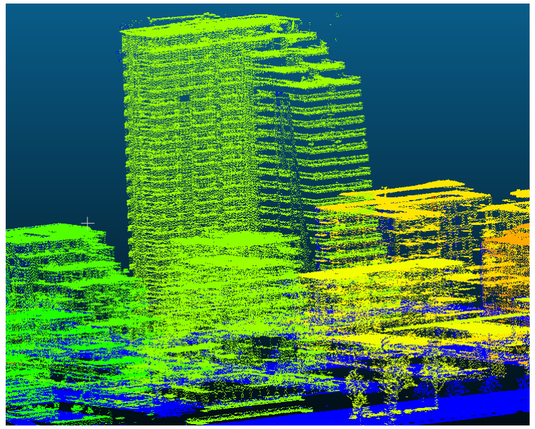
Re-project

Select View

Point
Segmentation

Output

Point-Level label



Climate Projection

Key Point

3D point cloud data provided by a terrestrial laser scanner could play an interesting role for flood mapping.

Challenge

No one single dataset in the public domain is properly detailed to describe for primary research. Water loss from subgrade soil subjected to dry weather is possible to cause soil cracking. On the contrary, intruded water will cause failures because of the wetting swelling or collapsing of the subgrade soils.

Solution

Currently, the risk of floods is mapped on a global scale using technology like satellite imagery and remote sensing. LiDAR derived flood inundation model can be used to simulate flood hazard estimation using probability analysis and flood scenario.

Source: Johnston et al., 2021

Reference

[1] Iqbal, Z., Shahid, S., Ismail, T., Sa'adi, Z., Farooque, A., & Yaseen, Z. M. (2022). Distributed hydrological model based on machine learning algorithm: Assessment of climate change impact on floods. *Sustainability*, *14*(11), 6620.

[2] United Nations Office for Disaster Risk Reduction. (2020). The Human Cost of Disasters: An Overview of the Last 20 Years (2000-2019). Retrieved from https://www.undrr.org/publication/human-cost-disasters-overview-last-20-years-2000-2019

[3] Allsop, W., & Harrop, J. (2009). Flood risk management: research and practice. In *Proceedings of the European Conference on Flood Risk Management Research into Practice (Floodrisk 2008). Oxford, UK, CRC*.

[4] Aanstoos, J. V., Hasan, K., O'Hara, C. G., Dabbiru, L., Mahrooghy, M., Nobrega, R., & Lee, M. A. (2012, October). Detection of slump slides on earthen levees using polarimetric SAR imagery. In *2012 IEEE Applied Imagery Pattern Recognition Workshop (AIPR)* (pp. 1-7). IEEE.

[5] Morris, J. H. T. M., Hess, T. M., Gowing, D. J. G., Leeds-Harrison, P. B., Bannister, N., Vivash, R. M. N., & Wade, M. (2005). A framework for integrating flood defence and biodiversity in washlands in England. *International Journal of River Basin Management*, *3*(2), 105-115.

[6] Mahrooghy, M., Aanstoos, J. V., Nobrega, R. A., Hasan, K., Prasad, S., & Younan, N. H. (2015). A machine learning framework for detecting landslides on earthen levees using spaceborne SAR imagery. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *8*(8), 3791-3801.

[7] Kim, S. Y., Kwon, D. Y., Jang, A., Ju, Y. K., Lee, J. S., & Hong, S. (2023). A review of UAV integration in forensic civil engineering: From sensor technologies to geotechnical, structural and water infrastructure applications. *Measurement*, 113886.

[8] Kahraman, S., & Bacher, R. (2021). A comprehensive review of hyperspectral data fusion with lidar and sar data. *Annual Reviews in Control*, *51*, 236-253.

Reference

[9] Mezaal, M. R., & Pradhan, B. (2018). An improved algorithm for identifying shallow and deep-seated landslides in dense tropical forest from airborne laser scanning data. *Catena*, *167*, 147-159.

[10] Jaboyedoff, M., Oppikofer, T., Abellán, A., Derron, M. H., Loye, A., Metzger, R., & Pedrazzini, A. (2012). Use of LIDAR in landslide investigations: a review. *Natural hazards*, *61*, 5-28.

[11] Guo, C., Xu, Q., Dong, X., Li, W., Zhao, K., Lu, H., & Ju, Y. (2021). Geohazard recognition and inventory mapping using airborne LiDAR data in complex mountainous areas. *Journal of Earth Science*, *32*, 1079-1091.

[12] Xu, Q., Zhao, B., Dai, K., Dong, X., Li, W., Zhu, X., ... & Ge, D. (2023). Remote sensing for landslide investigations: A progress report from China. *Engineering Geology*, 107156.

[13] Cheng, H., Li, Y., Li, H., & Hu, Q. (2023, April). Embankment crack detection in UAV images based on efficient channel attention U2Net. In *Structures* (Vol. 50, pp. 430-443). Elsevier.

[14] Yuheng, S., & Hao, Y. (2017). Image segmentation algorithms overview. *arXiv preprint arXiv:1707.02051*.

[15] O'Shea, K., & Nash, R. (2015). An introduction to convolutional neural networks. *arXiv preprint arXiv:1511.08458*.

[16] Johnston, I., Murphy, W., & Holden, J. (2021). A review of floodwater impacts on the stability of transportation embankments. *Earth-Science Reviews*, *215*, 103553.

[17] Congalton, R.G. and Green, K., 2009. "Assessing the accuracy of remotely sensed data: principles and practices." CRC Press.

[18] Lillesand, T.M., Kiefer, R.W., and Chipman, J.W., 2015. "Remote sensing and image interpretation." John Wiley & Sons.

[19] Colomina, I., and Molina, P., 2014. "Unmanned aerial systems for photogrammetry and remote sensing: A review." ISPRS Journal of Photogrammetry and Remote Sensing, 92, pp.79-97.

[20] Kahraman, S., & Bacher, R. (2021). A comprehensive review of hyperspectral data fusion with lidar and sar data. *Annual Reviews in Control*, *51*, 236-253.
[21] Xiang, T. Z., Xia, G. S., & Zhang, L. (2018). Mini-UAV-based remote sensing: techniques, applications and prospectives. arXiv 2018. *arXiv preprint arXiv:1812.07770*.
[22] Casagli, N., Intrieri, E., Tofani, V., Gigli, G., & Raspini, F. (2023). Landslide detection, monitoring and prediction with remote-sensing techniques. *Nature Reviews Earth & Environment*, *4*(1), 51-64.
[23] Zhao, L., Hu, Y., Yang, X., Dou, Z., & Kang, L. (2024). Robust multi-task learning network for complex LiDAR point cloud data preprocessing. *Expert Systems with Applications*, *237*, 121552.