DAMSAT

DAMSAT - Dam Monitoring from Satellites

Case study

April 2020

Executive summary

DAm Monitoring from SATellites (DAMSAT) uses satellite technology to remotely monitor water and tailings dams and other tailings deposit areas.

The project:

- supports the reduction of the environmental and social impacts of water and tailings dams and other tailings deposits failures at 31 sites in the regions of Cajamarca, Pasco and Junín in Peru;
- influences the adoption of Earth Observation monitoring tools by engaging with key stakeholders and developing capacity building activities;
- provides government agencies timely information about dam health indicators over multiple sites in a non-invasive way and in a consistent manner irrespective of ownership or access. This will eventually increase the capacity of government oversight and help to create improved transparency in the operations and governance of the extractive sector;
- demonstrates to dam operators the capability of multi asset monitoring of large areas with up to millimetre-level accuracy in real and near real time.

DAMSAT provides a one-stop portal to access information on the performance of the monitored dams by combining the use of:

- satellite derived data (SAR and optical);
- in-situ data from SUMMIT-SHM (GNSS) equipment;
- weather forecast data;
- and modelling studies of dam releases and loss of life in communities downstream.

Combined with the expertise of project partners, this makes the DAMSAT offering unique.

Engagement has been key to ensure the development of a system that meets the needs of stakeholders and the ownership of the system beyond the project. Pre-agreements with Peruvian stakeholders and among UK partners are key towards the sustainability of the project.

Project team

The project is led by HR Wallingford with UK and Peruvian partners: Siemens, Telespazio Vega UK, Satellite Applications Catapult, Oxford Policy Management Limited, The Smith School of Enterprise and Environment, CIEMAM, Fundación Nacional de Ingeniería Hidráulica (National Foundation for Hydraulics) and School of Engineering of University of Cajamarca). DAMSAT is funded by the UK Space Angency under the International Partnership Programme (IPP). The programme aims to use space solutions to make a positive and practical impact on the lives of those living in emerging and developing economies. IPP is funded by the Global Challenges Research Fund, a fund from the UK Government which supports cutting-edge research and innovation strengths to deliver sustainable economic or societal benefits to emerging and developing countries around the world.

Project partners:

Project funded by:

Cover image: Cerro Corona tailings dam in Cajamarca

Project overview

The challenge

Water storage dams serve multiple functions for a society such as drinking water supply, flood protection and hydroelectricity generation. Tailings dams are embankments of compacted earth used to store toxic mining waste. The likelihood of failure of tailings dams is higher than that of water storage dams, although in both, the consequences of failure are catastrophic for communities and ecosystems downstream. Consequences can include loss of numerous lives, destruction of infrastructure and pollution of the environment, drinking water sources and the food chain.

The main challenge of this project was to develop an effective method to monitor water and tailings dams and other tailings deposit areas, especially those in remote areas, that can help predict potential catastrophic failures. These dams and other tailings deposit areas may be operational, closed or abandoned.

The project focused its work in the mining regions of Cajamarca and Pasco, with an additional site in Junín, in Peru. A recent study of 743 dams in Peru (85% of which were water dams and 15% were mining dams) carried out by the Ministry of Agriculture and Irrigation[1], concluded that many dams in the country are not safe and pose a risk to the population living downstream. The same report recommended the implementation or improvement of monitoring and control systems to the dams to manage the risk through means of early detection and identification of problems that could cause a breach.

Historic dam failures have shown that more effective government inspection is needed. This is currently difficult because of:

- **Limited resources:** the number of sites that need to be monitored far exceeds most regulators' capacities as a result of issues related to time, distance, and cost.
- **Lack of transparency:** government agencies have limited or infrequent access to observation data gathered by the dam owners.

The context

The system developed by the project is being tested on 31 sites comprising water and tailings dams as well as operational, closed and abandoned tailings storage facilities in the mining regions of Cajamarca, Pasco and Junín in Peru.

Peru is classified as an "upper middle income country" by the OECD's Development Assistance Committee and is a country with a long mining experience. It's the world's second largest producer of copper, silver and zinc and the leading producer of gold, zinc and lead in Latin-America. It also has the world's largest reserves of silver and the third largest of copper, zinc and molybdenum[2]. Within Peru there are approximately 200 metal mines in operation and thousands of closed, abandoned and illegal mines, which have no state permission meaning no land rights, mining license, exploration or mineral transportation permit. In abandoned mines, acceptable mine closure and reclamation has not taken place or is incomplete. In most cases, mine owners of closed or abandoned mines cannot be found or are financially unable or unwilling to carry out the proper closure and clean-up of the mine site. In 2015, in Peru alone there were at least 9,000 abandoned and "orphaned" facilities, a nine-fold increase since 2005.

