Gas Networks Ireland (GNI) Project

Draft Report

29th August 2023

Investigation of novel A.I. & Decision Support technologies for improved Environmental & Sustainable Management of GNI's Right of Way (RoW)

A Research Project coordinated by Maynooth University (MU), in partnership with GNI and co-funded by both Science Foundation Ireland (SFI) and Gas Networks Ireland (GNI)

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Contents

Abbreviations, Acronyms & Glossary

Artificial intelligence (AI) is the ability of machines to perform tasks that are typically associated with human intelligence, such as learning and problem-solving. Traditional AI domains include reasoning, knowledge representation, planning, learning, natural language processing, perception, and support for robotics.

Beyond Visual Line Of Sight (BVLOS) operation means a type of UAS operation which is not conducted in VLOS (see further below) i.e. where the drone is no longer in view of the operator.

Digital Surface Model (DSM) is a geocoded model of real-world environments comprising both the bare ground, vegetation and man-made features (infrastructure, buildings etc)

Digital Terrain Model (DTM) is a geocoded model of real-world environments comprising just the bare ground without any vegetation and man-made features (infrastructure, buildings etc)

Earth Observation (EO) is the gathering of information about the physical, chemical, and biological systems of the planet Earth. This can be performed via remote-sensing technologies (Earth observation satellites) or through direct-contact sensors in ground-based or airborne platforms such as survey aircraft or drones.

Geographic Information System (GIS) comprises integrated computer hardware and software that store, manage, analyse, edit, output, and visualize geographic data

Light Detection And Ranging (LiDAR) is a method for determining ranges by targeting an object or a surface with a laser and measuring the time for the reflected light to return to the receiver. LiDAR may operate in a fixed direction (e.g., vertical) or it may scan multiple directions, in which case it is known as LiDAR scanning or 3D laser scanning, a special combination of 3-D scanning and laser scanning. LiDAR has terrestrial, airborne, and mobile applications.

Machine learning (ML) is an umbrella term for solving problems for which development of algorithms by human programmers would be cost-prohibitive, and instead the problems are solved by helping machines 'discover' their 'own' algorithms, without needing to be explicitly told what to do by any human-developed algorithms.

Multispectral imaging captures image data within specific wavelength ranges across the electromagnetic spectrum. The wavelengths may be separated by filters or detected with the use of instruments that are sensitive to particular wavelengths, including light from frequencies beyond the visible light range, i.e. infrared and ultra-violet. It can allow extraction of additional information the human eye fails to capture with its visible receptors for red, green and blue.

Normalised Distribution Vegetation Index (NDVI) is a widely-used metric for quantifying the health and density of vegetation using sensor data. It is calculated from spectrometric data at two specific bands: red and near-infrared (NIR).

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{Red})}{(\mathrm{NIR} + \mathrm{Red})}$$

Orthophotomosaic or Orthomosaic is a raster image made by merging orthophotos — aerial or satellite photographs which have been transformed to correct for perspective so that they appear to have been taken from vertically above at an infinite distance.

Photogrammetry is the science and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring and interpreting photographic images and patterns of electromagnetic radiant imagery and other phenomena

Point Cloud comprises a collection of digital points of geocoded data, captured usually using a LiDAR sensor (can also be generated from photogrammetry), representing the 2.5D or 3D geometry and shape of real-world environments including natural features e.g. topography and built e.g. buildings

Remotely-Piloted Aircraft System (RPAS). A set of configurable elements consisting of a remotely-piloted aircraft, its associated remote pilot station(s), the required command and control links and any other system elements as may be required, at any point during flight operation. Can be used interchangeably with UAS

Remote Sensing is the acquisition of information about an object or phenomenon without making physical contact with the object, in contrast to in situ or on-site observation. The term is applied especially to acquiring information about Earth and other planets. Remote sensing is used in numerous fields, including geophysics, geography, land surveying and most Earth science disciplines (e.g. exploration geophysics, hydrology, ecology, meteorology, oceanography, glaciology, geology).

Topographic Survey is a survey characterized by capturing and recording large-scale detail and quantitative representation of relief features, usually using contour lines (connecting points of equal elevation), but historically using a variety of methods such as photogrammetry, LiDAR and Total Stations. Traditional definitions require a topographic map to record both natural and artificial features.

Total Station (TS) or total station theodolite (TST) is an electronic/optical instrument used for surveying and building construction.

Unmanned Aircraft System (UAS) An aircraft with no pilot onboard comprising the unmanned aircraft vehicle (UAV) , ground station (GS) and the data/telemetry communication link between the UAV and GS. Can be used interchangeably with RPAS

Unmanned Aircraft Vehicle (UAV) An unmanned aircraft (fixed-wing, rotary or hybrid)

Visual Line Of Sight (VLOS) operation means a type of UAS operation in which, the remote pilot is able to maintain continuous unaided visual contact with the unmanned aircraft, allowing the remote pilot to control the flight path of the unmanned aircraft in relation to other aircraft, people and obstacles for the purpose of avoiding collisions – typical VLOS distances are in the order of 300m to 500m.

1 Introduction

The motivation for this project stems from Gas Network Ireland's (GNI) core critical energy service activities of developing, operating and maintaining natural gas transmission and distribution networks and providing gas transportation services to suppliers and shippers. Underpinning this activity is a corporate commitment to responsible energy management practices and to carry out this activity in an environmentally responsible and sustainable manner (GNI Energy & Environment Policy, 2021).

> *"We have adopted an iterative multi-year approach to reducing the environmental impact of its business activities. Significant milestones on this journey have been the implementation of an Environmental Management System (certified to ISO14001) in 2012, achieving the Energy Management System certification (ISO50001) in 2014 and being one of the first companies in the country to achieve the Asset Management System Standard ISO55001 in 2015.*
>
> *We continued to published the annual Sustainability Report in alignment with the United Nations Sustainability Development Goals in 2021, outlining progress in implementing the principles of sustainable development across all aspects of our operations. Last year's report met the Global Reporting Initiative standard for sustainability reporting for the first time. Gas Networks Ireland won both the Green Business of the Year Award and the Green Large Organisation of the Year Award at the 2021 Green Awards." (Source GNI Environment Statement)*

A collaborative pathfinder R&D activity, coordinated by Maynooth University, commenced in 2019 with the U-Flyte team focused around research into drone technology and applications, to explore the role of broader Earth Observation in supporting GNI's mapping and monitoring tasks. Earth Observations deals with Satellite, Airborne and ground-based platforms including in-situ sensors to capture and record information about various real-world environments and processes. This study began by examining the role of drones but was broadened to include spaceborne satellite platforms and aircraft, equipped with latest optical, LiDAR, radar and navigation. Light Detection And Ranging (LiDAR) is a method for determining ranges by targeting an object or a surface with a laser and measuring the time for the reflected light to return to the receiver. LiDAR may operate in a fixed direction (e.g., vertical) or it may scan multiple directions, in which case it is known as LiDAR scanning or 3D laser scanning, a special combination of 3-D scanning and laser scanning. LiDAR has terrestrial, airborne, and mobile applications. The objective was to research, develop and test various innovative mapping and monitoring techniques that could be developed for both operational and strategic management of GNI's right of way (RoW) transmission network & AGI infrastructure throughout Ireland.

2 U-Flyte GNI Work-programme

The original work programme comprised four tasks shown in Table 1. These tasks were modified (Appendix 3) in terms of target activities and completion dates due to changing areas of interest for GNI as well as operational impacts of Covid-19 pandemic.

Task	Date of Delivery
Kick-off meeting for project	10th Sept 2021
T2.1 Use of combined Satellite and Drone sensors to detect and measure vegetation encroachment at selected sites. Some of this work will investigate the detection of Invasive Species such as Japanese Knotweed.	29-Apr-2022
T2.2 Dynamic Methane (CH_4) leak detection and measurement, from a Drone platform, over AGIs as well as along RoW	29-Apr-2022
T2.3 Use of Synthetic Aperture Radar (Sentinel-1) as well as other Optical Remote Sensing methodologies to gain a better understanding of flooding events at selected sites along GNI RoW. This will also involve time-series analysis, coinciding with historic flood events. Include Satellite & LiDAR Data Discovery.	27-May-2022
T2.4 Devising new aerial approaches to inspecting 'Markers' for defects, damage etc	27-May-2022
Project evaluation meeting (Remote session)	27-May-2022
Project close	27-May-2022

Table 1. Original 4 Tasks for GNI Project

Figure 1: Drones and Sensors tested and evaluated in the GNI Project

3 Aerial and Drone survey to support ROW Monitoring/3rd Party Intrusion

For gas network operators, it is important to maintain an up-to-date picture of the national pipeline network including ROW and associated assets. This requires regular mapping and monitoring surveys to understand the condition of the ROW and to detect any anomalous features or events and accurately predict when maintenance should be performed, thereby minimizing disruption of normal system operations. An efficient and fit for purpose monitoring programme results in reduced downtimes and higher system reliability. With high-quality geospatial information, interventions can be carried out and maintenance work can be optimised with the most efficient use of human resources.

There are various challenges in monitoring ROW in Ireland, these include the high incidence of cloud cover and frequent poor weather conditions. Cloud cover can result in reduce usefulness of multispectral Satellite data such as data received from the European Copernicus 10m pixel resolution datasets Sentinel-2 where each pixel represents 10m x 10m square on the ground. Multispectral imaging captures image data within specific wavelength ranges across the electromagnetic spectrum. The wavelengths may be separated by filters or detected with the use of instruments that are sensitive to particular wavelengths, including light from frequencies beyond the visible light range, i.e. infrared and ultra-violet. It can allow extraction of additional information the human eye fails to capture with its visible receptors for red, green and blue.

On the other hand, aerial monitoring can be costly and also dependent on favourable weather conditions. A monitoring service based on the exploitation of combined satellite imagery, aircraft and drone data may well provide a solution for more effective national scale ROW monitoring.

Traditional inspection utilises both airborne platforms (helicopters), and ‘boots on the ground’ (line-walks) to assist in conducting inspections. However, combining ground-based teams with airborne teams remains a costly and inefficient exercise. Some key constraints include:

1. **Data quality**: Although capable of long endurance and long range, helicopters may not be the most efficient tools for close range visual inspection of critical infrastructure assets with regards to data quality. Adverse weather conditions and operations in difficult terrain also increase potential data collection errors. Helicopters use an on-board visual spotter which requires manual interpretation of the imagery to extract relevant information.
2. **High-risk working environments**: Working in challenging terrain and weather conditions are often the main challenges for ground-based teams, whilst heli-operators face a dangerous task flying at low altitude along the gas network.
3. **Human error**: Given the intense manual nature of the inspection work, be it from a helicopter or ‘boots on the ground’, the potential for the human to make an error increases exponentially the longer the survey continues. This is noted in Gas Network Ireland’s tender requirements whereby “*the performance of the observer will be monitored on an ongoing basis to ensure potential issues on the network are being identified and reported appropriately. This will be done through spot checking of survey performance, monitoring of reports and attendance on some patrol flights by GNI nominated personnel*.”
4. **Cost Effectiveness:** Utility companies require weekly and/or fortnightly surveys to be undertaken to ensure no construction, development or other activities interfere with the pipeline by unknown 3rd party within close proximity (e.g. 100m) to their asset. In Ireland, the national gas transmission network is approximately 1,626km, 85km of which is surveyed on a weekly basis and 1,541km of which is surveyed fortnightly. The constant/repetitive nature of this work is costly and often

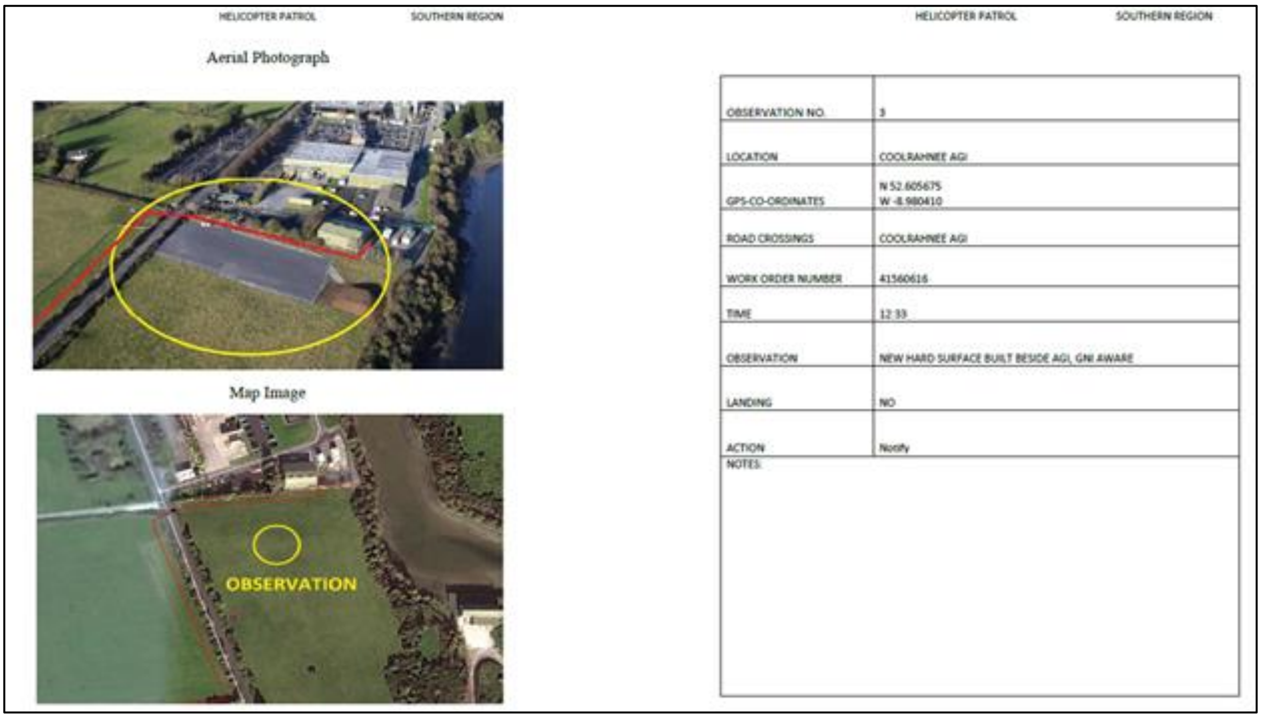
inefficient, and so the introduction of automated systems could (in the near future when airspace regulations and technology align) provide greater efficiency and reliability for monitoring assets across the network.

3.1 Test Case#1: Drones for GNI ROW monitoring / 3rd party intrusion

Gas Networks Ireland are required to carry out aerial surveillance of their network on a regular basis to ensure there are no un-authorised ground-works, building-developments or digging being carried out on or near the pipeline and no excessive vegetation growth on or near the pipeline. The current method of inspection is undertaken by a helicopter with a visual observer (spotter) on board. According to UKOPA, typical activities that the observer should be looking for include:

- construction of any building work which may infringe proximity or population density criteria
- any previously unknown third-party activity on or adjacent to the pipeline
- the condition of pipeline marker posts
- fires of any description – including straw burning
- tree felling and timber transportation
- discolouration of vegetation or other evidence of leakage
- blasting or mineral extraction
- ground movement
- erosion and changing water courses
- soil removal
- tipping
- vegetation overgrowth on easement

The manual recorded observations (notes/photographs of any intrusion) are provided to the GNI network operator in the form a short PDF report (Figure 2). This is effective in identifying issues, however, there is a heavy reliance on human interpretation, both at the acquisition stage and analysis stage. For example, the camera operator on board the helicopter can, through lack of concentration, miss a potential critical infringement. Also, accurately locating and cataloguing multiple inspection reports is difficult over time given the high frequency of aerial surveys which take place. These reports prove more useful at the time of inspection, rather than providing a more comprehensive ROW survey, capturing a complete, continuous record of the RoW. A continuous geospatial record, captured as a time-series, would help identify trends or specific areas of concern for network operators i.e. repeat infringement or increasing vegetation encroachment.


HELICOPTER PATROL SOUTHERN REGION

Aerial Photograph

Map Image

OBSERVATION

HELICOPTER PATROL SOUTHERN REGION

OBSERVATION NO.	3
LOCATION	COOLRAHNEE AGI
GPS-CO-ORDINATES	N 52.605675 W -8.980410
ROAD CROSSINGS	COOLRAHNEE AGI
WORK ORDER NUMBER	41560616
TIME	12:33
OBSERVATION	NEW HARD SURFACE BUILT BESIDE AGI, GNI AWARE
LANDING	NO
ACTION	Notify

NOTES:

Figure 2: Typical helicopter incident report following an aerial inspection survey

It is currently difficult for helicopters to survey under the approach path to the new runway at Dublin Airport due to high number of movements and airspace restrictions. This has caused delays in carrying out more regular monitoring of this critical section of pipeline. An alternative means of inspecting the 30km corridor of pipeline west of the runway were required. A traditional alternative method has been a 'line-walk' but this can be time-consuming since it covers >10km of ROW corridor.

A trial was conducted using drones to evaluate if this method might be a more efficient and cost-effective solution. A Data Privacy Impact Assessment (DPIA) was undertaken (Appendix 2) to ensure compliance with GDPR guidelines and permission was sought and granted by the Irish Aviation Authority in conjunction with Air Traffic Control at Dublin Airport to inspect this section of line. Permission was granted for regular aerial surveys over a 6-month window (Figure 3) with the option to extend this drone survey activity should it be required. Drones fly at a very low altitude, compared to conventional helicopters, and so the level of risk for such aerial activities in close proximity to airports is often considered lower risk than manned aircraft with appropriate risk mitigation measures in place. Drones typically operate at <100ft above ground level (AGL) whereas helicopters typically operate between 500ft and 1000ft AGL when inspecting a pipeline. A drone can usually land in tens of seconds if required whereas moving a manned helicopter out of the path of an in-bound/out-bound aircraft can take a lot more time in terms of the helicopter pilot manoeuvring in/out of active approach and also result in higher workloads for ATC together with higher overall traffic management risks.

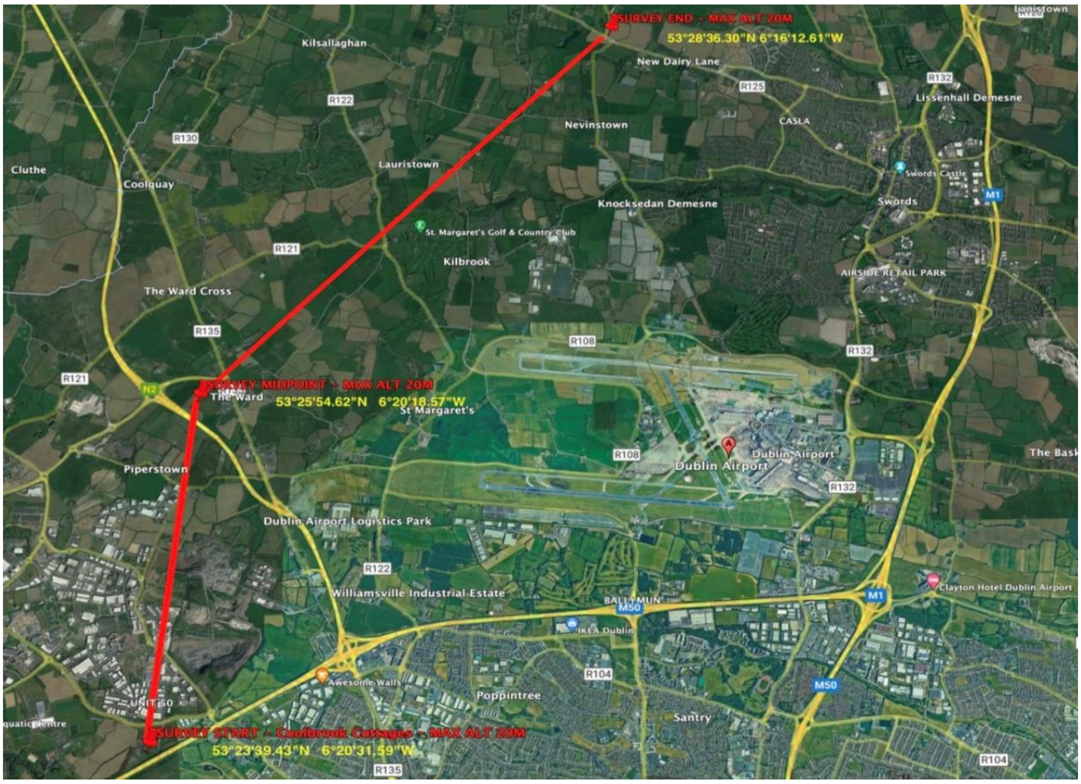


Figure 3: Section of GNI's pipeline which was inspected using drones (highlighted in red)

During the drone survey a livestream of geocoded video (video and position of drone on a moving map) from the drone operator in the field was provided to the flight operations team at a remote operations centre for oversight and safety purposes and this enabled personnel at a remote location the ability to view the video feed from the drone in real-time. For future surveys, a live feed from the drone could be streamed to a GNI operations co-ordination centre or to a designated visual inspector/spotter who does not need to be on site with the drone operations team, thus saving additional resources and enabling specialist inspectors to access a live feed from a remote location i.e. GNI headquarters (Figure 4).

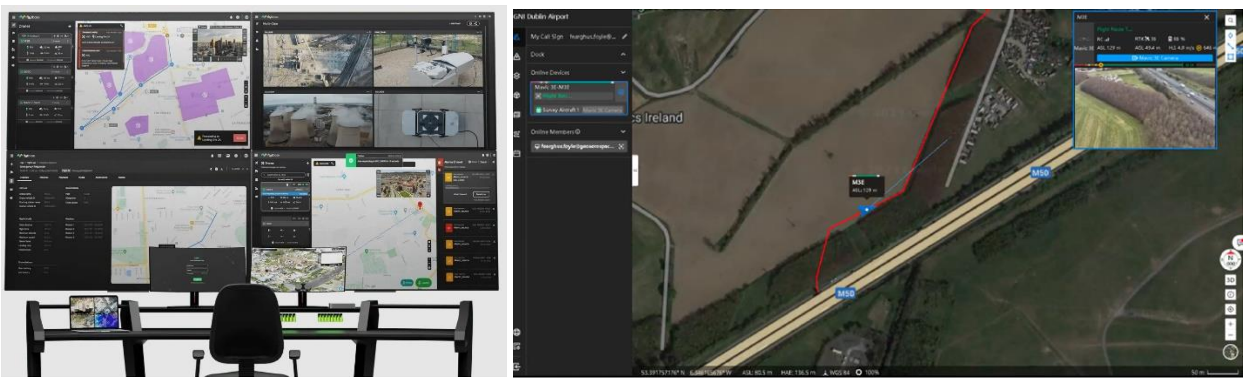


Figure 4: Remote Operations Centre for drone operations (left image) and live stream video and map showing position of drone and drone operator in the field (right image)

The drone survey was carried out over the course of a day at Dublin Airport and the data was collated and presented to GNI in the form of an inspection report to mimic current manual observations using the helicopter. During this survey, several issues were highlighted by the drone team on site. These observations included ongoing construction activity close to and along the pipeline network. These activities were notified immediately to the GNI team. The two locations where potential issues were identified on this section of line were recorded at Rosemount Business Park and at Roadstone Quarry. Figure 5 & Figure 6 detail video image together with the position of drone, time/date stamp and overview map of survey area with image centred on pipeline route.

- **Cappagh Road in Rosemount Business Park**: The drone highlighted ongoing construction immediately adjacent to the pipeline (just to the left of the centre - in the image) close to the business park as can be seen in Figure 5 below.

Figure 5: Cappagh Road located in Rosemount Business Park

- **Roadstone Quarry:** The drone highlighted/identified potential encroachment on the pipeline immediately adjacent to the quarry edge (left side of image) as can be seen in Figure 6 below.

Figure 6: Rosemount Business Park within Roadstone Quarry

The results of the drone survey demonstrate the potential of drones to carry out visual inspection in hard to reach or challenging areas where more conventional methods, e.g. helicopter surveys, are restricted. Some key advantages over helicopter patrols include:

- Drones offer a more detailed geospatial assessment of the environment of the pipeline – critical details can be extracted from the data such as exact position of 3rd party infringement, time/date stamp and overview map of survey area at the time of inspection.
- Reduced risk of human error – drones follow an automated route over the pipeline and do not require the operator to focus on following a flight path with manual input and so there are less distractions and less change to miss a critical infringement.
- Drones offer potential to relay a live stream to a remote location for oversight by a specialist observer.
- $C0_2$ emissions are significantly less with drones (battery operated) than helicopters.
- Drones offer the potential to use Machine Learning (ML) to process video data-streams captured by these aerial platforms, automatically highlighting un-authorised events, building activities etc. These new Artificial Intelligence (AI) techniques may result in more cost-effective inspection processes.

Artificial intelligence (AI) is the ability of machines to perform tasks that are typically associated with human intelligence, such as learning and problem-solving. Traditional AI domains include reasoning, knowledge representation, planning, learning, natural language processing, perception, and support for robotics. Machine learning (ML) is an umbrella term for solving problems for which development of algorithms by human programmers would be cost-prohibitive, and instead the problems are solved by helping machines 'discover' their 'own' algorithms, without needing to be explicitly told what to do by any human-developed algorithms.

Currently, Drones are not suitable to replace the work of conventional helicopter surveys due to a combination of regulatory (operator to remain within line of sight of drone) and technology (typically 30-minute survey due to battery limit coupled with relatively slow survey speed 30km/hr). Drones should be considered as a compliment to conventional helicopter surveys, for example, where rotary craft cannot access certain sections of the network, rather than replace them. Drones will play a much more significant role in the visual inspection of pipeline networks, possibly in the medium to long term (within 2-5 years), with appropriate BVLOS approvals. Beyond Visual Line Of Sight (BVLOS) operation means a type of UAS operation which is not conducted in VLOS i.e. where the drone is no longer in view of the operator. Carrying out these types of test flights, in collaboration with the Irish Aviation Authority, will help with generating flight operations data and so help with the a more expedient regulatory approval of BVLOS operations.

In the interim period, GNI should consider integrating aspects of drone operations into the organisation even in a limited capacity to ensure operational, legal and safety protocols are all in place when regulations and technology do align. Such developments could include more frequent but short section aerial patrols over inaccessible areas, development of a Common Operational Picture and/or Drone Operations Centre in tandem with gaining approval for BVLOS Operations at a strategic test site along the pipeline network.

3.2 Test Case#2: Aerial LiDAR & Optical Imagery for targeted ROW mapping

The gas pipeline network and its associated infrastructure are a critical asset of national importance which requires up to date geospatial information of its condition throughout its lifecycle i.e. at the planning, construction and operational stages. This can include information of the pipeline route itself, Above Ground Installations (AGI's) and the surrounding environment (terrain, vegetation etc.). Currently this GIS information is obtained by a combination of sources i.e., weekly/bi-weekly helicopter patrols, line-walks every four years and utilisation of historic GIS datasets. Geographic Information System (GIS) comprises integrated computer hardware and software that store, manage, analyse, edit, output, and visualize geographic data. Much of this information however requires significant human interpretation and so may be subjective in nature for example in classifying objects or estimating distances etc.

The utilisation of automated remote sensing techniques, specifically survey aircraft, for national scale mapping and monitoring offers a scalable solution to provide up to date geospatial information of the entire network, particularly at the planning and development stages of new routes. In addition to regular helicopter inspection surveys during their operation, a nationwide aerial survey programme (LiDAR and image-based surveys) which captures mapped data over the entire network, could provide GNI with additional critical information on the condition of the network for the purposes of Right of Way management (vegetation encroachment, land classification, line marker inspection, reinstatement work assessment etc.).

A survey aircraft (Figure 7) which was equipped with a LiDAR scanner for collecting 2.5D information of the terrain and optical (blue-green-red composite colour images) camera sensors for creation of high resolution 2D maps was flown over approximately 100km of the GNI pipeline in west Cork. The goal of this test was to assess the information content of the geospatial data captured by the fixed-wing survey.

Figure 7: Aerial survey aircraft equipped with LiDAR and RGB sensors (note sensor attached to starboard wing strut)

Flight plans were generated to ensure complete coverage of the route (Figure 8) in advance of any surveys. These flight plans can be used repeatedly if the network is to be surveyed regularly to ensure consistent data is collected each time. Once flight plans were generated, the aircraft was deployed over the site for half a day and the data (imagery and associated navigation) was then post processed and delivered as LiDAR point cloud and orthomosaics to GNI. Orthophotomosaic or Orthomosaic is a raster image made by merging orthophotos — aerial or satellite photographs which have been transformed to correct for perspective so that they appear to have been taken from vertically above at an infinite distance. These geospatial products were published on a cloud platform enabling GNI personnel rapid data discovery and visualisation of these 2D and 2.5D geospatial datasets.

Figure 8: Aerial survey aircraft flight lines over a section of the pipeline in East cork – the aircraft follows a predetermined flight path to ensure that data is collected for the entire pipeline and surrounding environment

In addition to this large-scale aircraft survey, localised drone surveys were undertaken across specific parts of the GNI network to showcase the various datasets that can be obtained using high resolution optical photogrammetry and LiDAR sensors. Photogrammetry is the science and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring and interpreting photographic images and patterns of electromagnetic radiant imagery and other phenomena. These included aerial surveys at the following locations:

Aircraft Surveys:
- Cork LiDAR and photogrammetry surveys over approximately 100km of GNI network

Drone Surveys:
- Gormanstown AGI LiDAR and photogrammetry surveys
- Photogrammetry surveys at Boyne Valley, Shannon, Fermoy, Glanmire and east Cork (near Aghada)

The aircraft & drone surveys provide additional mapped information of the route during planning, construction and operational stages of a gas pipeline lifecycle. This geospatial information includes:

Planning:
- Topographic Surveys (LiDAR & Photogrammetry) for high resolution mapping and pipeline surveys
- Video flythroughs for initial route options/planning

Construction:
- Track & record on-site progress
  - Monthly progress reporting
- Streamline communication and decision-making
  - Remote / Off-site decision support
- Build detailed maps and 2.5D models
  - 2.5D Reconstruction
  - As Built Models
- Security Surveillance
  - Personnel Safety
  - Keep site staff away from dangerous areas

Operations:
- Visual inspection & line monitoring
- Leak detection
- Subsidence assessment
- Sonar – river depth profiling

Included below are some images of the deliverables presented to GNI as part of this project at various sites across their network. Figures 9 & 10 depict the results of the drone surveys over Gormanstown AGI which created both 2D maps and 2.5D models of the AGI. Traditionally, this type of work would require surveyors to enter the site and using more conventional tool for example, a Total Station, manually measure the locations and dimensions of various objects, infrastructure and building. A Total station (TS) or total station theodolite (TST) is an electronic/optical instrument used for surveying and building construction. In this case, the drone survey using LiDAR produced a 2.5D model (Figure 10) of the AGI facility without the requirement to access the site itself, enabling assessment/review of the as-built site to be carried out remotely.

Figure 9: Drone imagery (left image) and 2D photogrammetry survey (right image) of Gormanstown AGI showing high resolution mapping with geospatial information available to analyse

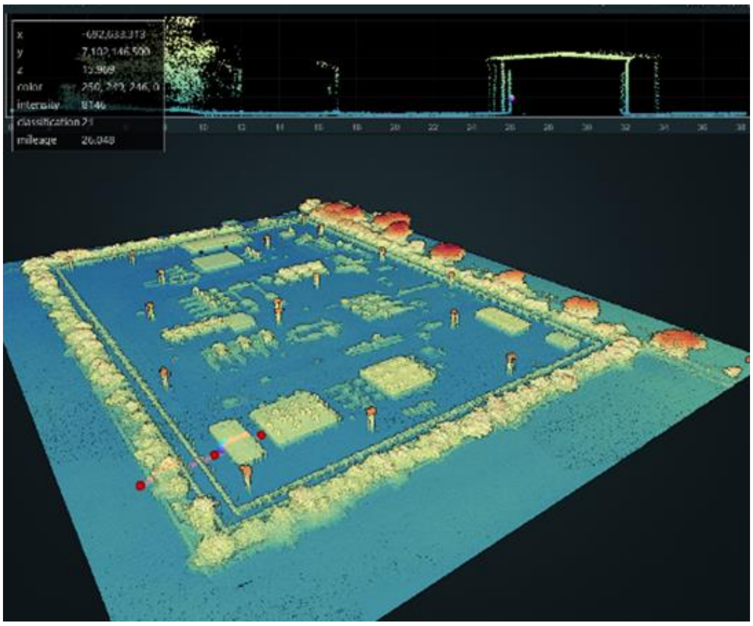


Figure 10: Drone LiDAR Survey over Gormanstown AGI showing as built 2.5D model of the structure with geospatial information available to analyse

Figures 11 & 12 below, details further examples of data collected using the survey aircraft over West Cork. In this case, the high-resolution imagery of the pipeline and AGI's was used to produce high resolution orthoimages of the route network for the purposes of detecting markers. Measurements and dimensions of objects contained in the orthomosaic can be carried out by the user. Aerial surveys produce useful image-maps which can be used for multiple planning, operational applications. These geocoded image-map outputs can be more useful than single, *once-off, oblique photographs* captured by a human operator since the entire section of ROW can be recorded, including markers, and measurements together with features attributes which can then be extracted for all ROW objects post-survey.

Figure 11: 100km route covered by survey aircraft (left image) and shows zoomed in area with existing pipeline route overlaid and markers clearly visible in the data (right image)

Figure 12: Pipeline route captured by survey aircraft (left image) and zoomed in area of the route with markers clearly visible in the data (right image), ground photo of marker also inserted in right image

In addition to helicopter patrols, the data captured from a survey aircraft can also aid in monitoring the pipeline for 3rd party encroachment e.g. site preparation for agriculture activity or building, as is evident in the example below (Figure 13).

Figure 13: Aerial survey data (orthomosaics) enables precise measurements of objects captured in the imagery

Also visible from mapped aerial survey data are areas of reinstatement works post construction (Figure 14). These areas can be recorded, quantified and monitored over time with regular aerial surveys. The advantage of geocoded map products such as orthomosaics and LiDAR surveys is that measurements can be taken and attributes of objects extracted to determine set back distances from pipeline ROW such as the development seen in the image below.

Figure 14: Aerial survey data (orthomosaics) enables reinstatement works to be clearly identified

The survey aircraft was able to capture and produce high resolution aerial maps of a sufficient quality that could be utilised for assessing the location of markers. Key advantages of aircraft and drone surveys include:

- Up to date geospatially mapped information of the network can be collected efficiently and quickly with survey aircraft.
- High resolution aerial maps can be captured of a sufficient quality that can be utilised for assessing the location of markers.
- Surrounding terrain and vegetation analysis can be performed using the data.
- Topographic surveys can be produced from the data collected.
- Repeat surveys can be carried out at set intervals to help identify change and these datasets can be easily stored in the cloud to detect and monitor change over time.

3.3 Test Case#3: River Crossing Surveys

River crossings often present logistical and operational challenges to network operators when assessing the condition of pipelines which traverse these corridors. Currently these hard-to-reach areas are inspected by divers, sometimes deployed using boat crews, which can result in higher degrees of risk to the various team members. The purpose of these surveys is to measure the dept of the river crossing and to check for any subsidence of the pipe, status of river floor as well as potential bank de-stabilisation issues over time. These are challenging and dangerous environments to work in and any remote sensing technologies which can support the inspection and survey of river channels not only provides useful data but can also help reduce risk to field-staff.

In order to test and develop alternative methods for carrying out these inspections, drones, equipped with sonar devices, were deployed over two river crossings; River Boyne (shallow water) and the River Shannon (deep water).

In order to perform this drone survey, a low-cost, compact sonar device was attached via a winch system to a drone and then deployed over the river crossing. In advance of the surveys, automated flight plans were generated over the pipeline route and the drone operator released the sonar device into the water via the winch along the river channel from a safe distance. An example of the flight plans and drone equipped with the sonar device can be seen in Figure 15 below over the River Shannon. In addition, secondary drones quipped with optical (RGB & multispectral sensor) and LiDAR scanners were also deployed to produce high quality topographic maps for the purposes of constructing a useful geocoded 2.5D model of the surrounding terrain and embankment profile.

Figure 15: Flight profile over river crossing (left image) and sonar device ('orange' ball shaped object) deployed under drone (right image)

Initial tests of drone-based sonar have indicated a potentially useful method for river depth profiling that can be easily integrated into current work practices. Drone based sonar should be compared to data collected by divers or boats to provide a more accurate assessment of the results and associated data quality. Drones equipped with sonar devices may provide an effective alternative to deployment of divers. In principle, the use of airborne sonar does offer significant potential to minimise human risk when compared to traditional methods as the drone can be operated remotely from a safe distance. Nevertheless, challenges do remain for drones such as vegetation (trees/shrubs) along the river banks which can result in snagging the sonar line. Further work should be carried out here using more sophisticated soar devices and at the same time as the diver survey. Some of the results from the River Shannon sonar survey are detailed below in Figures 16 & 17.

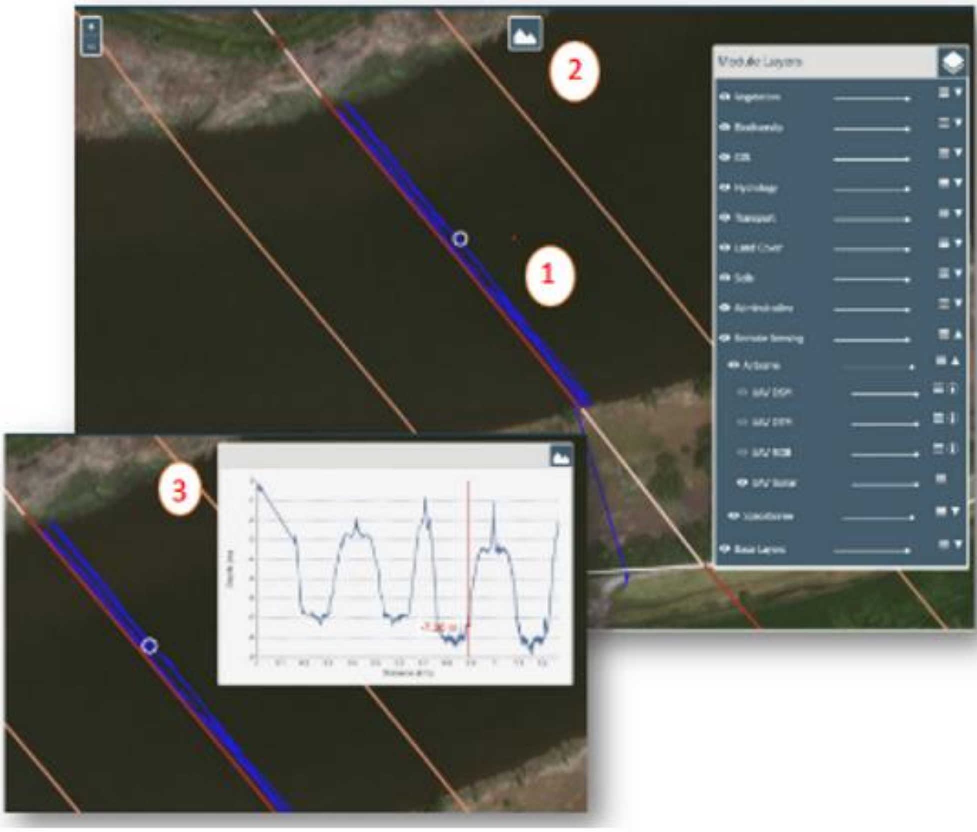


Figure 16: Data captured at the Shannon River crossing (upper image) and cross-section detail (lower image)

Figure 17: Topographic information of the River Shannon embankments; imagery (upper image) and DSM (lower image) accessible through the GNI prototype data platform

3.4 Test Case#4: Gas Leak Detection

Methane emissions are a major focus of the IPCC to control climate change and the oil and gas industry is under pressure to find ways to cut methane leaks from gas pipelines both to improve safety and to reduce the environmental impact. Detecting gas leaks is a challenging and complex problem, particularly identifying leak points along a nationwide network of pipelines. Finding the location of a gas leak requires a team of inspectors who utilize an array of detectors and monitoring equipment which can be challenging. Traditional gas leak detection methods (fixed, automatic and portable) have been beneficial in industrial applications, however, there remains issues relating to effective detection in a timely manner as well as reducing risk to maintenance personnel.

Visual ground-based or helicopter patrol inspections are often used to identify areas close to the pipeline where vegetation has changed in colour due to methane leakage. While helicopters are generally more cost-effective per kilometre than drones (due in part to current line of sight regulations for drones), these platforms nevertheless are perceived as nosier, more intrusive and producing higher emissions so alternative means are necessary.

In order to test more novel approaches, a methane detection camera was acquired from Workswell via their Irish Distributors, Butler Technologies, in order to test the capability of a drone-based analyser system to determine whether it can offer an accurate and effective solution to gas leak detection. The sensor used was a Workswell Wirus GIS-320 which was mounted on an DJI M600 drone, Figure 18 below.

Figure 18: Workswell Methane Sensor GIS-320 mounted on a DJI M600 drone

Due to the complexity (and safety) of operating this heavy-lift drone and sensor in an active AGI facility, it was determined that a series of ground-based tests would be undertaken instead. Based on a detailed risk assessment of the proposed site at Abbottstown AGI by the drone operations team, it was agreed that drone flights would not take place at this location due to specific site constraints which would impact safe operation of a complex drone/sensor system. The specific site constraints were assessed under current aviation regulations i.e. operations within both Open Category and Specific Category. Safety buffers and flight profile configurations are detailed in Figure 19 below. Having reviewed both potential flight scenarios, it was decided that ground tests at this specific site would be more suitable, given the complex nature of the drone/sensor setup.

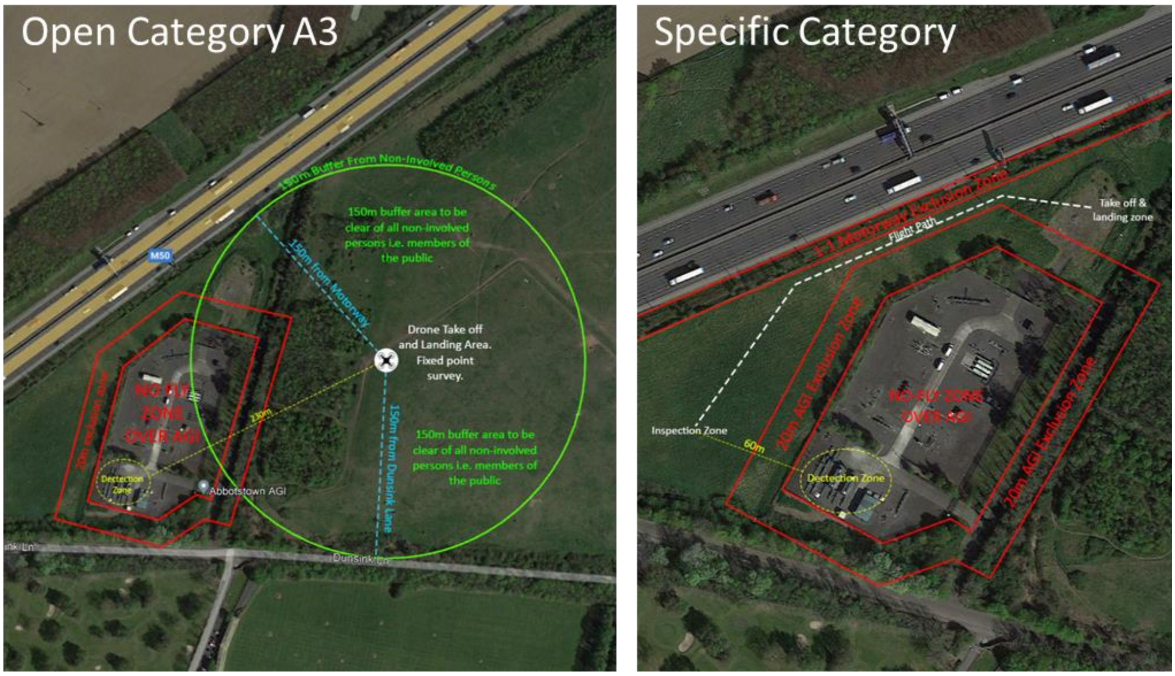


Figure 19: Abbottstown AGI - airspace restrictions illustrated when operating under Open Category, highly restricted (left image) and Specific Category, more flexible, (right image)

Prior to the site visit to the AGI, several controlled tests using butane gas were undertaken to test the sensors capability i.e. in a sheltered environment with no wind and an exposed environment with wind. The drone and sensor were configured to emulate real world remote-control operation. Butane gas was emitted from the cylinder and recorded using the Workswell Methane Sensor GIS-320, Figure 20. The gas was not visible to the naked eye and was only visible when recorded by the sensor.