Despite the large revenues generated by mining in Peru, it often generates social discontent and inequalities owing to its impacts on ecosystem services and local communities' livelihoods. For example, in 2008, a state of emergency was declared at a mine near Lima over fears that arsenic, lead and cadmium from its tailings dam could pollute the main water supply for the capital. An earthquake in 2010 led to an embankment failure at Caudalosa Chica mine in Huachocolpa (Huancavelica region) releasing a large volume of tailings leading to the contamination of the Escalera and Opamayo Rivers up to 110 km downstream of the rivers. Other incidents in Peru include the failure of the tailings dam at Marsa in 1963, which failed by overtopping, resulting in 6 deaths, and the failure in 1996 of the tailings dam at Amatista Nazca releasing more than 300,000 m^3 of tailings that contaminated farmers' land.

Abroad, in January 2019 the failure of Brumadinho dam in Brazil released some 10 million m3 of mining waste which killed between 270 and 320 people, highlighting again that failures of tailings dams pose a significant risk to the health of people and the environment, especially in many low income countries where the extractive industry makes a significant contribution to the nation's wealth.

[1] Autoridad Nacional del Agua (2016), Inventario de presas en el Perú. Primera parte – 2015 (in Spanish)
[2] MINEM (2018) Anuario Minero 2017 (in Spanish)

How space can help

In many low and middle income countries it is challenging for governments to maintain oversight of the management of tailings dams and water retaining structures, given limited financial resources and a scarcity of appropriate technical experts. Space observations provide a synoptic and comprehensive ability to observe, measure, qualify and quantify over wide areas with a very high frequency regardless of the relative inaccessibility and hazardous nature of the terrain.

Earth Observation-based tools to monitor tailings and water retaining dams would be less expensive and require less expertise to employ than existing methods. These tools will also allow the assessment of historical changes in critical structures and could complement in-situ measurements in particular with its ability to provide independent calibration and validation of measurements derived from local devices.

Aims of the project

The purpose of the project is to develop an effective monitoring system for water storage dams, tailings dams and other tailings deposits based on space technology. DAMSAT (Dam Monitoring from SATellites) will help reduce the risk of failure of these structures and therefore, the risks to population downstream.

DAMSAT incorporates monitoring data from a combination of INSAR (Synthetic Aperture Radar) images and Global Navigation Satellite System (GNSS) techniques combined with on-site instrumentation providing real-time measurements. It also uses optical data for the detection of pollution indicators, incorporates weather forecast data into hydraulic models and develops downstream risk and impact assessment models. All this information is integrated into a cloud-based platform which generates alerts for behavioural changes or unusual weather conditions that could cause infrastructure failure.

DAMSAT is currently monitoring 31 tailings and water storage sites in the regions of Cajamarca, Pasco and Junín in Peru.

The aim of DAMSAT is to:

- support the reduction of the environmental and social impacts of water and tailings dam failures at 31 sites in the regions of Cajamarca, Pasco and Junín in Peru;
- influence the adoption of Earth Observation monitoring tools for tailings and water retaining dams by engaging with key stakeholders and developing capacity building activities;
- provide government agencies timely information about dam health indicators over multiple sites in a non-invasive way and in a consistent manner irrespective of ownership or access. This will eventually increase the capacity of government oversight, and help to create improved transparency in the operations and governance of the extractive sector;
- demonstrate the advantages of using satellite data to monitor several assets and, on occasions, several sites with the same system for planning, operations and general maintenance;
- demonstrate to dam operators the capability of multi asset monitoring of large areas with up to millimetre-level accuracy in real and near-real time.

Contribution to the United Nations Sustainable Development Goals

The project will contribute towards two of the United Nations Sustainable Development Goals (SDGs).

SDG 1.5.1: Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population.

Reducing the exposure and vulnerability of disadvantaged communities to extreme events related to climate change and other economic, social or environmental disasters.

SDG 6.3.2: Proportion of bodies of water with good ambient water quality.

Improve water quality by reducing pollution, eliminating dumping and minimising release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.