Figure 20: Ground tests using butane gas in controlled sheltered environment – thermal view of gas leak (main image) depicts gas emission and image of gas leak which, was not visible to the naked eye (RGB thumbnail image upper right)

The methane sensor was further tested in a number of range field tests (5m – 50m) with butane gases emitted under windy conditions. The gas which was otherwise invisible to humans was detected by the sensor at close range (5-10m), Figure 21. At longer ranges (50m), the results proved more challenging, with high wind speeds resulting in rapid gas dissipation once emitted from the cylinder.

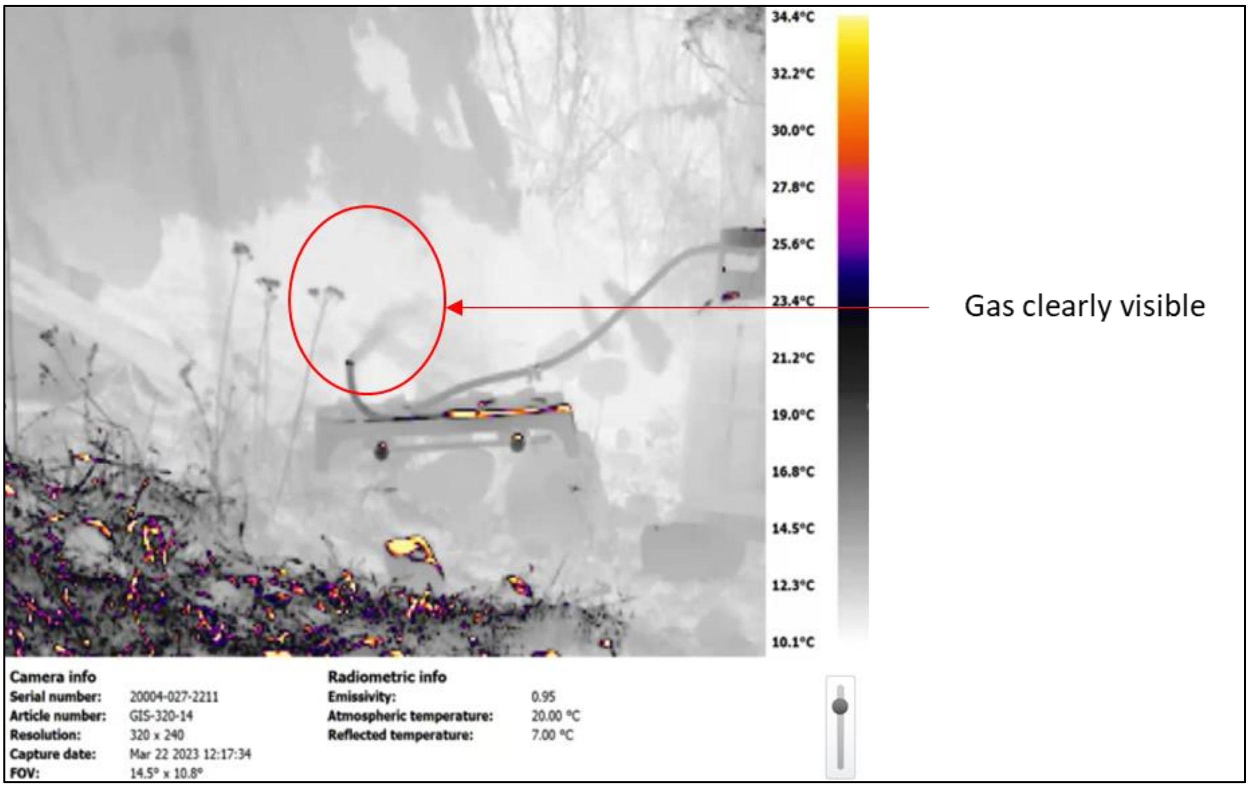


Figure 21: Ground tests using butane gas in controlled windy environment – thermal view of gas leak shows gas emissions whilst this was not visible to the naked eye

The final tests occurred at Abbottstown AGI facility and the results were conclusive in so far as a small plume of gas was observed from the flue stack on the right but it was challenging to distinguish this from dynamic cloud movement in the sky. This can be seen in Figure 22 below, however challenges still remain in terms of the environmental conditions at the time of survey, such as wind and cloud cover which reduce the ability to detect gas. Further work is required to assess the capability of optical sensors to detect methane leakage.

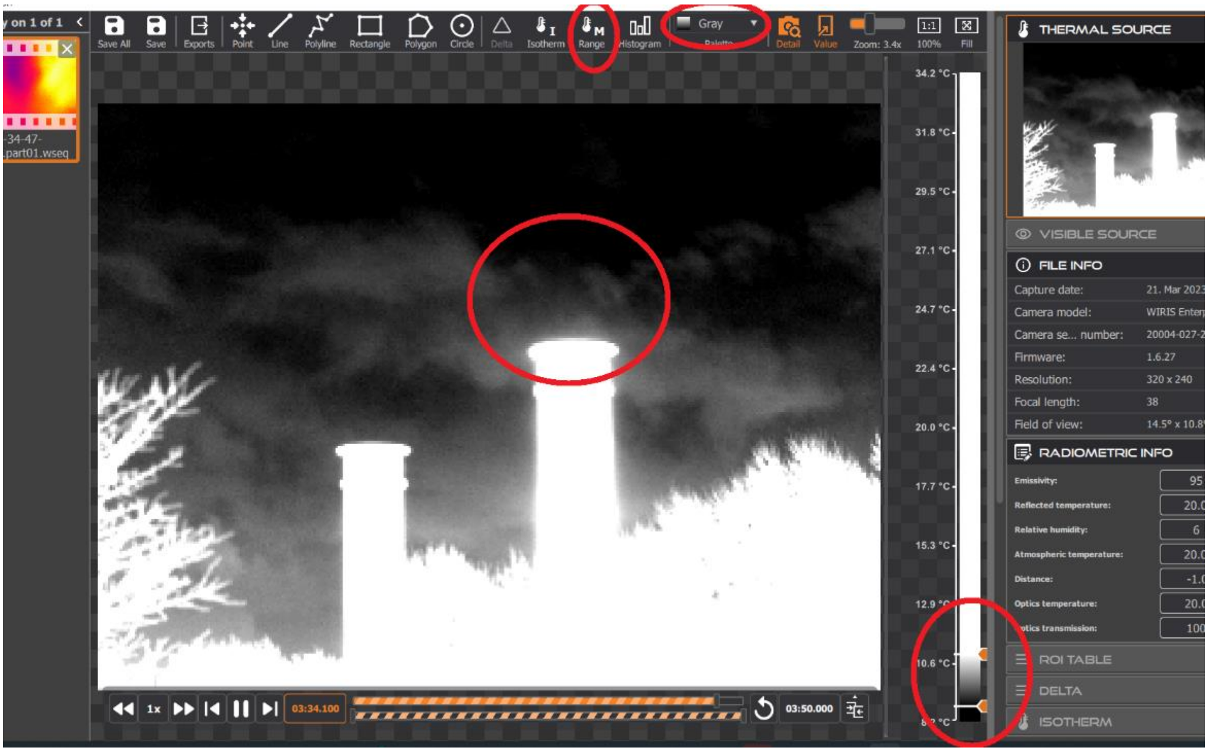


Figure 22: Gas leak detected at Abbottstown AGI (note right flue stack) – this screen-shot image depicts gas trace emissions from the flue stack but can be difficult to see against the backdrop of moving clouds

A heavy-lift drone would be more suitable to test these more complex and often times larger sensors at an AGI facility. Alternative sensors have appeared on the market and it is worth exploring a number of these alternative methane gas sensors. It is also worth considering the use of a tethered drone system (a drone physically tied to a take-off point) due to the inherent risk associated with operating drones at an AGI facility. Tethered systems are an effective method of mitigating risk associated with 'fly-aways' and may be more suited to AGI monitoring. They also have the advantage of providing long flight times as the tethered cable can be used to supply power to the drone in addition to restricting its ability to fly away.

Introducing drones as a potential solution to gas leak detection can also significantly reduce risk exposure to humans, since detection, with the right sensor, can be carried out by the drone, potentially at 100m to 150m distances from the source of leakage. However, careful consideration needs to be given to the sensor integration with a drone (fully integrated methane sensor is preferable), operational limitations at AGI's (tethered vs non-tethered) and sensor data quality and reliability in detecting the leaking gas.

3.5 Main findings Aerial platforms, Drone Mapping & Monitoring tests

Various drone platforms (Hybrid, VTOL and Tethered) were assessed during this initial performance review. A number of test surveys were carried out over existing ROW sections; Cork, Limerick and Meath which includes examples of general rural ROW, heavily vegetated ROW and River crossings (Boyne & Shannon). Data captured included optical datasets which were used to produce georeferenced video, ortho-mosaics and 360-degree panoramas as well as geocoded point cloud datasets. One set of tests focused on the assessment of drones equipped with an optical Methane sensor for gas detection.

General Observations

- **Safety, Security & Privacy**: There are Safety, Security, Privacy, Cost & Technology aspects to consider when using Drones
- **Operational Costs:** Cost of drones & mapping sensors (Optical, LiDAR, Navigation) have decreased over last five years
- **More complex mapping & monitoring tasks:** Potential for using more sophisticated sensors (optical methane detection for gas leak detection, bathymetry for river environments, GPR for underground service mapping)
- **Information Content:** Drones are capable of capturing very high-quality, high-resolution image (2D maps) and LiDAR (2.5D models) data which, when geocoded, enables precise, detailed measurements to be carried out over any component (e.g. AGI) or area of the network.

ROW Mapping

- **ROW Mapping**: Drones currently useful for localized (typically 500m radius) mapping and monitoring including inputs into vegetation encroachment and un-authorised development
- **Conventional survey aircraft and helicopter:** These manned-platforms will still have a key role to play in monitoring and mapping GNI's network in the short term. Consideration should be given to recording both optical and LiDAR data using conventional aircraft and helicopter platforms. This will require cloud solutions for cataloguing and storing large volumes of geospatial data, however these datasets can be converted into actionable reports and work orders to greatly increase operational efficiency across the network.

River Crossings

- **River Crossings**: Sonar devices deployed on a drone for the purposes of measuring river depth profiles at selected river crossings demonstrated good potential. Further work is required to test more sophisticated sonar devices.

AGI Monitoring

- **AGI Monitoring & Gas Leak Detection**: Methane detection from drones does appear to have significant potential, specifically at AGI's, but careful consideration needs to be given to the sensor integration with a drone (fully integrated methane sensor is preferable), operational limitations at AGI's (tethered vs non-tethered) and complexities around the quality of the data and subsequent review.

3.6 Industry Trends

- Longer distance, Beyond Visual Line of Sight drones will gradually become more common place with European aviation authorities now beginning to approve use cases for these long range operations.
- Long distance, remote control, autonomous drone operations, using new technologies e.g. Dock Stations, Figure 23, have already begun to appear and will become more ubiquitous over next 5 years.
- Artificial Intelligence (AI) will play an increasing role in GNI's Right of Way mapping & monitoring – not just in Data Capture but also Analysis and Decision-Making support i.e. automatically identifying and classifying 3rd party encroachment e.g. machinery/vegetation.

Figure 23: Drone dock stations: Remote, Long distance BVLOS control of drones are currently undergoing testing in Ireland for various remote, mapping tasks.

3.7 Conclusions

The main conclusions include;

- **ROW Monitoring/Inspection**: Drone surveys have an important role to play in monitoring GNI's infrastructure and assets, reducing risk to maintenance and survey personnel as well as reducing costs.
    - Wider deployment of drones is impeded by current Drone operation restrictions which constrain operation to typically <500m from the operator. These restrictions are expected to ease over coming 5 years to gradually enable beyond visual line of sight (BVLOS) operation.
    - Drones should therefore be considered as a compliment to helicopter platforms rather than replace these aerial platforms at the present time.
    - GNI should consider integration of certain drone operations into current mapping and monitoring workflows. These include short ROW sections where detailed geospatial data is required as well as sections and locations where helicopter survey may be unable to operate.

4 Satellite imagery for remote sensing of vegetation encroachment

Vegetation encroachment monitoring is of interest to GNI to ensure that pipeline infrastructure and ROW is not affected by unmanaged vegetation growth of trees, gorse etc. Unmanaged vegetation growth can impede top-side regular ROW pipeline surveys and also may affect the pipeline itself with underground root development etc. Another important part of this study is the ability to detect unauthorised development due to change detected in the spectral signature usually associated with normal grass, shrub or Hedgerow growth.

Vegetation encroachment monitoring comprises data captured using Satellite such as European Copernicus Sentinel-2 (10m pixel resolution i.e. each pixel covering 100 sq.m of area) as well as more detailed data captured using aerial/helicopter and drone platforms. The vegetation encroachment analysis uses cloud free Sentinel-2 data available on the Terrain-AI open data cube platform. Three locations in Shannon were tested as a proof of concept. A buffer of 50 meters on either side of gas pipelines was created for restricting analysis only to areas close to the pipelines. Sentinel-2 images at 10*10 sq. m pixel resolution during the years 2015-2021 were selected for three sites with different encroachment situations as shown in Figure 24 below. The three sites show different vegetation cover around the pipelines i.e. tree-covered, general vegetation-covered and gorse-covered. A general seasonal pattern emerges in the buffer area, where vegetation is greener in the earlier half of the year and then gradually dries away in autumn.

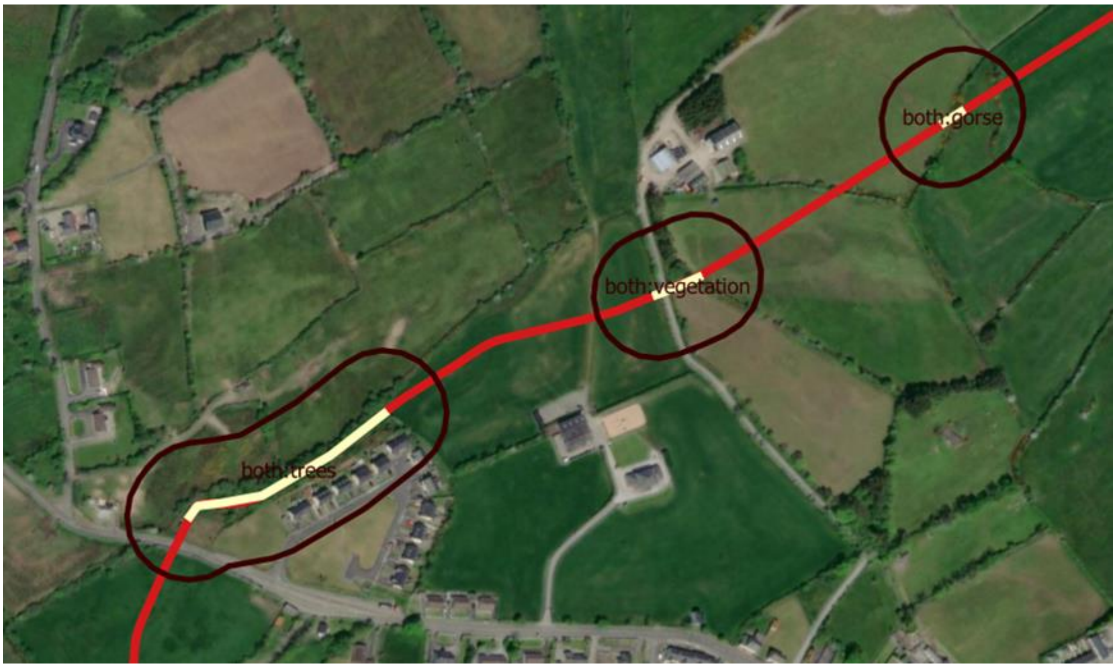


Figure 24. Pipeline in red, encroached areas in yellow and 50m buffer around encroached areas in black. These areas were examined using Sentinel-2 data.

Subsequently, the Normalised Difference Vegetation Index (NDVI) was calculated for each temporal sentinel-2 image. NDVI is a ratio between the near infra-red and red reflectance, and is widely used for monitoring vegetation greenness, density and health. It is an unitless measure and ranges from -1 to 1, where water and soil are below 0 and 0.1 respectively in the scale. Values beyond 0.2 in the NDVI scale includes mid to high density green vegetation. The NDVI images from the month of June of each year were stacked together (to select only peak vegetation growth/ late-spring images and to remove seasonality in the yearly time series) and their linear trends were calculated. Increasing trends in June NDVI over the years indicate increase in vegetation vigour and hence a higher risk of vegetation encroachment. Analyses of June NDVIs shows that the majority of the pixels in all three sites remain vegetated (with NDVI > 0.2) through the years (Figures. 25, 28, 30). The June NDVI values at the pixel level also reveal increasing linear trends around the pipelines (Figures. 27, 29,31). The Sentinel-2 data (like any optical dataset) is affected by cloud cover and has data available only every 5-6 days. It is expected that with the use of higher temporal resolution drone or Very-High-Resolution data (Pleiades 1.5m or similar), the probability of encountering cloud free images would increase.

Figure 25 shows the cloud free true colour images obtained for the month of June at the three covered sites across 2015-2021. The varying greenness in the temporal images is visible in these true colour images. This greenness of vegetation was quantified using the NDVI image for each corresponding date as shown in Fig 26. The changing June greenness or NDVI values is clearly seen in the figure. The buildings on the right side of the site consistently show figures with the lowest NDVI value (dark red colour) as expected.

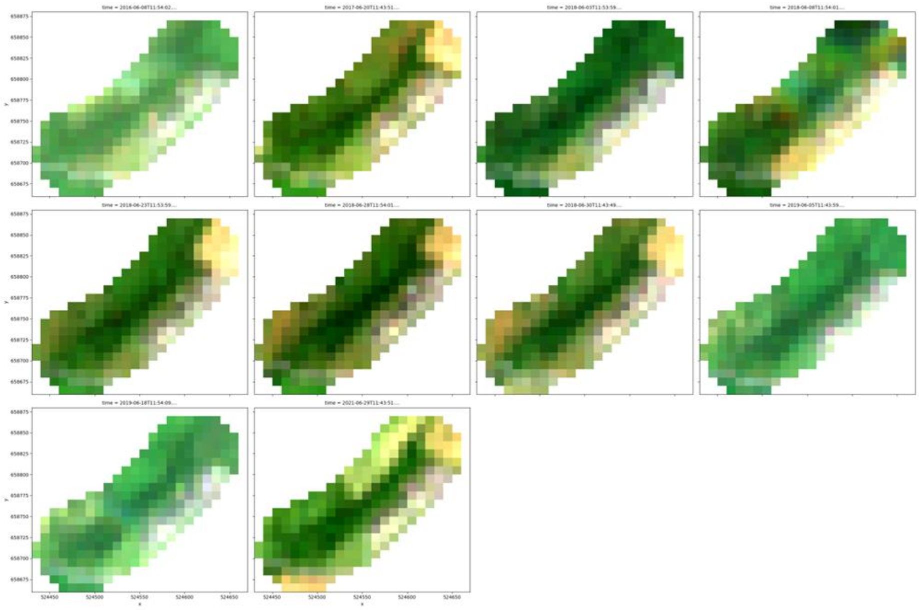


Figure 25. A selection of cloud free June month true colour images for the tree site for the years 2015-2021.

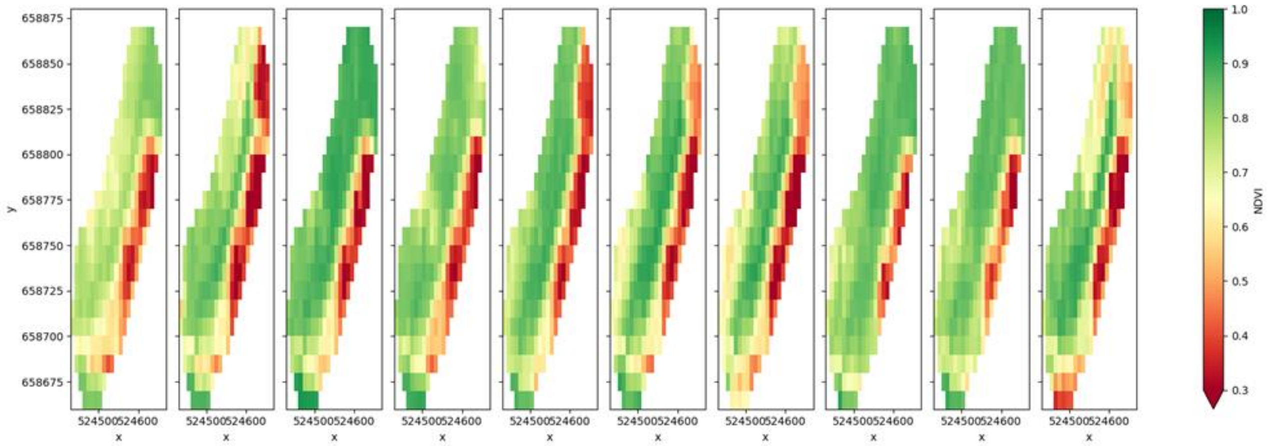


Figure 26. June month NDVI images for the three sites for the years 2015-2021. NDVI images for different years show high NDVI values for majority of pixels and the right portion of the site is covered with low vigour vegetation (including buildings/ houses).

Analysis of linear trends of June NDVI values at the three covered sites (Figure 27) reveals varying spatial patterns. A decreasing trend is visible (dark red colour) in the southern part of the site. The region around the pipeline however shows increasing trends (in dark green colour) and indicates increasing vegetation vigour/greenness. Such areas could be more susceptible for encroachment and need further investigation on the ground.

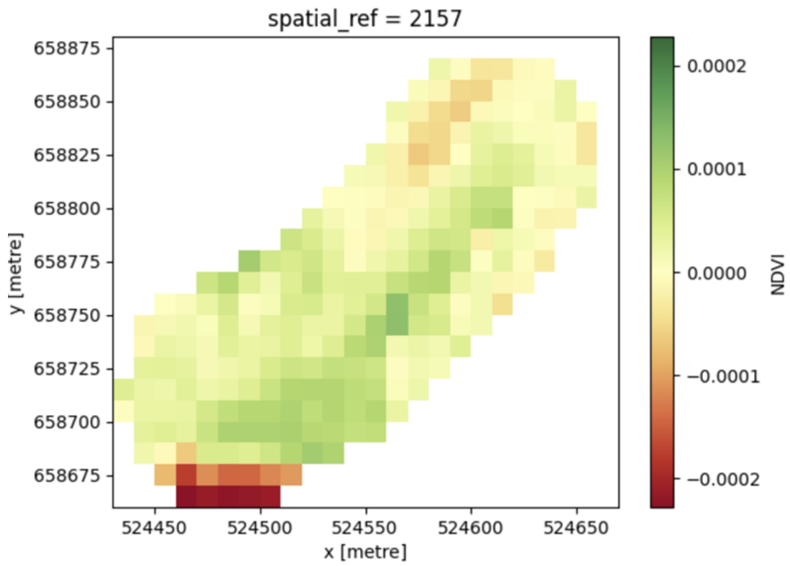


Figure 27. Pixel wise linear trends for June-NDVI at the tree site during 2015-2021. Note: greener pixels show increasing greenness (positive slope) through the years and hence at higher risk of vegetation encroachment.

Similarly, Figure 28 shows the June NDVI images for the gorse covered site. The greenness of the site changes across the years but remains covered with vegetation at all times (mostly above ~ 0.4 in the NDVI scale). Analysis of NDVI trends (Figure 29) for the period reveals mostly decreasing values. The area immediately around the gas pipeline however shows very weak positive trends.

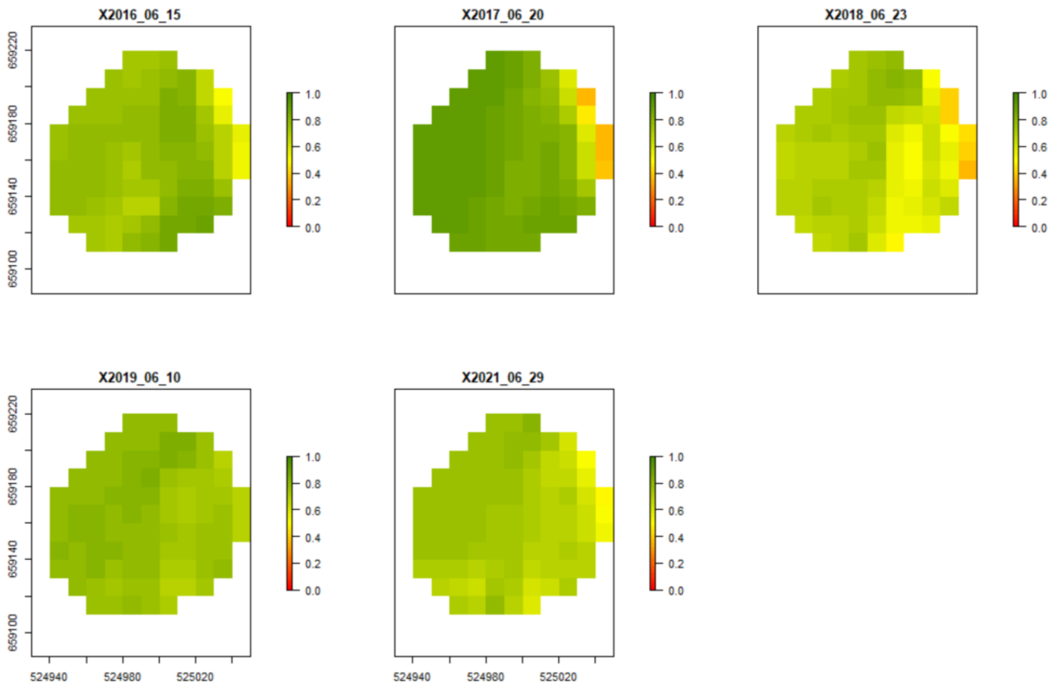


Figure 28. Selected June images for different years at the gorse site shows high NDVI values and hence is completely covered with vegetation across all years.

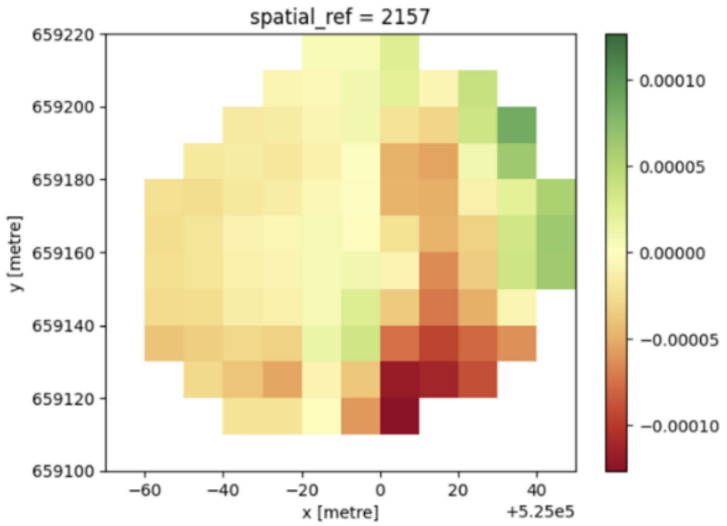


Figure 29. Pixel wise trends (for the gorse site) for June-NDVI during 2015-2021. Note: greener pixels show increasing greenness (positive slope) through the years and hence at higher risk of vegetation encroachment.

The June NDVI images for the vegetation covered site is shown in Figure 30. Majority of the pixels show medium density vegetation cover (NDVI >=0.2) across the years. The linear trends of June NDVI (Figure 31) shows majorly declining trends except for some regions to the north of the gas pipeline, probably due to presence of tree cover.

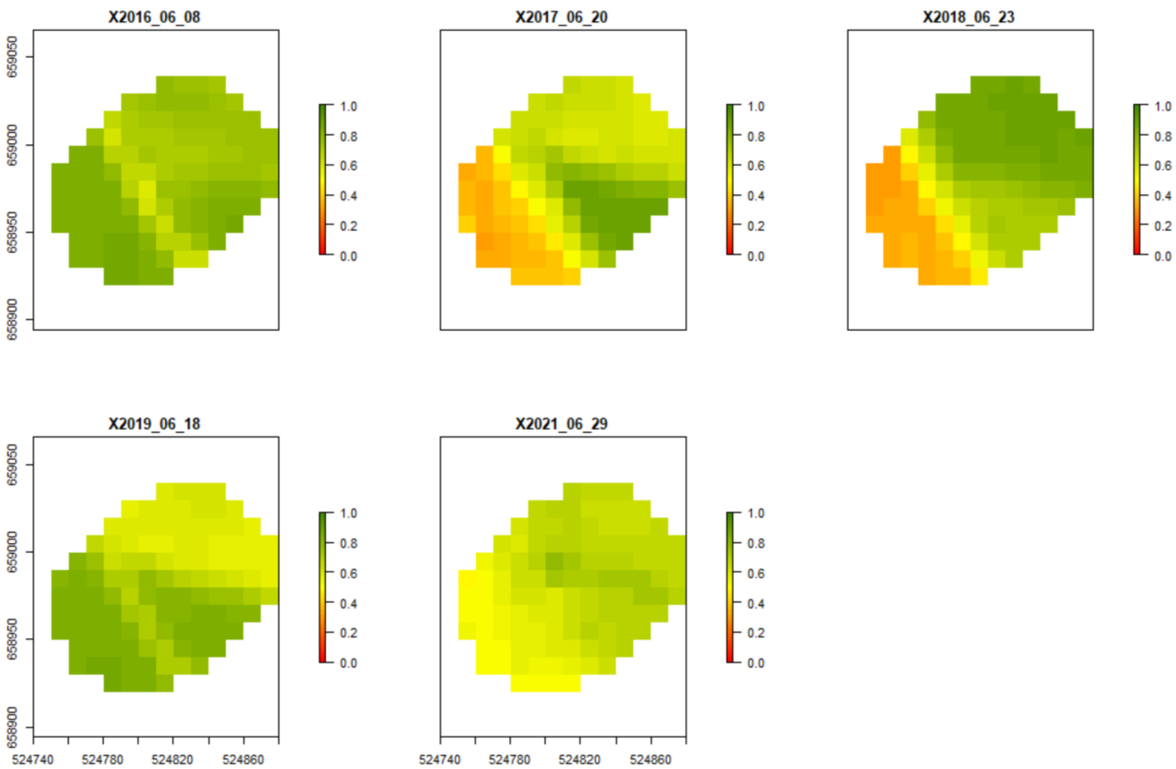


Figure 30. Selected June images for different years at the vegetation site shows high NDVI values and hence completely covered with vegetation.

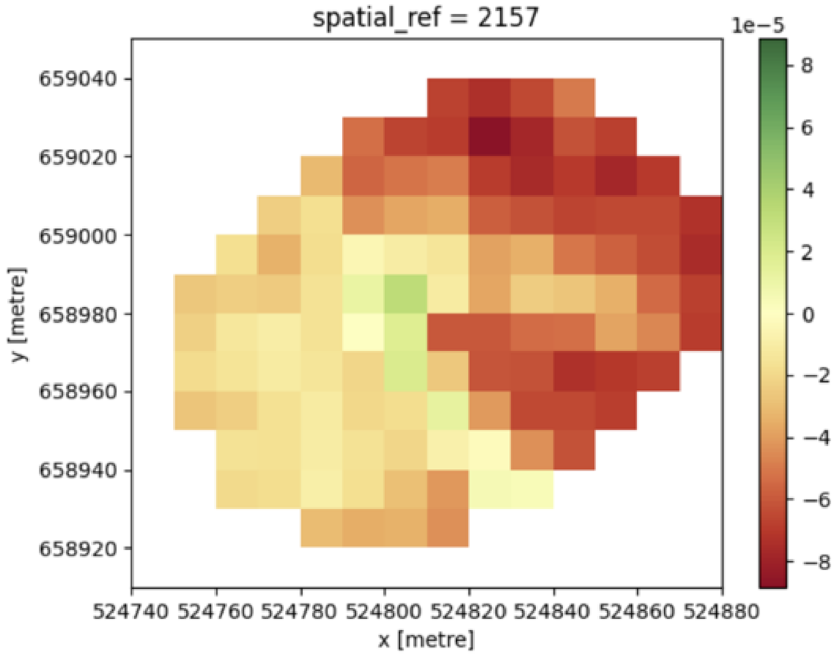


Figure 31. Vegetation site trends for June-NDVI during 2015-2021. Note: greener pixels show increasing greenness (positive slope) through the years and hence at higher risk of vegetation encroachment.

4.1 Conclusions

- The EO analyses revealed limitations in sourcing high frequency cloud-free satellite data in Ireland. However, existing satellite sensors such as Sentinel-2 with its 5-6 days temporal frequency can still prove valuable in monitoring vegetation growth on ground.
- Sentinel-2 analyses in this report proved beneficial in evaluating vegetation growth status. Carrying NDVI time series analyses over June (in this report) helped mitigate the seasonality issues that exist in typical vegetation datasets. However, seasonality could itself also provide important insights into persistence of vegetation cover over each month of the year. This however requires long un-interrupted time series data. GNI could instigate an annual monitoring of Sentinel-2 data and gaps in data could be infilled (to be tested) using other similar sensors such as Landsat-8/9, etc.
- Specific regions of higher importance or known higher/ intense encroachment issues (from expert knowledge and/ or from Sentinel based analyses) could be monitored with higher resolution data such as the commercial Pleiades (1.5m and daily frequency) or a more focused flight/drone imagery. Such an approach could help optimise costs incurred and also avoid the issue of cloud cover to a large extent.
- Use of LiDAR and/or other spectral information could be used to quantify biomass and classify the vegetation type (i.e. gorse, grass, trees, etc) in the encroached areas. Classification of encroached vegetation could also help in decision making (in consultation with ecologists) regarding offsetting trim back along ROW with re-wilding, protecting sensitive ecosystems, biodiversity. For e.g. encroachment areas with shallow root type vegetation could be left intact/unmanaged, if they are considered harmless for the gas pipelines beneath them.
- Such a multi-year semi-automated system can help identify hotspots of encroachment and create/maintain a rich database containing attributes such as vegetation type, biomass, etc. This can further help in risk assessment and developing further strategies.

5 Prototype Cloud ROW Environmental Management System

Part of this project dealt with how data was managed once it was captured by satellite, aerial, helicopter and drone platforms. This entailed designing, building and testing a prototype Azure based cloud platform that enabled Remote Sensing and GIS data to be ingested, indexed, analysed, modelling and visualised.

5.1 Cloud Platform Development

A pair of prototype geospatial web applications ("app") have been developed to share the data collated for the GNI project, and are currently available online at https://gni.terrainai.com and https://tai-dashboard.azurewebsites.net/login .

The former website aims to provide users with a comprehensive catalogue of associated datasets, allowing them to search, browse, and access relevant information efficiently, this is the *GNI Data Catalogue*. Leveraging the robust capabilities of Microsoft Azure, the catalogue application ensures a secure and seamless user experience through Microsoft Authentication. Users log in with their Microsoft accounts, benefiting from Single Sign-On (SSO) convenience. Invitations and role-based access control further enhance security and provide personalized roles and permissions, making user management efficient.

A set of geospatial maps are also available through an earlier prototype GNI website- the *Legacy Dashboard*, offering users an interactive and dynamic experience to explore the selection of project location sites. Additional geospatial layers enrich the context of the locations, providing a comprehensive view of the 'Areas of Interest' (AoI).

The subsequent sections describe the various features of the applications in more detail.

5.2 GNI Data Catalogue

This GNI projects revolves around a central data catalogue (DC), which serves as the foundation for comprehensive information on the GNI ROW locations available for exploration.

5.2.1 Access Control and Authentication

To enhance security and provide personalized user experiences, the web app implements access control and authentication mechanisms. Users are required to log in before gaining access to the app's catalogue data and features. The web app leverages the Microsoft Authentication framework to handle user authentication. This allows users to log in using their existing Microsoft accounts- a personal Outlook.com account for example- as well as organizational or enterprise accounts through Azure Active Directory (Azure AD). The app supports Single Sign-On (SSO) functionality; once a user logs in to their Microsoft account, they can seamlessly access the web app without the need to provide their credentials again for subsequent visits. This streamlines the user experience and eliminates the need for separate account management within the web app. The initial screen requesting log-in and the subsequent third-party authentication screen are shown in Figure 32.

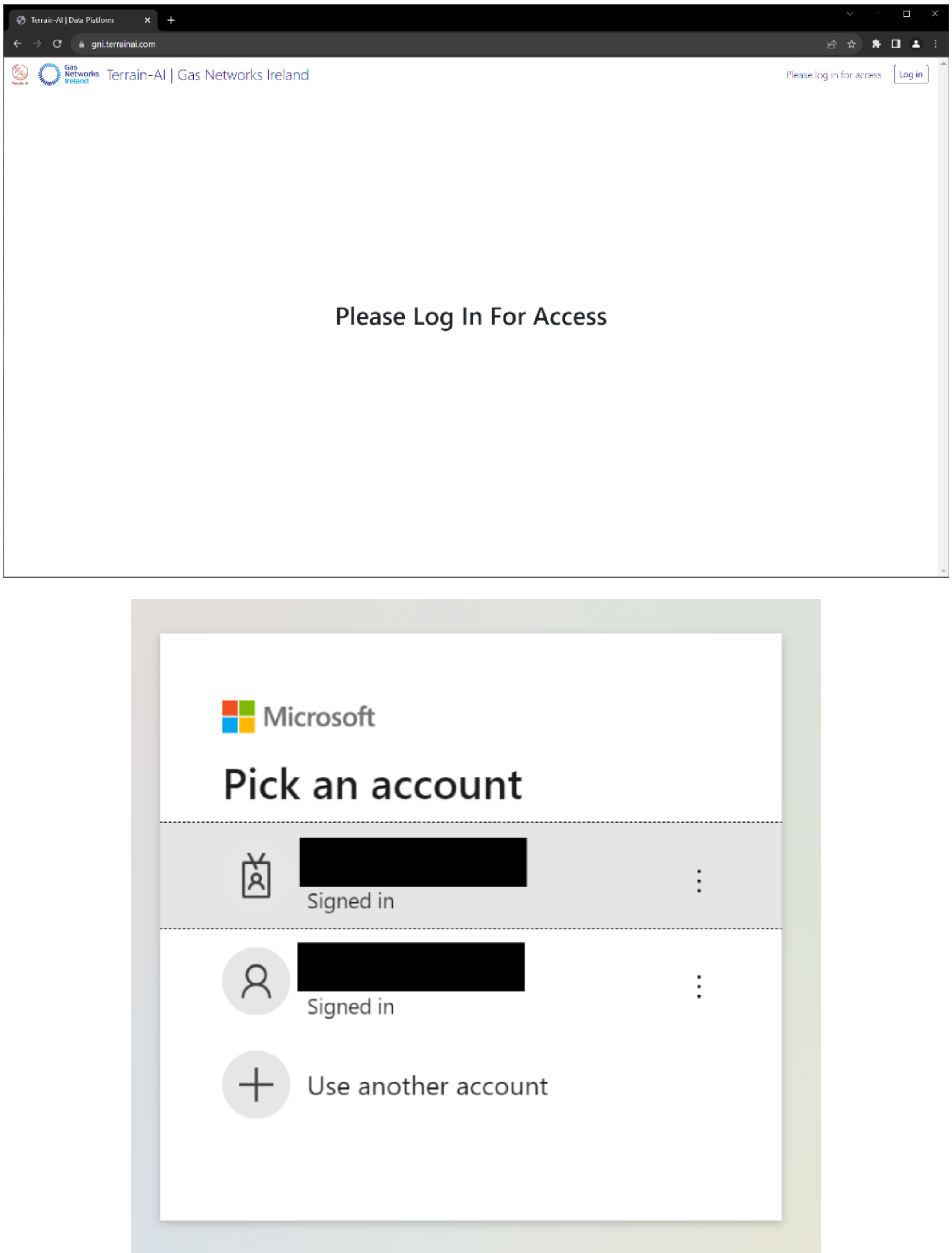


Figure 32: Screen requesting log-in and authentication dialogue for the data catalogue

Upon successful authentication, the web app employs user authorization mechanisms to control access to different parts of the application based on user roles and permissions. However, before users can access the app, they must be invited by an administrator. The invitation process involves sending an email or notification to the prospective user, containing an invitation link or instructions on how to join the app. Staff of GNI who wish to access the data catalogue should contact a Terrain-AI liaison. This is a vital level of security to protect sensitive data.

5.2.2 Catalogue Datasets

The web app provides users with the ability to search and filter the catalogue data to find specific items or narrow down their search based on specific criteria. As shown in Figure 33, search and filter form elements populate the left-hand side of the screen, while the datasets resulting from a filter or search query appear listed on the right.