Project partners

Partners based in UK

HR Wallingford is a not-for-profit independent engineering and environmental hydraulics organisation. We deliver practical solutions to the complex water-related challenges faced by our international clients. A dynamic research programme underpins all what we do and keeps us at the leading edge. Our unique mix of know-how, assets and facilities includes state of the art physical modelling laboratories, a full range of numerical modelling tools and, above all, enthusiastic people with world-renowned skills and expertise.

www.hrwallingford.com

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Telespazio VEGA UK has been developing space services for over 40 years, with expertise in EO, satellite communications and navigation. Telespazio Vega UK has developed a real-time GNSS based object motion product with alerting and visualisation tool called SUMMIT SHM. SUMMIT can be deployed world-wide to most environments and it is entirely designed, manufactured, deployed and remotely maintained by the Telespazio Vega UK team. Survey data output can be remotely accessed and analysed from any computer anywhere in the world with internet provision. All the system maintenance is also done remotely. SUMMIT GNSS data can be combined with InSAR to detect millimetric surface deformations over wider areas and water catchments.

www.telespazio.com

Siemens is an innovation and technology leader in industrial automation and digitalization. In close cooperation with partners and customers, Siemens is the driving force for the digital transformation in the discrete and process industries. Siemens intelligent clean and waste water management solutions are sustainable and support reducing risks such as unconsented spills leading to pollution incidents, pump failures and the risks of internal and external sewer flooding and sewer collapse. IoT and AI solutions help clients to improve environmental compliance, sewer network availability and operational efficiency.

new.siemens.com/uk/en/markets/water.html

The Satellite Applications Catapult is one of a network of UK technology and innovation companies which aims to drive economic growth through the commercialisation of research. The aim of the Catapult is to support UK industry by accelerating the growth of satellite applications and to contribute to capturing a 10% share of the predicted global space market by 2030. It aims to achieve this by exploiting the innovation potential in the UK industrial and academic communities, by being a focal point where small and medium enterprises, large industry and end-users can work together with researchers to challenge barriers, explore and develop new ideas, and bring these to commercial reality.

sa.catapult.org.uk/

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Oxford Policy Management Limited (OPM) is an international development consultancy committed to helping policy makers design and implement sustainable reforms for reducing social and economic disadvantage in low-income countries. OPM has over 35 years' experience in providing rigorous analysis, policy advice, management and training services to national governments, international aid agencies and other public sector and non-government organisations.

www.opml.co.uk

Dr McElroy from the **Smith School of Enterprise and the Environment, Oxford University** is a partner of the project. Her work has focused on the interactions between the mining industry, environment and development. She has addressed the institutional challenges to private sector involvement in development through an investigation of the use of corporate foundations in the mining industry, involving fieldwork with major mining firms in South Africa, Namibia, Mongolia and Chile.

Partners based in Peru

Ciemam is a mining and environmental research and consultancy company founded in 2015 and operating in the Cajamarca region in Peru. CIEMAM specialises in environmental assessments, rehabilitation and restoration projects and capacity building activities.

ciemam.com

The **Fundación Nacional de Ingeniería Hidráulica (National Foundation for Hydraulics)** carries out studies and projects related to hydrology and hydraulics with the objective of minimising natural hazards. They work closely with the mining industry in Peru and in the region of Cajamarca where most of the mines are located.

The **Facultad de Ingeniería y Escuela de Ingenieria Hidraulica (Faculty of Engineering)**, founded in 1963 is part of the **Universidad Nacional de Cajamarca (National University of Cajamarca)**, one of the leading training institutions in the north of the country. The School of Hydraulic Engineering is one of the six main departments of the Faculty and was created with the objective to contribute to the scientific research on the use of renewable resources for sustainable development.