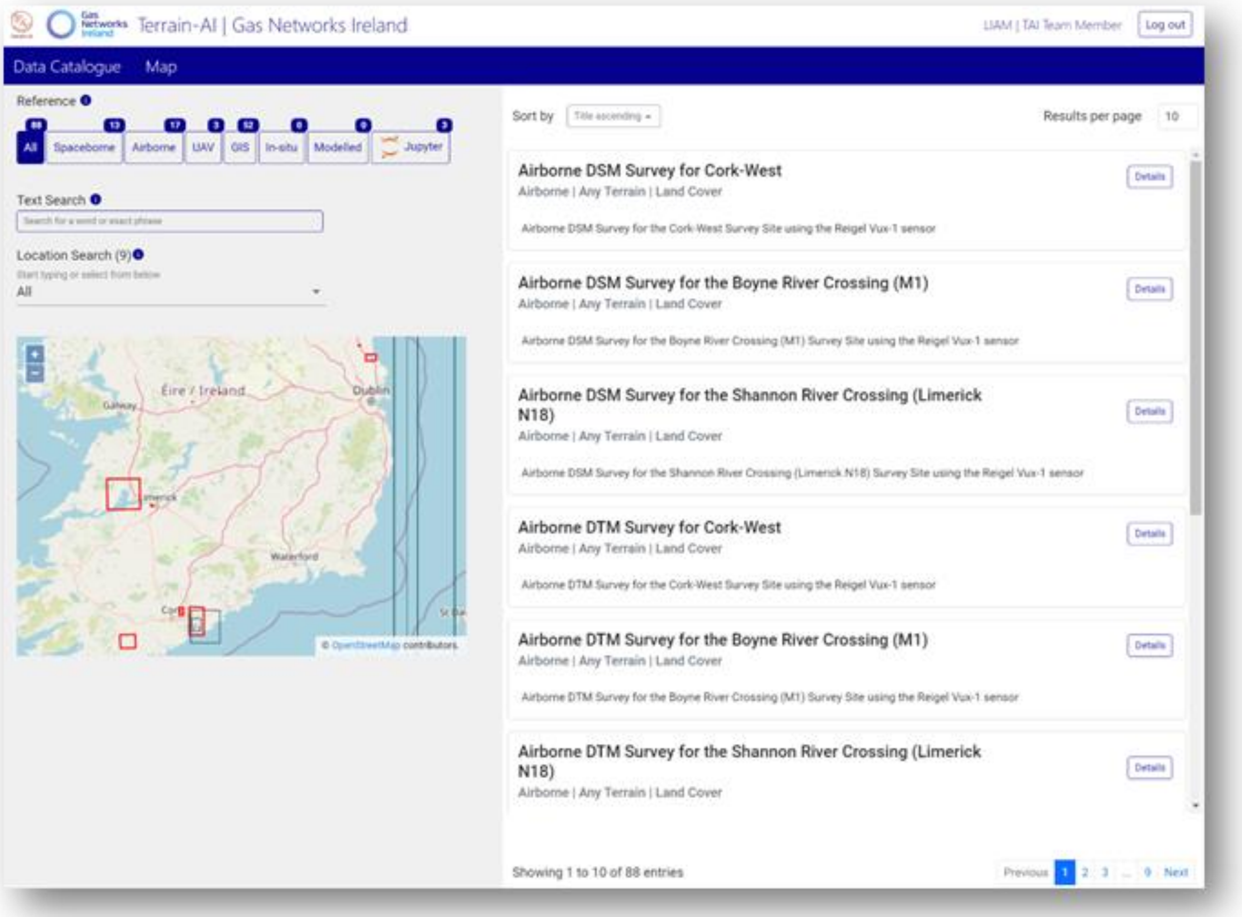


Figure 33. User interface for the Data Catalogue, showing search and filter elements on the left-hand side of screen-shot and dataset results on the right

The catalogue data is organized using a hierarchical structure and closely adheres to the INSPIRE data model[1] for interoperability of spatial datasets. Datasets are divided into *Reference* categories, which serve as the highest level of organization. Each category represents a distinct domain so that various sources can be integrated while remaining discoverable. For example, satellite photogrammetry can be singled-out by clicking the *Spaceborne* button, while aerial surveys carried out by plane appear under *Airborne*. A free-text search filters results based on other INSPIRE-compliant fields, such as keywords and the *Resource Abstract*. Finally, a menu of locations allows the user to select a particular 'Area of Interest (AoI)' from a list of sites of particular focus during the project, and see the datasets that apply there.

5.2.3 Dataset Details

Specific details of a dataset record can be accessed by clicking on the *Details* button on the right-hand side of the result (Figure 34).

Figure 34. A single dataset record showing the 'Details' button

The details page for a dataset displays the values for the various INSPIRE-compliant fields as well as additional information as shown in Figure 35. Apart from the text, a map showing the bounding box for the data is displayed in the top right-hand corner.

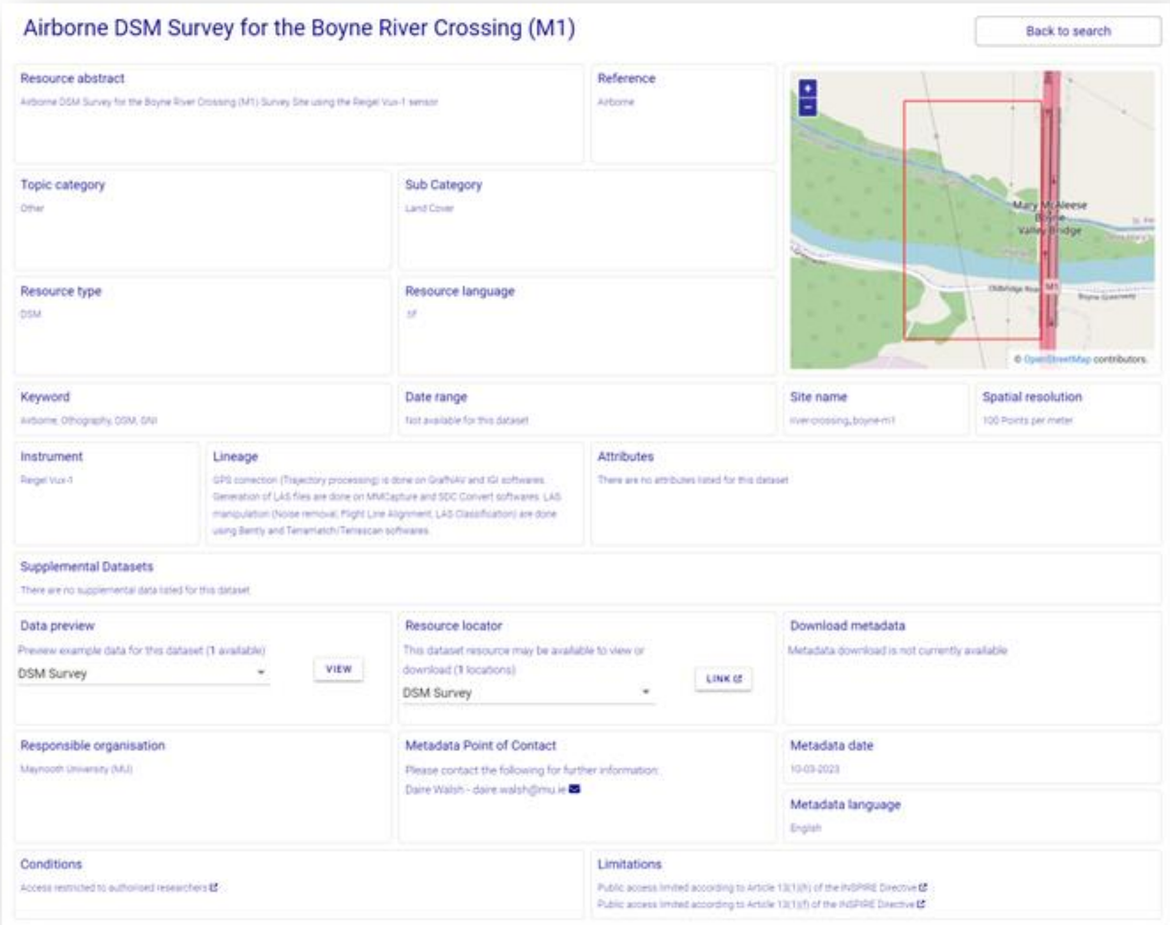


Figure 35. Details page for a dataset

Access to the data itself is provided by interactive elements. The *Data Preview* element allows the user to select a preview which opens as a locally-rendered map view or an external link (Figure 36).

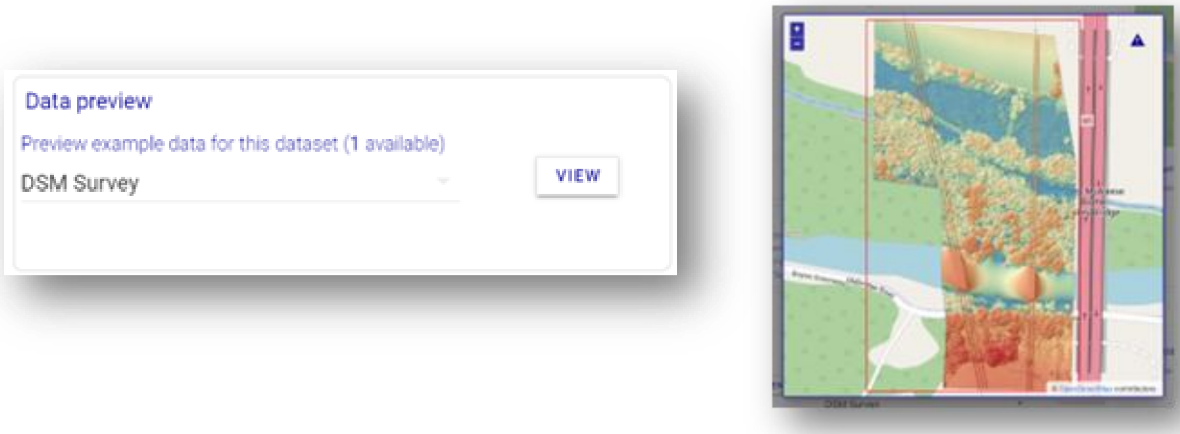


Figure 36. Data Preview element (left) and an on-page map view (right)

Similarly, authorised users can access the data directly via the *Resource Locator* element; this provides a dialog to download the data directly or a link to an external source (see Figure 37).

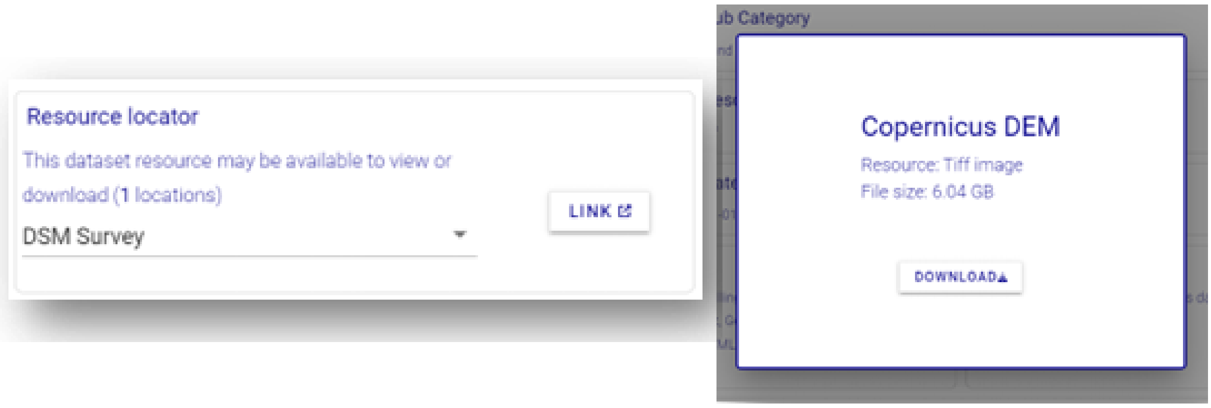


Figure 37. Resource Locator element (left) and direct download dialog (right).

5.3 GNI Geospatial Maps

A spatial dashboard has been developed which allows users to visualize a selection of location sites for the project. The dynamic maps included enhance the user experience and facilitate efficient exploration of project-related data. An existing prototype exists in the form of a legacy dashboard and is detailed in the next section. We are currently in the process of integrating this application into the data catalogue previously described, and it will be available on the *Map* page. The incorporation of the full-featured maps will provide enhanced functionality and a more seamless user experience under a common access system.

5.3.1 Legacy dashboard

This is the prototype geospatial dashboard (Figure 38) for Terrain-AI proofs-of-concept showcasing multiple projects. Note that this website is currently being phased-out in favour of a bespoke dashboard for each project. The map interfaces for GNI are to be integrated into the GNI data catalogue application.

> Log into the legacy dashboard with your @gni email address and the password you were given at registration. For access issues, please email liam.osullivan@mu.ie

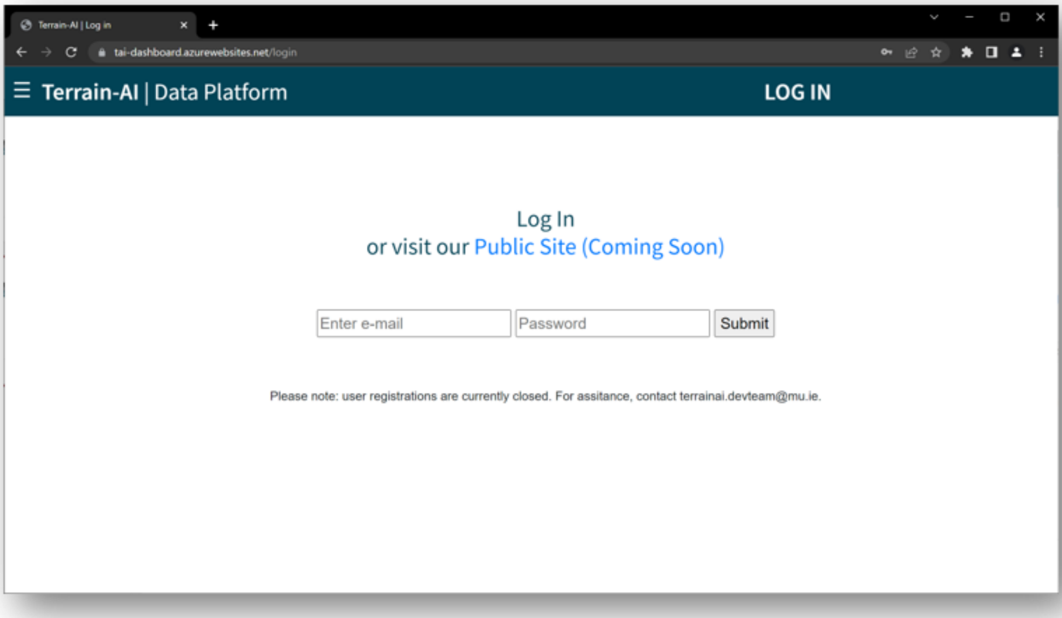


Figure 38. Legacy geospatial dashboard login screen.

Once logged-in, the *Index Map* will be shown (Figure 39). This contains benchmark sites which are test sites for various T-AI projects.

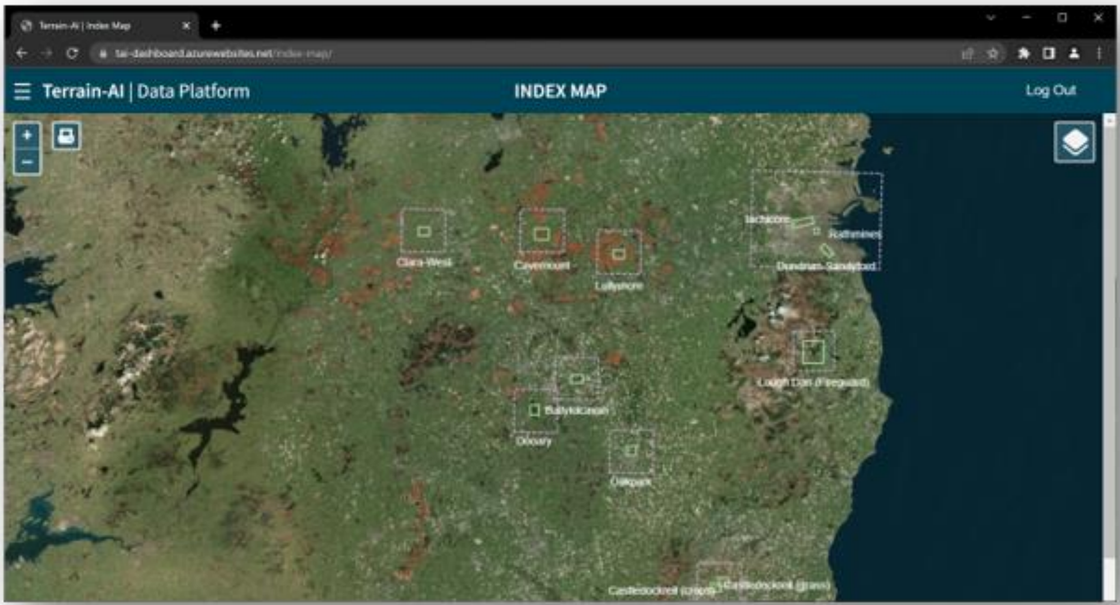


Figure 39. Index Map view

The hamburger toggle at the top left of the screen opens the side menu and the GNI project can be found under the *Projects* heading (Figure 40).

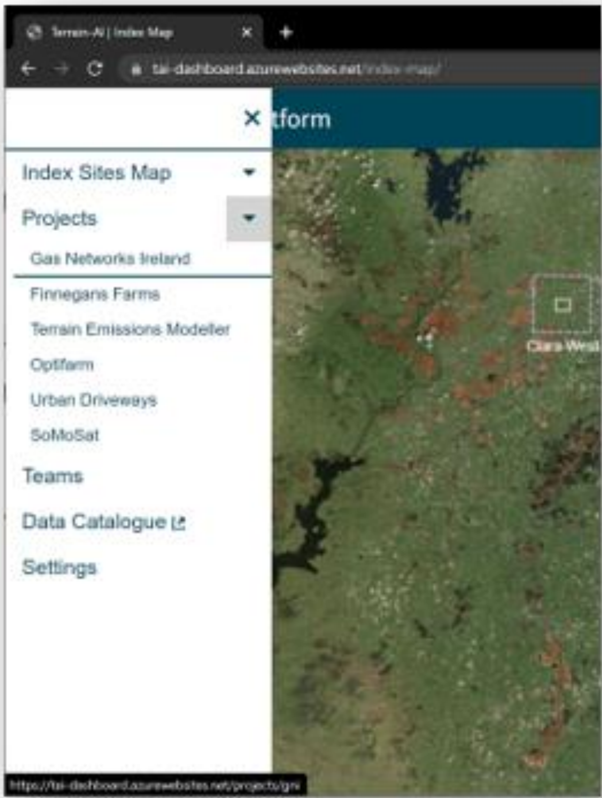


Figure 40. Geospatial dashboard side menu showing the projects sub-menu

Selecting the GNI project opens the *Project Overview Map*, the intuitive and interactive map interface shown in Figure 41. All maps on the platform provide the ability to pan, zoom, and explore various geographic areas seamlessly. Users can use familiar gestures such as clicking, scrolling etc. to navigate and interact with the map. The overview showcases a curated selection of location sites pertinent to the project. Each site is represented on the map with a bounding area, providing a visual reference to its geographical coordinates corresponding to the centreline gas pipeline and a set of 'Areas-of-Interest (AoI)'.

Hovering over an AoI highlights it (e.g. Shannon River Crossing), while clicking through then opens the map for that location.

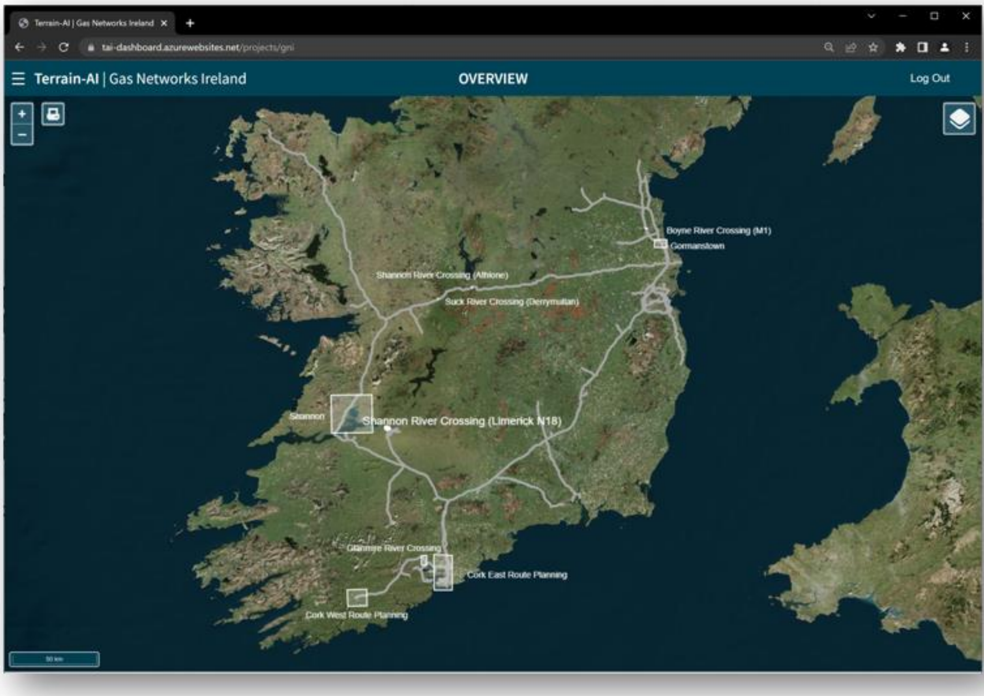


Figure 41. Overview map of locations for the GNI project

Clicking the AoI on the previous *Overview* opens a map for that location. The image shows the **Shannon River Crossing** on the N18 national road in Limerick. The set of available layers for the AoI will populate the Layer Switcher on the right of the screen. The GNI pipeline is shown in orange/red colours with a 100m buffer area either side (Figure 42).

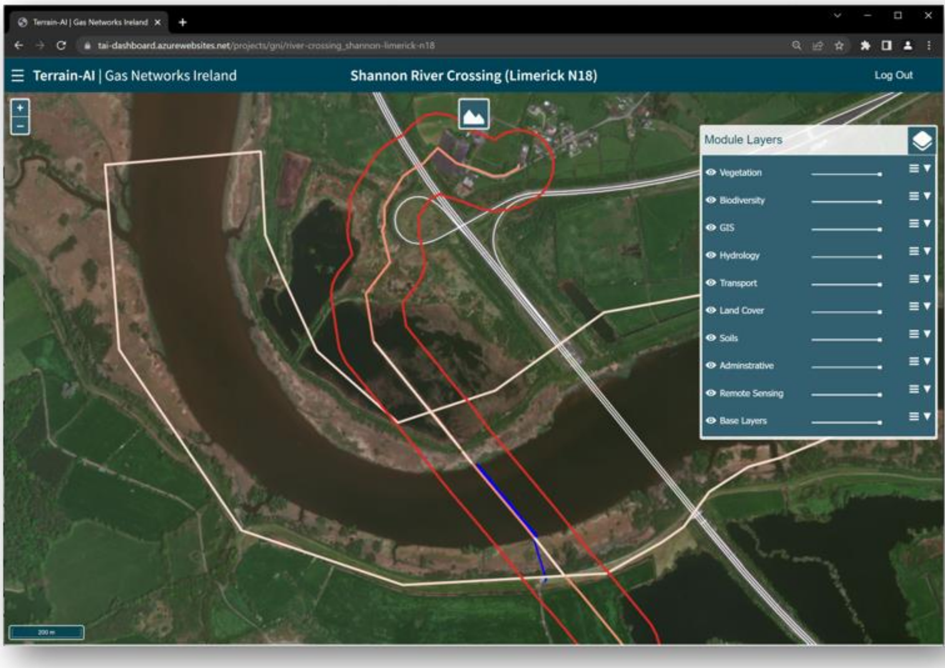


Figure 42. Location map for the Shannon River Crossing area of interest

To provide users with control and flexibility over the spatial display, the map offers layer controls. Users can toggle the visibility of specific map layers, focusing on the data that is most pertinent to their analysis or exploration. The layer controls may also include filtering options to further refine the displayed information based on attributes, categories, or other criteria.

The *Layer Switcher* (Figure 43) controls the visibility of the various layers added to the map. Layers to the top of the switcher appear 'in front' of other layers on the map from the perspective of the viewer. For example, the base layer of the map appears 'behind' other map layers, so is located at the bottom of the layer switcher.

Clicking the *eye icon* button toggles visibility. Note that 'switching on' a layer may fetch additional data from an external source (e.g. a map service), so there may be a slight delay before an effect is seen on the map. Note that toggling visibility for a group affects all sub-groups and layers within that group. Layers are grouped under headings according to the type of data contained within. A closed group (or sub-group) can be toggled open using the *down-arrow* button. An open group can be closed with the *up-arrow button*. The opacity of a group can be controlled using the *slider control*, allowing layers beneath to be viewed through layers above to varying degrees.

In addition to the data captured as part of the project, the location map enhances its layers with additional relevant information by incorporating geospatial data from external sources or third-party APIs. This may include topography, land cover, transportation networks, administrative boundaries, or any other geospatial data relevant to the project's scope. The following section illustrates some examples of these various layers.

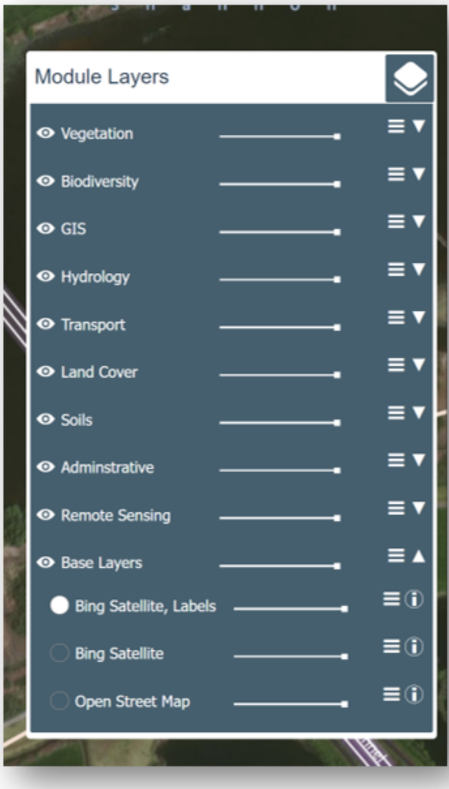


Figure 43. Layer Switcher depicting the various map layers available on the Shannon River Crossing location map

5.3.2 Map Layer Examples

Figure 44 shows the map when viewing the *Copernicus 10M DEM* layer from the *Spaceborne* sub-group within the *Remote Sensing* group. Note that the satellite imagery covers the whole AoI for the location, which is shown with a white outline. The boundary and pipeline line drawings are contained in the GIS group, and are visible by default.

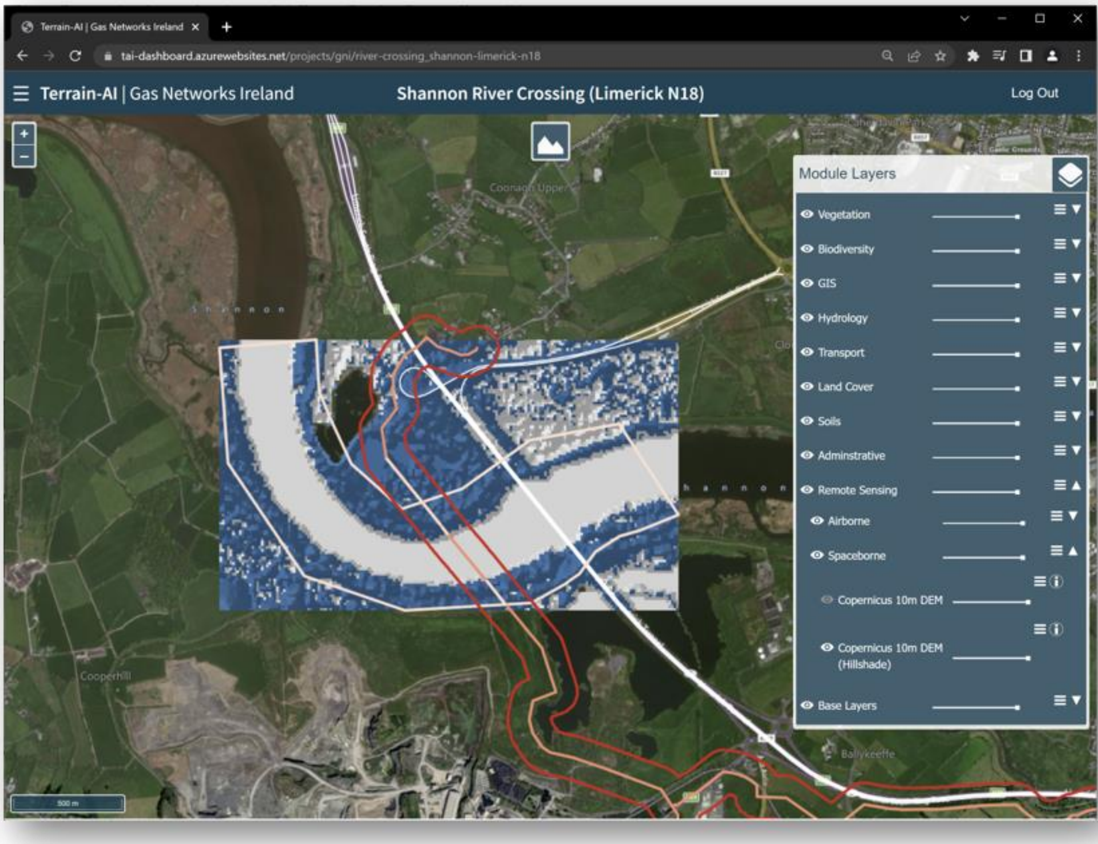


Figure 44. Shannon River Crossing location map with the Copernicus DEM layer (blue/grey) visible

Note the various Unmanned Aerial Vehicle (UAV) layers from the *Airborne* sub-group within the *Remote Sensing* group, Figure 45. Airborne imagery usually covers a smaller region within the AoI than satellite data, but at greater resolution. UAV imagery is commonly captured using a drone at low altitude and high resolution, while an aircraft will cover a larger area from a higher altitude. Various sensors and processing provide different views of the location, including RGB photogrammetry and DSM/DTM elevation models. A Digital Surface Model (DSM) is a geocoded model of real-world environments comprising both the bare ground, vegetation and man-made features (infrastructure, buildings etc). A Digital Terrain Model (DTM) is a geocoded model of real-world environments comprising just the bare ground without any vegetation and man-made features (infrastructure, buildings etc)

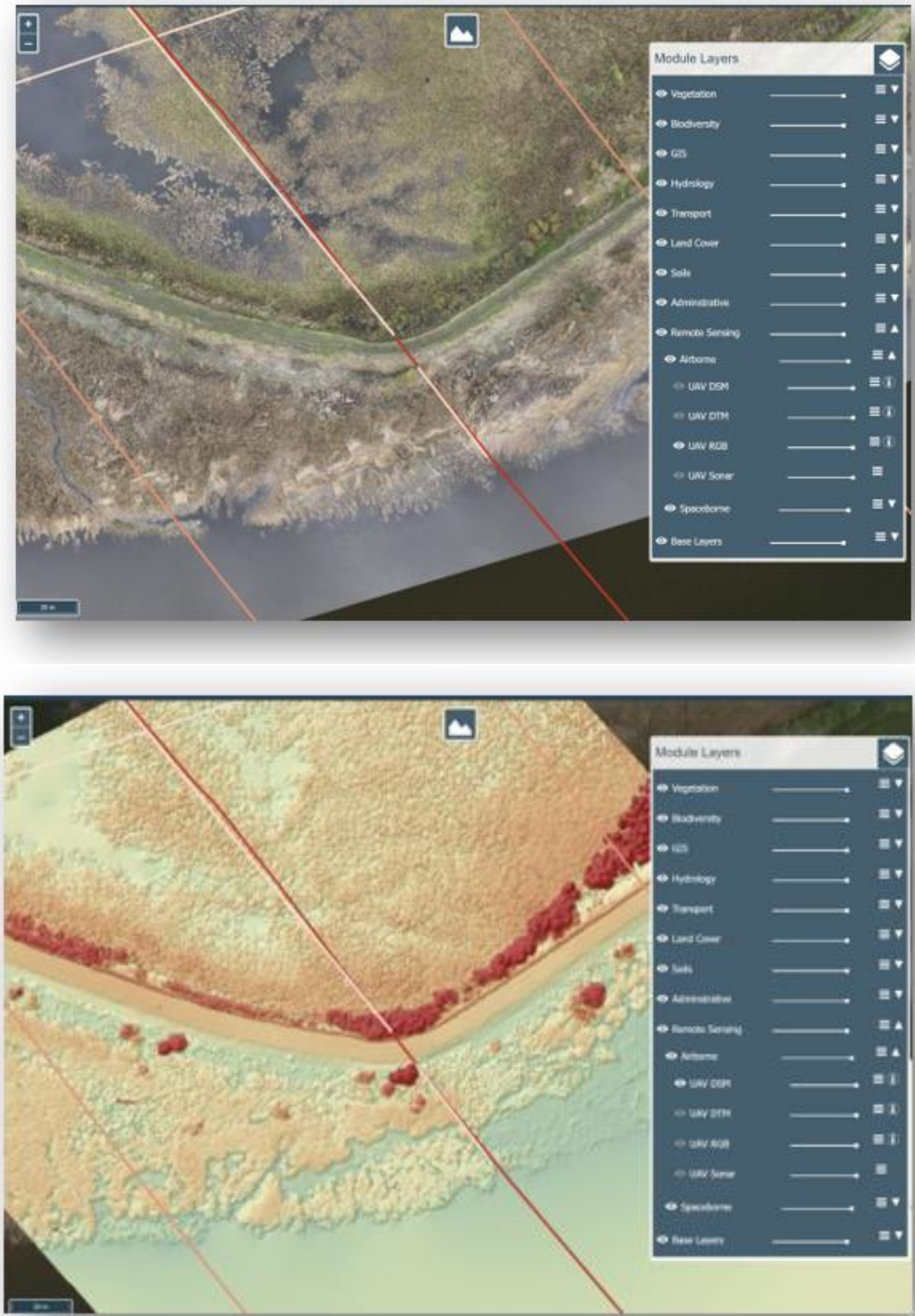


Figure 45. Shannon River Crossing location map showing various layers (top) under the Airborne sub-group (bottom)

Various layers are displayed as vectors (markers, lines and shapes) or images (such as the photogrammetry layers previously shown) visualising data captured and processed as part of the project. For example, a drone survey using sonar equipment was performed to experiment with measuring the depth of the channel at the Boyne River crossing. Figure 46 shows this data being visualized on the Map by viewing the *UAV Sonar* layer from the *Airborne* sub-group within the *Remote Sensing* group. Clicking the *UAV Sonar* layer displays the path of the drone in blue, repeatedly crossing the river. The depth profile toggle at the top of the map opens an interactive plot of the river bottom depth detected, as shown in Figure 38. Dragging the cursor along the drone path on the map shows the depth on the graph plot and vice versa.

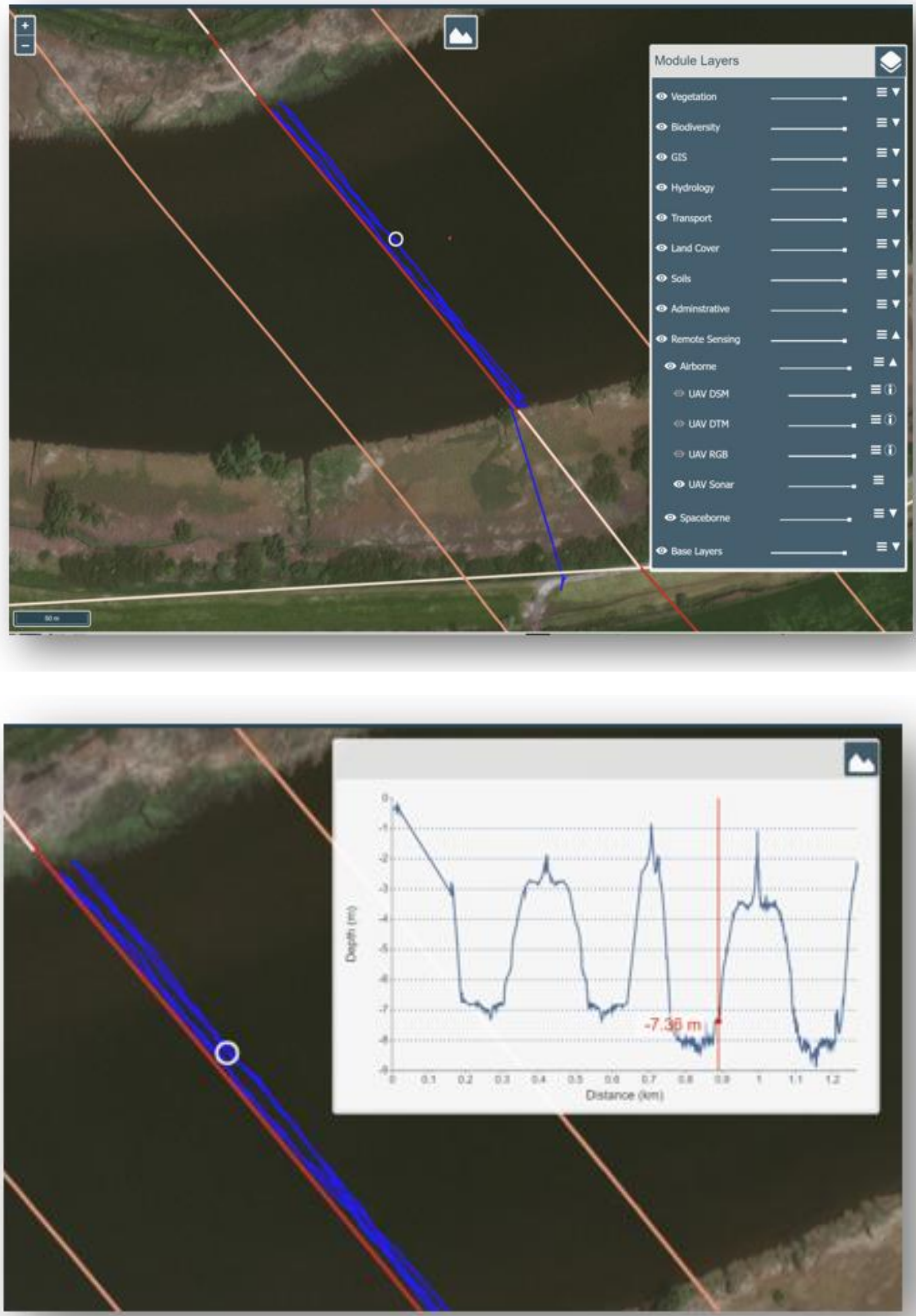


Figure 46. Boyne River Crossing location map showing the UAV sonar layer (top) and river depth visualisation (bottom)

There are numerous other data layers on the map which can have their visibilities toggled in order to explore the AoI. These include infrastructure, administrative boundaries, hydrology and other static data sourced from external sources. Clicking on any feature on the map will produce a popup which displays any available additional information for that feature (Figure 47).

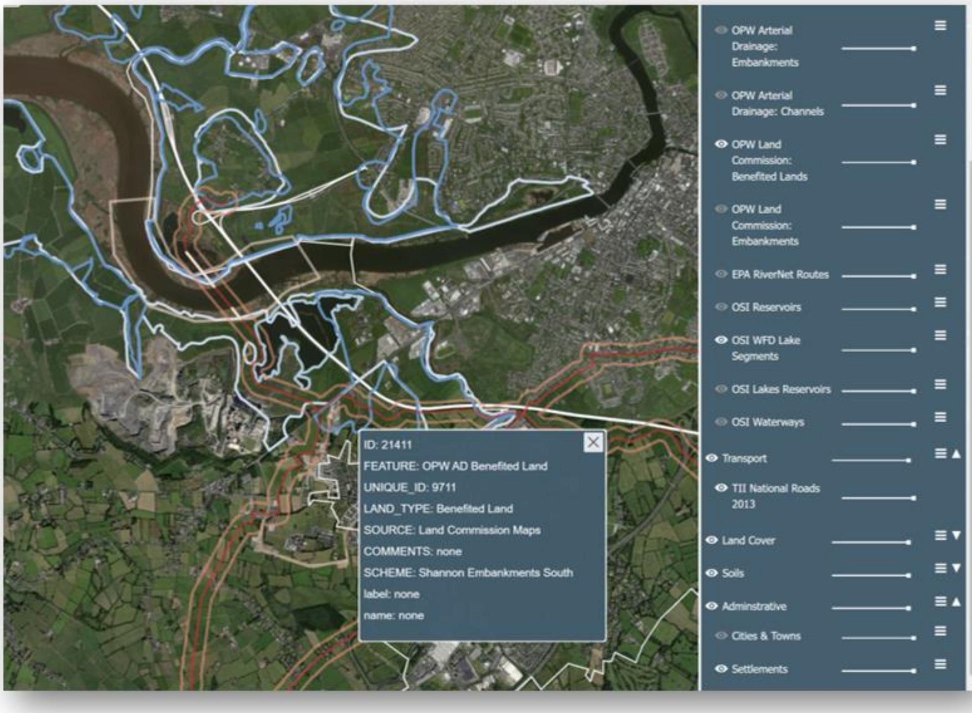


Figure 47. Shannon River Crossing location map, showing various GIS layers and additional information on a map feature displayed in a popup.

Also included is biodiversity and vegetation information where available, which has been manually labelled and/or detected using an automated process (Figure 48).

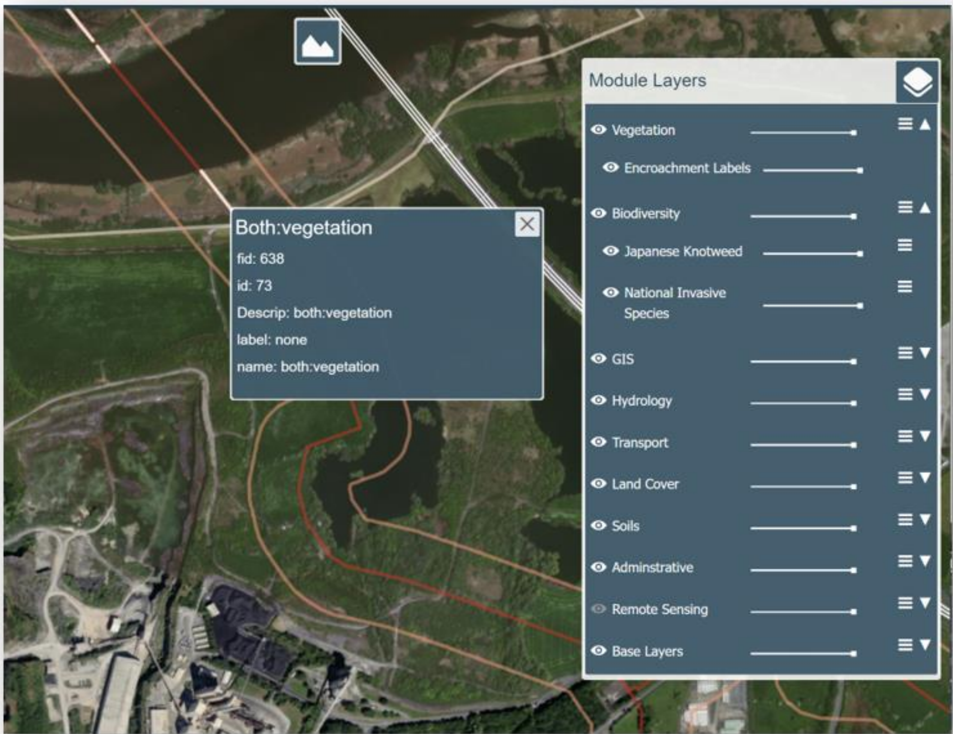


Figure 48. Location map showing vegetation encroachment

5.4 Hyper-localised Mapping using PanAlt360 Tool

Low-cost Drones (ca. €500) can be used to take-off from a point, climb to say 50m AGL and capture panorama images in a few minutes. These images can be uploaded, processed, spatially encoded and published (GNI password protected site) online in minutes using MU high automated PanAlt360 tool. These easy to use, hyper-local, intuitive geospatially encoded panoramas are integrated with a *moving-map* display, enabling the user to position objects and features of interest within the panorama, Figure 49. Ranges to various objects, appearing in the panorama, can be measured and distances as well as areas computed. Elevation profiles and viewsheds can also be calculated using PanAlt360.

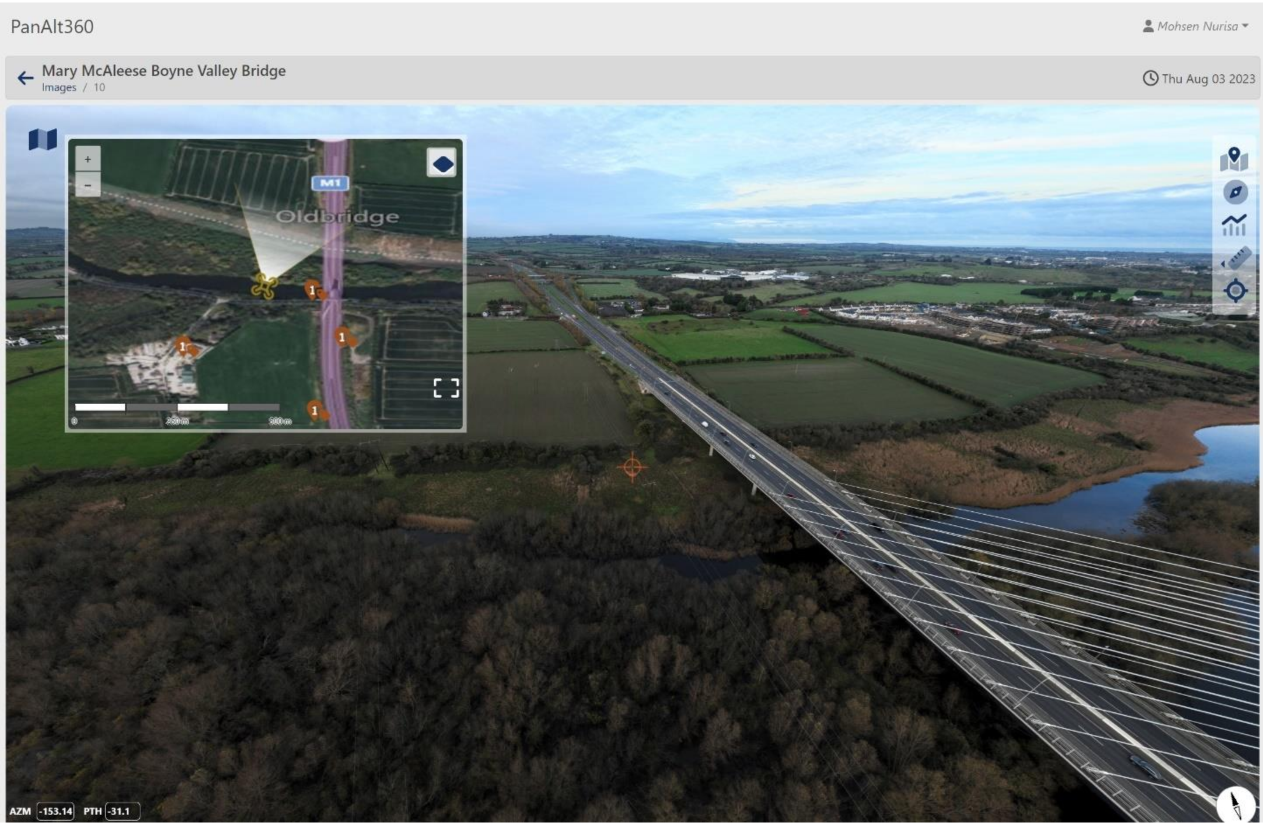


Figure 49. U-Flyte's PanALt360 tool displaying a geospatially encoded Panorama captured over Boyne River Crossing

Users can tag objects in the panorama and the panorama together with tag details sent to other work colleagues via an email (token) link. A Smartphone App is currently being coded and will allow user to both capture and receive/visualise panoramas on their smart phone.

5.5 Conclusion

A prototype Web-App (comprising a Data Catalogue and Dashboard) were developed as part of this GNI research project. The first, GNI Data Catalogue, is organized hierarchically to an industry-standard model and provides functionality for search, filtering, and access to project data.

The second Web-App comprises interactive maps on the legacy dashboard provide a dynamic and visually engaging platform for users to visualize the project's location sites and associated data. The map interface allows for easy navigation and exploration of geographical areas. By integrating data from the catalogue and other geospatial sources, users can gain valuable insights into the project's spatial relationships. Layer controls and customization options further empower users to focus on specific aspects of the data, promoting efficient analysis and decision-making.

Future work in the short term will integrate the legacy dashboard functionality into the catalogue, providing a more seamless user experience of the web app's data visualization ecosystem. The platform serves as a powerful tool for collating, visualising and interpreting GNI's geospatial information to support environmental management over its national ROW infrastructure and assets.

6 Conclusions & Recommendations

This assessment, in terms of challenges, capabilities and benefits of Drone platforms and sensor technologies to support GNI engineers manage the national pipeline infrastructure, generated a number of findings which have, in turn, being grouped under conclusions and recommendations

6.1 Conclusion

The main conclusions revolve around the use of Remote Sensing platform including Satellites, Aircraft, Helicopters and Drones as well as Artificial Intelligence (AI), and scalable Cloud platforms – in generating increasingly diverse and high-volume datasets – which when processed can be exploited to help support GNI's drive for more Sustainable ROW management practices.

- **Drone Platforms:** Various Drone platforms equipped with optical, LiDAR sensors were tested and assessed for a number of key GNI mapping and monitoring tasks dealing with management of ROW and AGI sites.
    - These drone platforms proved useful for localised high-quality mapping over inaccessible sections (Terrain, ATC clearance).
    - Preliminary results for Methane detection around AGI show potential in controlled environments detection was possible, but further field tests are required utilising different detection methods and technologies.
    - There are draw-backs in terms of current regulatory environment (<500m operational range, relative high cost per km, GDPR) which are likely to be improved in the medium term.
- **Integrated Aerial/Drones Platforms:** The increasing role of drones to support conventional aerial (helicopter and survey aircraft) activity was noted. Changing landscape in terms of regulatory regime for drones (Drone Dock stations, BVLOS) as well as higher performance and versatile platform sensor technologies. A range of optical, LiDAR and environmental sensors can now be deployed on Drone sensors. Issues such as Data Privacy and potential nuisance need to be addressed.
- **Satellite Data:** Useful as a screening tool to highlight vegetation encroachment. Drawback in Ireland is usually 100% cloud covered 50% of the time, results in usually 8 to 10 cloud-free scenes (sometimes less) per year over any area in Ireland. Normalised Distribution Vegetation Index (NDVI) is a useful analysis stool when used with time-series Sentinel-2 images. Potential to provide historic 'section profiles' which could be used to highlight anomalous activity i.e. not just vegetation encroachment but also un-authorised development.
- **Cloud Platform:** A suitable platform is required to collate all GNI ROW environmental data and ensure these datasets are made available across the GNI Business Departments. This platform needs to include Data Catalogue, Ingestion, Indexing, Processing, Analysis, Modelling, Visualisation and Reporting Functions. Data Management will become an issue with an increase in field surveys and data capture activities.

6.2 Recommendations

The main recommendation revolves around the Aerial/Drone platform and digital platform.

- **Aerial/Drones:** Draft a strategy for both role of Aerial platforms (Helicopters) and Drones as these relate to GNI's ROW mapping and monitoring covering;
  - Reliable, timely, cost-effective Data & information requirements (Content, Quality, Cost etc)
  - Platforms, Sensor technologies;
    - Orthoimagery – specifically as these geocoded image-map products relate to ROW mapping, AGI modelling as well as RGB and multispectral mapping along RoW
    - LiDAR Point Cloud – digital AGI modelling, challenging ROW terrain sections, also ROW sections susceptible to potentially higher incidents of un-authorised development (change differencing between 2 X LiDAR surveys)
    - Methane Gas Detection – investigate latest optical sensors as well as suitable heavy lift Drone and/or tethered Drones
  - Regulatory aspects including safety, security, privacy and nuisance
  - Operational, Organisational, Budget and Oversight - how these new tools can be incorporated into GNI's existing work-practices
  - Specific attention to GDPR and securing permission to operate (Appendix 1 and 2)

- **Digital Platform:** Consider upgrading current data handling activities to address the present and future data/information needs, associated increasingly diverse range of data inputs as well as taking into account the rapidly changing data-technology landscape;
  - Emphasis on designing and delivering *fit-for-purpose* decision support for GNI engineering and Ops staff
  - Handle diverse range of data (Remote sensing, GIS, environmental sensors, Socio-economic, Human Activity)
  - Review of existing corporate data handling systems and how new information needs and functionality could be implemented
  - Desk study on the role and practical integration of AI technologies withing GNI's data capture, collation, processing and analyses
  - Draft a Corporate Data Management Plan to cover data-handling, cost-benefit, regulatory compliance, licensing, GDPR, ethics & governance
  - AI including; robotics platforms e.g. Drones, sensor technologies as well as machine learning processors are likely to play an increasing role in GNI's future field data collection, data processing, analysis and supporting decision making and so, warrant closer investigation.

7 Appendix

7.1 Appendix 1 Sample Data Protection Policy for Drones

Introduction

Data Protection is the means by which the privacy rights of individuals are safeguarded in relation to the processing of their personal data. As part of its day-to-day business, *Entity Name* may collect 'Personal data' i.e. any information relating to an identified or identifiable living person ('data subject'). Those individuals ("data subjects") have privacy rights in relation to the processing of their personal data. *Entity Name* must therefore comply with the EU General Data Protection Regulation (GDPR) replacing the Data Protection Directive 95/46/EC which came into effect on 25/05/2018.

When we refer to "**Entity Name**", "**we**", or "**us**" in this Data Protection Policy, we refer to *Entity Name*. who is responsible for your Personal Data and acting as "data controller". This will be the entity with whom you intend to conclude - or have concluded - a contract, whose premises you have visited, whose website(s) you have accessed or with whom you interact in any other way.

In this Data Protection Policy, we describe how *Entity Name* uses Personal Data of (prospective) clients, suppliers and (website) visitors. More specifically, we describe how we collect, store, secure and use ("**process**") your Personal Data when you purchase our products or services, supply products or services to us, visit our premises or access our website(s).

When we refer to "**Personal Data**" under this Data Protection Policy, we mean any information through which we can identify you as an individual (e.g. your name, telephone number, email address etcetera).

More specifically, as a drone operations company, *Entity Name* is required comply with GDPR regulations in the context of the capture of imagery/video using aerial platforms and this is further described below.

Scope of this Data Protection Policy

This Data Protection Policy applies to the processing of Personal Data of (prospective) clients, suppliers and (website) visitors.

(Prospective) clients - When we do business with our clients, the Personal Data we process includes the contact details of (legal) representatives and contact persons of the client. This Personal Data is collected in different ways, for example, by our website, over the telephone, via email or through forms or requests you submit, and during business events and/or meetings.

Suppliers - When we do business with our suppliers, the Personal Data we process includes the contact details of (legal) representatives and contact persons of the supplier. This Personal Data is collected in different ways, for example, over the telephone and via email.

Visitors – When you visit our premises, we process your Personal Data as part of our safety and security measures.

Website visitors - When you visit our website(s) we process your Personal Data among others in connection with registrations, purchases, inquiries, and subscriptions for receiving direct marketing. We also collect limited data automatically when you browse our website(s).

Aerial Data - Drones (common name for Unmanned Aerial Systems (UAS)) are a broad category of aircraft of various sizes which are remotely piloted without humans on board, equipped with technology for collecting images, videos, sounds and/or other information (data collection system) and transmitting them to smart devices (for example, to cloud storage). Drones are also capable of knowingly/un-knowingly capturing personal identifiable information (PII) such as individual facial features, vehicle number plates especially in outdoor environments. It is therefore prudent to carry out a Data Protection Impact Assessment (DPIA) to identify and address these potential risks through appropriate mitigation actions. We have included below a typical example of a DPIA developed as part of our drone operations. This follows a logical set of questions and answers that address the rationale, methodology to highlight any potential breaches of Data Protection and associated mitigated action to remove or reduce that risk.

What Personal Data do we process?

The type of Personal Data we process varies depending on the type of relationship we have with you and the kind of services we provide to you.

(Prospective) clients and suppliers - We process the following Personal Data of our (prospective) clients and suppliers to the extent available to us and in accordance with applicable law and regulation:

your contact details - your name, address and any other contact details you provide, such as your telephone number and e-mail address;

your communication data - any requests or complaints you make and any other data that we receive if we communicate with you via email or through our website;

your use of our services - information relating to your use of our Services, such as information related to your purchases;

your financial details - financial information disclosed to us which can be linked to you as a client or supplier, such as bank account details or invoicing details;

video surveillance footage - when you enter our office or premises, you are subject to image retention via the video surveillance systems (CCTV). Image retention may also take place during events and fairs where video footage is made;

webinar recordings and recordings of other events - when you attend webinars or other meetings hosted by us, we may make sound and/or video recordings and or photos. We will inform you beforehand if this is the case. You can choose to leave the webinar or meeting in case you have objections to such recording;

drone imagery/video - this includes any Personal Data that we may knowingly or unknowingly capture during aerial surveys and may therefore be subject to a Data Privacy Impact Assessment (DPIA) which is assessed and determined with our client in advance of any survey which may capture personal data; and

any other Personal Data - this includes any Personal Data that you disclose in the course of your contractual relationship with us.

Visitors to our premises - We process the following Personal Data of persons visiting our premises:

your contact details - your name and any other contact details you provide, such as your address, telephone number and email address; and

Website visitors – We process the following Personal Data when you access our website(s):

your contact details - your name, address and any other contact details which you provide to us, such as your telephone number and email address;

your communication data - any requests or complaints you make and any other data that we receive when communicating with you; and

data collected automatically - when you access our website(s), we collect data automatically through your browser or device by making use of cookies and other technologies including Google Analytics. In this way we track website visitors and collect information about your use of our website(s). If you want to know more about these automatically collected data, please see our Cookie Policy.

For what purposes do we process your Personal Data?

Processing takes place in order to carry out our obligations arising from contracts entered into with you, and to provide you with the information and services you request. This includes managing and handling your requests, inquiries or complaints, and sending you our invoices or paying your outstanding fees.

If you are a (prospective) client or website visitor, we process your Personal Data to send you marketing communications (such as newsletters) via email or other electronic means. We will only do so after we have received your consent. You can withdraw your consent at any time (see section 10).

We process your Personal Data to comply with legal obligations, such as maintaining appropriate business records, complying with lawful requests from governmental agencies and public authorities, and to comply with applicable law and regulation.

We also process your Personal Data for our legitimate (business) interests, which include the following:

to manage our internal client database (CRM) and to maintain contact with you for marketing purposes or other commercial purposes;

to operate and expand our business activities, to develop and improve the quality of our Services, to better understand you as a client (client optimisation), and to generate aggregated statistics about the users of our Services;

to measure and understand the effectiveness of our marketing;

to ensure the integrity of our systems (for example, prevention of hacking, fraud and spamming) and to maintain the security of our buildings and premises;

to fulfil management and recordkeeping purposes as well as training and learning purposes; and

to facilitate business operations and corporate transactions (e.g. in case of a merger or acquisition).

What is our legal basis for processing your Personal Data?

At all times, we process your Personal Data in accordance with applicable data protection laws. This means that we will only use your Personal Data if this is sufficient, relevant and limited to what is necessary. We will only process your Personal Data if we have a legal basis to do so.

The legal bases for processing your Personal Data are the following:

to perform our **contract(s)** with you;

to act upon your **consent**;

to comply with a **legal obligation;** and

to pursue our **legitimate (business) interests** (or those of third parties) unless your interests and fundamental rights override our interests.

With whom do we share your Personal Data?

We share your Personal Data with third parties who assist us in the delivery of our services, or in order to operate and expand our business activities. We will only do so on a strictly need to-know basis and after entering into the necessary contractual arrangements with such parties.

We share your Personal Data with the following parties:

other entities - Your Personal Data may be shared internally with other *Entity Name* group entities for internal administrative, management or business purposes. Your Personal Data will only be used by *Entity Name* group entities for marketing purposes if we have a legal basis to do so;

service providers - To assist us in providing our services we engage third party vendors, such as business partners, suppliers (including IT service providers) and analytics and search engine providers supporting us in the improvement and optimisation of our website (e.g. Google Analytics);

third parties in case of legal requirement - We also disclose your Personal Data to third parties where this is required by law (e.g. tax authorities or governmental or judicial agencies) or in the context of an investigation, regulatory requirement, judicial proceeding, court order or legal proceeding; and

third parties in case of corporate transactions - Information about our clients, including Personal Data, may be disclosed as part of a corporate transaction (e.g. a legal merger).

How do we share your Personal Data?

We take all necessary steps to ensure that your Personal Data is shared and treated securely and in accordance with this Data Protection Policy and applicable legislation. This means that we enter appropriate legal arrangements with recipients of your data, such as Standard Contractual Clauses ("SCC's") as approved by the European Commission of the European Union or equivalent arrangements with parties outside the European Economic Area. You are entitled to receive a copy of any documentation showing the appropriate safeguards that have been put into place by making a request via email address.

How do we secure your Personal Data?

Entity Name takes reasonable steps to ensure that your Personal Data is properly secured using appropriate technical, physical, and organisational measures.

We take steps to limit access to your Personal Data to those individuals who need to have access for one of the purposes listed in this Data Protection Policy. Furthermore, we contractually ensure that any third party processing your Personal Data on our behalf maintains at least equal security and integrity standards.

How long do we store your Personal Data?

We store your Personal Data on the basis of applicable law and regulation and as long as is required to satisfy the purpose for which the data is processed (for example, for the time necessary for us to provide you with client service, answer queries or resolve technical problems), unless a longer period is required for purposes such as complying with retention obligations for record keeping or commercial requirements. If you would like to receive further information on how long we store your Personal Data, please contact email address.

Which rights do you have with respect to your Personal Data?

You have several rights in relation to the Personal Data processed by *Entity Name*. For example, you have the right to request, review, correct, update, restrict or delete Personal Data you have provided to us. If you wish to exercise your rights, you can contact us by sending an email to email address. We will respond to your request consistent with applicable law.

As part of your request, please indicate which Personal Data you would like to receive, have changed or removed from our database or what limitations you would like to put on our use of the data. We will comply with your request in accordance with applicable law and regulation and as soon as reasonably practicable. Please note that we may need to retain certain Personal Data for recordkeeping purposes and/or to complete any transactions that you began prior to requesting a change or deletion.

In the event your Personal Data is processed on the basis of your consent, you may withdraw consent at any time by sending an email to email address. Please note that a withdrawal of consent does not affect the lawfulness of any processing which has taken place prior to your consent being withdrawn and that we can only action your request in accordance with applicable law.

If you believe that the processing of your Personal Data infringes this Data Protection Policy or applicable law, please contact us at email address to raise your concern. If you are a client or supplier, you can also address your concerns to your *Entity Name* contact person. Lastly, if you feel that *Entity Name* has not addressed your concerns properly you have the right to lodge a complaint with the supervisory authority in your country of residence or place of work.

Does this Data Protection Policy apply when you link through to other websites?

Our websites may, from time to time, contain links to and from third-party websites, such third-party websites may be managed by business partners or social media networks. If you follow a link to any of these websites, please note that these websites have their own Data Protection Policies and that we do not accept any responsibility or liability for these policies/notices. Please consult the policies/notices posted on such websites before you submit any Personal Data.

How do you contact *Entity Name* with privacy related questions?

If you have any questions or concerns about this Data Protection Policy or the processing of your Personal Data in general, or if you wish to exercise any of your rights, please email us at email address and be sure to indicate the nature of your query.

7.2 Appendix 2. Data Privacy Impact Assessment Dublin Airport

Drone Surveys – Data Privacy Impact Assessment (DPIA)

Data Privacy and Drones

Every EU citizen has the fundamental right to privacy. The EU General Data Protection Regulation (GDPR), which is applicable to all individuals in the European Union as well as companies that conduct business with EU citizens, primarily governs data protection.

Drones (common name for Unmanned Aerial Systems (UAS)) are a broad category of aircraft of various sizes which are remotely piloted without humans on board, equipped with technology for collecting images, videos, sounds and/or other information (data collection system) and transmitting them to smart devices (for example, to cloud storage).

Drones can be used for a variety of tasks, including surveying, security, agriculture, real estate, photography, live entertainment, and more. These aerial platforms are ideally suited for capturing imagery to produce high quality image-map mosaics. These image-map mosaic can be used by engineers, planners, landowners for routine maintenance, planning and a variety of environmental monitoring tasks.

Drones are also capable of knowingly/un-knowingly capturing personal identifiable information (PII) such as individual facial features, vehicle number plates especially in outdoor environments. It is therefore prudent to carry out a Data Protection Impact Assessment (DPIA) to identify and address these potential risks through appropriate mitigation actions. A DPIA, detailed in following sections, follows a logical set of questions and answers that address the rationale, methodology to highlight any potential breaches of Data Protection and associated mitigated action to remove or reduce that risk.

Step 1: Identify the need for a DPIA
Explain broadly what project aims to achieve and what type of processing it involves.

GeoAerospace have been engaged by Maynooth University (**Data Processor**) for the purposes of surveying Gas Networks Ireland (**Client**) pipeline west of Dublin Airport along 16km of their network. As part of the project, GeoAerospace (**Data Controller**) will collect imagery of lands within Dublin County. GeoAerospace will collect the data and it will be processed by Maynooth University in order to create geo-encoded video streams for the purposes of assessing the condition and integrity of the pipeline in the interest public safety. The intention is not to capture and record any imagery of people or personally identifiable information, however given the nature of aerial imagery data capture, there is a risk that personal data of passers-by (data subjects) may be captured and so merits a more detailed examination, as set-out in this DPIA.

Step 2: Describe the Data Capture

The project plan is to collect RGB (standard colour) video at locations along the 16km of pipeline. This will include imagery captured over an urban environment (e.g., Blanchardstown) and nearby roads/land. The purpose of the mapping exercise is to produce geo-encoded video for subsequent visual assessment by Gas Networks Ireland to ensure no third-party intrusion is occurring along the pipeline network i.e. construction work.

Data privacy is at the heart of our work and so while the exercises will not require the collection of any personally identifiable information, it is, nevertheless, advisable to adhere to best practice and GDPR guidance. Therefore, the team are carrying out this DPIA as part of a data-audit to ensure compliance with GDPR legislation, and ethical standards. The GDPR defines personal data as:

"*Any information relating to an identified or identifiable natural person…*"

To mitigate any potential to collect personally identifiable information during drone surveys, data and privacy protection measures are fourfold.

1. The drone sensors are configured to mitigate data collection and ensure privacy of individuals through flight profile and onboard camera settings. Flight profile includes flying at the maximum altitude permitted by the aviation authority (300ft) to reduce, as much as possible, the possibility

of capturing personal identifiable information. The camera will not use any zoom settings and so, will default to focal length configure for imaging infinity. From an altitude of 100m, it is extremely difficult to clearly identify an individual. The Data Controller (**GeoAerospace**) will be responsible for ensuring that all data captured is checked on-site before being recorded on to storage devices for subsequent processing. All drone data will subsequently be reviewed by the Data Processor (**Maynooth University**) during processing, and any data that is deemed to contain any personally identifiable information will be identified and either deleted or ensure that the feature is pixelated. For the survey at the Site, the drone will be flown at 300ft due to height restrictions (https://www.iaa.ie/general-aviation/drones/uas-geographic-zones) and to mitigate any potential data capture of people in an urban/rural environment, the survey area footprint has been reduced to the pipeline corridor (50-100m wide) so that the focus of the survey is the pipeline and not the surrounding streets/roads/buildings where people may be present.

2. The drone will only use lower resolution cameras (i.e. 1080 not 4k) pointed at the pipeline to mitigate the opportunity to capture car number plates, people's faces etc. which could occur if high resolution cameras, operating at lower altitudes are pointed at human subjects. The drone camera will not use any zoom functionality to reduce any potential to capture individual faces/cars etc.
3. The local area will contain public signage 'Drone in Operation' alerting any individuals or passers that a drone survey is taking place. The drone operator (and safety assistant where necessary) will be clearly visible and identifiable. The signage will contain details of the survey as well as the name and contact details of the operator.

Step 3: Describe the Data Processing

Data will be collected via drone sensors and processed within two weeks of the flights. No PII is anticipated to be collected. However, should any personally identifiable information be recorded, then this is mitigated by two further steps:

1) The raw imagery will be deleted at source by the Data Controller
2) Any PII featured in the imagery will be identified and pixelated by the Data Processor

The processed videos of the pipeline are designed for the purposes of visually inspection the pipeline for any construction works/3rd party intrusion that may be occurring close to the pipeline in the context of ensuring public safety i.e. ensure no construction work is occurring close to the pipeline that may need to be stopped by GNI authorised personnel.

Step 4: Describe the context of the Data Processing:

All sensor data will be first checked for PII and then transferred from the drone platform directly to a secure, password protected cloud storage platform on the same day. A data access log, detailing personnel that have access together with details (e.g., date, time) will be maintained by the project manager.

Step 5: Describe the purposes of the Data Processing:

Data (drone imagery) will be processed to produce videos of the pipeline route for the purposes of producing geo-encoded videos for assessing the condition of the pipeline. Only the drone data processing team, and the client will have access to the data through secure servers. These datasets will not be released to the general public.

Step 6: Consultation process:

Stakeholders from GNI **(Client)**, Maynooth University (**Data Processor**) and GeoAerospace **(Data Controller)** have discussed various technical, operational, data-processing, and regulatory compliance (drone operation, GDPR etc.) regarding this proposed. Suitable technology and operational steps have been taken to ensure GDPR compliance and mitigation of any inadvertent data collection that may impact privacy, or surveillance concerns by the public.

Step 7: Assess necessity and proportionality:

The Site & surrounding roads are located close to both rural areas/urban areas, high buildings, traffic etc and so the environment is perfectly suited to safe, efficient, responsible as well as high quality video capture of this pipeline corridor.

Step 8: Identify and assess risks:

Potential sources of risk have been identified and addressed. These are summarised in table below.

Risk	Details	Mitigation
Capture of PII	Potential of drones to inadvertently capture and record PII	1) Flight profile of drone and imaging sensor configured to minimise recording of any PII. 2) Data Controller (from Drone Ops Team) will examine all image data on-site and either delete or pixelate any images containing PII features.
Public concern over drone operations	Alerting any members of the public, passers-by of Drone Operations	Signage (details of drone mapping exercise) will be displayed publicly on the day and the Drone Operator (and safety assistant where relevant) will be clearly visible.
Data Management	Release of data to unauthorised personnel	Data will be processed and stored secured on double password protected server. Only GeoAerospace, Maynooth University and GNI-will have access to the data.

Step 9: Identify measures to reduce risk:

Due to the fact that there are no further risks in terms of the collection of PII as described in Steps 2- 4, it is deemed that no additional measures need to be taken.

7.3 Appendix 3. U-Flyte GNI SoW

Form of Statement of Work

This Statement of Work is entered into between the University and one or more of the Secondary Partners pursuant to the uFlyte Research Drone Research and Innovation Collaborative Agreement dated 10 June 2019 between Maynooth University, the parties named as Primary Partners in Schedule 1 thereto and the parties named as Secondary Partners in Schedule 2 thereto.

Participating Primary Partners and/or Secondary Partners in this SOW

Organisation Name	***Address***	***Contact Person***	***Telephone***	***Email***
Gas Networks Ireland	*Gasworks Road T12 RX96 Cork Ireland*	*Shane Geraghty*	*+353 1 8926109*	Shane.Geraghty@gasnetworks.ie

Principal Terms

Work Programme Title:	
Work Programme Start Date:	
Work Programme Finish Date:	
Principal Investigator:	*Dr Tim McCarthy*
Work Programme Leader:	
Work Programme Type:	*SFI Work Package 4:Commercial Applications*
Targeted Field:	*Critical Infrastructure*
Category of Project	*Demonstrator Project*

SIGNED for and on behalf of: **Gas Networks Ireland,**

By: ______________________________

Name: ______________________________
Title: ______________________________
Date: ______________________________

SIGNED for and on behalf of: **National University of Ireland Maynooth, Maynooth University,**

By: ______________________________

Name: ______________________________
Title: ______________________________
Date: ______________________________

APPROVED by the **uFlyte Management Committee** at its meeting on:

Date: ___________________________
Signed: ___________________________
Position: Principal Investigator

STATEMENT OF WORK – TERMS AND CONDITIONS

Scope of this Statement of Work: This Statement of Work is made under and forms part of the Collaborative Research Agreement (relating to uFlyte – Drone Research and Innovation) of 10th June 2019 between Maynooth University, the parties named as Primary Partners in Schedule 1 thereto and the parties named as Secondary Partners in Schedule 2 thereto (the "**Agreement**"). This Statement of Work and the Schedules hereto sets out the agreement between the parties to this Statement of Work (the "**Participating Parties**") in connection with the Work Programme referred to at Schedule 1 (the "**Work Programme**").

Imported Definition: Subject to the definitions set out in this Statement of Work or any Schedule hereto, words and expressions defined in the Agreement shall, unless it is expressly provided otherwise, have the same meanings when used in this Statement of Work.

Precedence: If there is a conflict between the terms of the Agreement and the provisions of this Statement of Work, then save as expressly provided otherwise in this Statement of Work, the provisions of the Agreement shall prevail.

Intellectual Property and Publication: Save as provided in Schedule 3 to this Statement of Work, the ownership, management, use and exploitation of Intellectual Property arising out of or in connection with the Work Programme shall be governed by the provisions of Clause 5 of the Agreement.

Term and Termination

Term: This Statement of Work shall continue in full force and effect from and including the Work Programme Start Date, and shall expire on the Work Programme Completion Date, or, subject to approval of the Management Committee, such later date as may be agreed between the Participating Parties of this Statement of Work in writing.

Termination with Cause

Where the Work Programme involves of just two Participating Parties and a SOW Termination Event (as defined in Clause 5.2(d) below) occurs in relation to one of the Participating Parties (the "**Relevant Party**") (whether such occurrence is voluntary, involuntary or occurs by operation of law or pursuant to a public body decree or order of any court), the other Party (the "**Other Party**") may terminate this Statement of Work. Any such termination shall be effected by notice in writing addressed to the Relevant Party.

Where the Work Programme involves more than two Participating Parties and a SOW Termination Event occurs in relation to one of the Participating Parties, then the other Participating Parties (the "**Other Parties**") acting in concurrence with each other, may terminate this Statement of Work with respect to the Relevant Party only. If the Statement of Work is terminated only with respect to the Relevant Party, then this Statement of Work shall terminate as regards the Relevant Party, but shall continue in full force and effect as regards the Other Parties until such time as a new Statement of Work in writing regarding that Work Programme supersedes this Statement of Work. Any such termination shall be effected by notice in writing addressed to all Participating Parties other than the Participating Party or Participating Parties issuing it.

The Other Parties may review the requirements of Schedule 1 (*work programme description*), Schedule 2 (*introduced background and confidential information*) and Schedule 3 (*special provisions*), and may make such changes as they think fit.

Each of the following shall be a SOW Termination Event with respect to a Relevant Party:

the Relevant Party fails (for whatever reason) to comply with its reporting obligations pursuant to clause 5.4 of the Agreement and as may be described in schedule 1 to this Statement of Work;

the Relevant Party fails (for whatever reason) to make available the Background described in Schedule 2 to this Statement of Work for use of the Project;

the Relevant Party fails (for whatever reason) to comply in any material respect with any obligation on its part under this Statement of Work (other than one contemplated by Clause 5.2(d)(ii)) and

that failure is not, in the reasonable opinion of the Other Party or Other Parties (whatever is applicable), susceptible to remedy; or

the failure continues for 45 days after notice from one or more of the Other Parties to the Relevant Party requiring the failure to be remedied;

an event relating to the Relevant Party entitling any Other Party or Other Parties to terminate the Agreement or a Statement of Work pursuant to Clause 11 of the Agreement occurs; or

the Agreement is terminated with respect to the Relevant Party.

Termination with Notice: If any Participating Party wishes to terminate its participation in the Work Programme prior to a time when it would have otherwise terminated participation, it may do so by providing written notice to the Management Committee and the Other Party or Other Parties (whatever is applicable) specifying the reason for its termination and the proposed date of termination ("**Termination Date**"), at least six (6) months prior to proposed termination.

Consequences of Termination: The provisions of clause 11 of the Agreement shall apply mutatis mutandis to the termination of this Statement of Work whether generally or with respect to one or more of the Participating Parties.

Specific Data Protection Measures (if any): The Participating Parties wish to supplement Clause 9 of the Agreement with more detailed particulars in the SOW as follows: [None].

No Assignment: No Participating Party may assign this Statement of Work or any or its rights or obligations hereunder, whether wholly or in part to third parties or to any legal successors by any Party without the prior written consent of the other Participating Parties, such consent not to be unreasonably withheld, conditioned or delayed. Notwithstanding the foregoing, a Party may assign its rights under this Statement of Work to an Affiliate or as the result of a corporate reorganization without the prior written consent of the other Parties.

Amendments: Any amendment or modification to this Statement of Work must be in writing and duly signed for and on behalf of each of the Participating Parties and be approved by the Management Committee.

Counterparts: This Statement of Work may be executed in any number of counterparts, each of which when executed and delivered shall constitute a duplicate original, but all the counterparts shall together constitute the one agreement. Transmission of an executed counterpart of this Statement of Work by fax or e-mail (in PDF, JPEG or other agreed format) shall take effect as delivery of an executed counterpart of this Statement of Work. If either method of delivery is adopted, without prejudice to the validity of the agreement thus made, each Participating Party shall provide the others with the original of such counterpart as soon as reasonably possible thereafter.

Signature: This Statement of Work is executed by the Participating Parties, and each person executing the Statement of Work represents to the Participating Party other than he or she represents, that he or she has the authority to sign on behalf of the Participating Party which he or she purports to bind.

SOW SCHEDULE 1
WORK PROGRAMME DESCRIPTION
Purpose: To research and develop novel approaches in carrying out various defect inspection, mapping and monitoring over GNI pipeline infrastructure (including AGI) and RoW.
Scope of work: Confined to R&D tasks with the objectives of producing results and assessments to help devise more efficient mapping and monitoring methodologies and work-flows as set out in Tasks/Milestones below.

Location of work: Research work at MU with testing on-site with GNI personnel at various locations throughout Ireland
Project timelines and Deliverables

The Demonstrator Project deliverables and timelines are outlined in **Table 2**.
Table 1 Project Deliverables and timelines

Task	Date of delivery
Kick-off meeting for project	10th Sept 2021
T2.1 Use of combined Satellite and Drone sensors to detect and measure vegetation encroachment at selected sites. Some of this work will investigate the detection of Invasive Species such as Japanese Knotweed.	29-Oct-2021
T2.2 Dynamic Methane (CH_4) leak detection and measurement, from a Drone platform, over AGIs as well as along RoW	26-Nov-2021
T2.3 Use of Synthetic Aperture Radar (Sentinel-1) as well as other Optical Remote Sensing methodologies to gain a better understating of flooding events at selected sites along GNI RoW. This will also involve time-series analysis, coinciding with historic flood events. Include Satellite & LiDAR Data Discovery.	14-Jan-2021
T2.4 Devising new aerial approaches to inspecting 'Markers' for defects, damage etc	11-Feb-2022
Project evaluation meeting (Remote session)	25-Feb-2022
Project close	25-Feb-2022

Safety standards
Please refer to the SUA document for details of the risk assessment for this project.
Table 2 Milestones and Deliverables

Description	Date
Milestone 1: Kick-off Meeting	**10/9/2021**
Output: Final comments/inputs for completion of 4 X Tasks Check LiDAR Data Processing & Drone GPR testing	
Milestone 2: Satellite/Drone for Vegetation Encroachment Mapping	**29/10/2021**
Output: Report with Data (Satellite & Drone) demonstrations over 3 X selected sites for vegetation encroachment. Initial report for using Hyperspectral & Multispectral sensors for Invasive Species detection	
Milestone 3: Methane (CH_4) leak detection and mapping	**26/11/2021**
Output: Test Results and test-flight demonstrators using Tuneable Diode Laser Spectrometry (TDLS). Optimum Flight Configurations testing. Data Analysis and modelling (plume, density, source). Assessment of system on-site at GNI AGIS etc. Pre-operational Methodology document.	
Milestone 4: EO/SAR for Flood Monitoring & Mapping	**14/01/2022**
Output: Report & Data demonstrators (location, extent of flooding) and time-series (changes of flood-plain extent over time). Also EO/LiDAR Discovery & Visualisation	
Milestone 5: GNI Marker Defect Inspection/Monitoring	**11/2/2022**
Output: Report, Demonstrator**,** Methodology for detecting, inspecting & assessing GNI Markers	
Milestone 6: EO/Drone Mapping & Monitoring Review Workshop	**25/2/2022**

Output: Workshop to review various mapping & monitoring activities using Satellite, airborne and Drone platforms

Resourcing and Equipment

Table 3 Resources and Equipment

Resource	Description
Personnel	The U-Flyte team from Maynooth University working on this Demonstrator project will comprise of Principal investigator – Dr Tim McCarthy Drone operations manager – Fearghus Foyle Drone pilot – Fergal McCarthy (IAA certified and contracted by MU via FlyteOPs Ltd.) Sensor technician and data processor – Daire Walsh Sensor technician and data processor – William Burke ML Engineer : Samuele Buosi Geospatial and Earth Observation expert – Aidan Magee GeoAerospace operations team (Contracted by MU) working on this Demonstrator project will comprise of Commercial pilot and IAA Certified pilot – Sean Mannion Sensor technician – TJ McNamara GNI Project manager GNI Engineer(s)/Pipeline/ROW inspector
Support	MU U-Flyte administration –Ann-Marie Burke MU Research Development Office finance – Siobhan Kelly and Petra Stolfova
Equipment	Aircraft: Cessna -172 UAV platforms: DJI Matrix 300, DJI M600, Inspire 2 and Phantom 4 RTK Sensors: LiDAR (Riegl VUX-1 LR laser scanner for Cessna 172) LiDAR (Zebb Horizon Scanner for M600) RGB Ortho-rectified imagery and video (Zenmuse HD20T & X5s) Mica sense Multi-Spectral Sensor (Drone survey over River Lee Urban Site) Sentroid DR200 & CH4 UgCS GPR
In-kind contribution	GNI will provide expertise and support (e.g. site access) throughout the Demonstrator project including planning, execution, and evaluation stages. GNI personnel will also attend the evaluation meeting and provide input and feedback in relation to existing inspection and survey techniques, and how they relate to proposed new techniques and improvements following the Demonstrator.

Management & Reporting

[Detail any specific management and reporting issues/obligations that the SOW will have]

Reporting issues/obligations	Who	Action
Safety and risk assessment of four test sites (To be carried out by Fearghus Foyle)	U-Flyte/Third Party	GNI to provide coordinates of the survey location and contact details of the relevant person who manages the subsection where the drone survey will be carried out
Site access to the agreed drone survey location	GNI	GNI to give written/email permission to U-Flyte to access any sites on the agreed data acquisition date

Check NOTAMS (Notice to Airmen) If the site is close to (<5km) or in controlled airspace the U-Flyte team will need to notify the Irish Aviation Authority (IAA) and relevant air traffic controllers of their activities and planned dates and times of operation	U-Flyte/Third party	Once GNI confirms data acquisition dates U-Flyte/Third Party to check NOTAMs and ATC in Cork Airport
Specific Operating Permission (SOP) Any UAV operators involved in this project will hold IAA-approved SOPs. An-IAA approved SOP requires that drone pilots are trained and hold a Certificate of Competency from the IAA.	U-Flyte/Third party	U-Flyte/Third party to share Certificate of Competency with GNI prior to data acquisition
Final report	U-Flyte	U-Flyte to finalise and share final report with GNI in September 2020.

SOW SCHEDULE 2

INTRODUCED BACKGROUND AND CONFIDENTIAL INFORMATION

The following Background IP (BIP) is being introduced to the Work Programme at the outset: *[Note that BIP may or may not also be Confidential Information. If it is both, then enter it under this BIP section and also in the CI section. Ensure that the text is identical]*

Introduced by	Item	Description	Restrictions	Additional Conditions of use
… No BIP is being introduced at the time of signing	…	…	*n/a*	

[Insert list of the Background IP being introduced in accordance with Section 2 of Schedule 5 to the Agreement.]

Confidential Information (CI)

Introduced by	Item	Description	Conditions of use
n/a at this point	n/a at this point	n/a at this point	n/a at this point

SOW SCHEDULE 3
SPECIAL PROVISIONS
[Include additional IP related terms and conditions and justifications for these 'Special Provisions']

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SOW SCHEDULE 4
INDUSTRY PARTY BUDGET & PAYMENT SCHEDULE

Gas Networks Ireland	
Industry Party Contribution	**€ 60,000(ex VAT)**

The Industry Party Contribution will be paid to Maynooth University in line with the following Payment Schedule:

Payment schedule *(VAT exempt)*	**Date due**	**Amount**
	26th Nov 2021 : Completion of Milestone-1 & Milestone-2	**€30,000**
	11th Feb 2022 : Final payment on Milestone-3 & Milestone-4	**€30,000**
	Total fees	**€60,000**

Industry Party's contact details for invoices	*Shane Geraghty,* *Gasworks Road, T12 RX96 Cork* *Ireland.* *Phone:+353 1 8926109* *Email: shane.geraghty@gasnetworks.ie*

Maynooth University Bank and Payment Details

University's contact details for invoices	RDO Finance, Petra Stolfova, finance.rdo@mu.ie
Payment Terms	30 days net. Payment shall be by way of bank transfer. The University shall knowledge payment by way of an authenticated copy receipt, with the original receipt to be held by the University.
Interest on Late Payment	Interest shall be automatically applied if payment has not been received within thirty (30) days of receipt of a valid invoice. Interest shall be calculated on a daily basis of two per cent (2%) above the EURIBOR monthly deposit rate.
Payment details for University	

Bank account name:	Allied Irish Banks (AIB)
Address of Bank:	Main Street, Maynooth, Co. Kildare
Bank account number:	21310767
Bank sort code:	93 32 01
SWIFT Code/Bic:	AIB KIE 2D
IBAN:	IE58AIBK93320121310767
Account Name:	National University of Ireland, Maynooth
Reference:	uFlyte_GNI_2021

Budget breakdown

Flight Operations and Data Acquisition (C-172)	**Cost (EUR)**
Description: Costs for aircraft hire, aircraft pilot, sensor technician and data acquisition over 3 days	**0**
Tasks	
Planning, permissions, flying and travel	
Sensor preparation and operation	
Data acquisition, uploading, backup	
Maynooth University/Uflyte (Drone Ops, Processing, Analysis & Reporting)	
Description: Costs for drone pilot (x2), sensor technician, drone data acquisition, data processing engineer, software development, machine learning engineer, EO specialist, project manager, lead investigator. 4 X Tasks (Average): 10 X Research Staff, 3 X test-flight days, 20 x days per task (€12.5k per task)	**50,000**
Tasks	
Planning, sensor preparation and operation, travel	
Drone data acquisition, data processing, data integration for the pipeline survey	
Software development for initial geotagging	
Project management, SOW, workshop organisation, final report	
Multispectral/Hyperspectral Vegetation Mapping Development of Machine learning techniques for automated marker post identification Methane Plume modelling & Mapping Flood Monitoring	
Expertise, liaison and oversight on project, workshop and future recommendations	
Sensor Hire Optical, LiDAR, CH4, GPR (as per SFI schedule), Field Trips, Travel (upto 6 X staff)	**7,500**
Engineering & Consumables (Fitting/Configuring New Sensors on Drones)	**2,500**
Sub-total (This work is VAT exempt according to the U-Flyte Collaborative Agreement).	**60,000**
VAT	**Exempt**
Total	**60,000**