www.unc.edu.pe

Project meeting at HR Wallingford

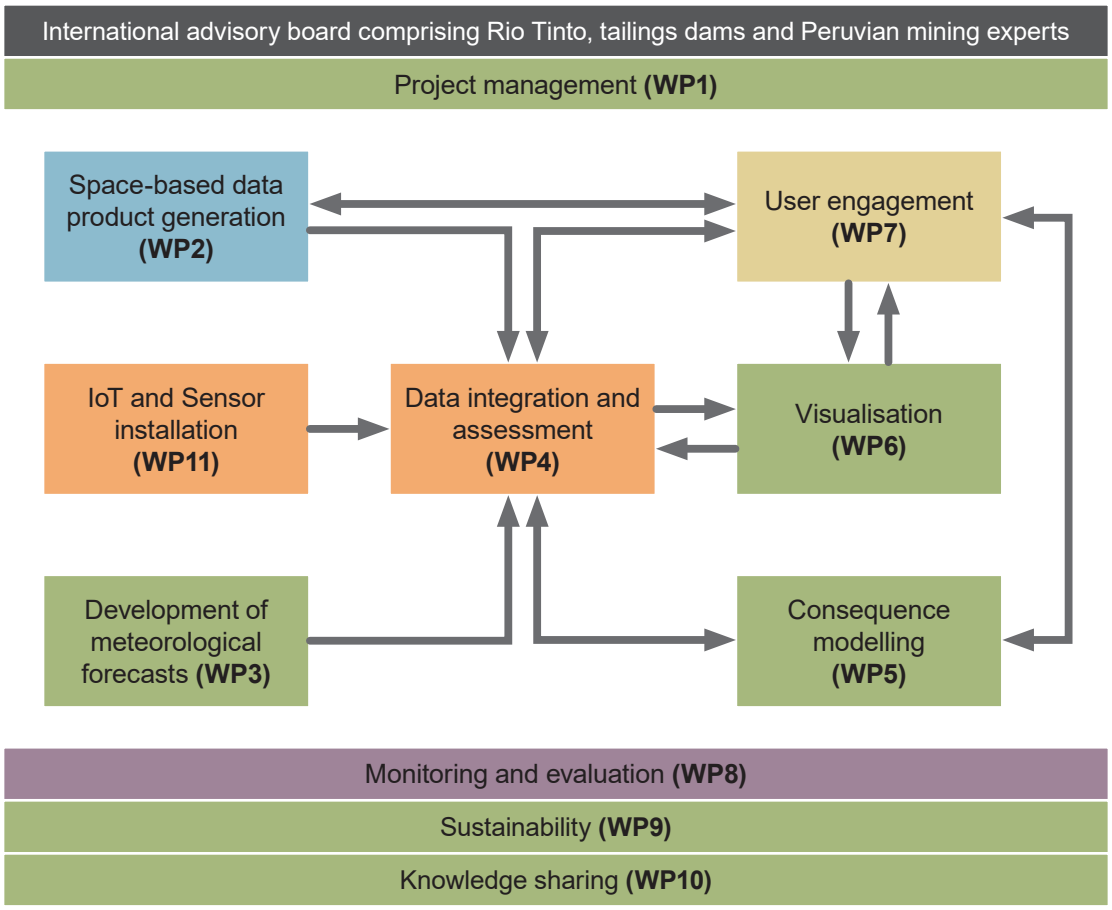
Visit of UKSA and Project Partners to Colquirrumi site managed by CIEMAM

Members of HR Wallingford and FUNAINHI at the British Embassy in Lima

Meeting with Peruvian stakeholders in Lima

General organisation of the project

The project is organised into 11 Work Packages (WP).



HR Wallingford leads the overall project (WP1) as well as the work related to the integration of meteorological forecasts with hydrological models (WP3), consequence modelling, about the estimation of impacts downstream of dams in case of failure, the results of which feed the Emergency Planning module (WP5), visualization of the products (WP6), sustainability of the project's products (WP9) and knowledge sharing activities (WP10).

Telespazio develops the GNSS (SUMMIT SHM) and InSAR based solution for detection of ground movements and supervises the installation of GNSS on two of the pilot sites (WP2).

Siemens brings their expertise in cloud-based management platforms and wireless monitoring (WP4) and the installation of in-situ sensors for dam monitoring on water retaining dams in the region of Pasco (WP11).

Satellite Application Catapult leads on user engagement (WP7) preparing workshops, events and the user requirements document.

Oxford Policy Management's dedicated Monitoring and Evaluation team oversees the design and implementation of the project's M&E (WP8) including the baseline, mid-line and end-line evaluations.

The Smith School of Enterprise and the Environment, represented by Dr Caitlin McElroy develops the assessments related to the environmental governance and social impacts relevant to the project being involved with the User engagement (WP7), Sustainability (WP9) and Knowledge Sharing (WP10) Work Packages.

Ciemam provides access to tailings dam sites they are working on in order to pilot the tools developed as part of the project. They also assist with collecting on the ground monitoring information at these sites, collecting general information and supporting knowledge sharing activities.

The National Foundation for Hydraulics assists with collection of ground-based monitoring data, including M&E tasks, coordinates the purchase of instrumentation and promotes the objectives and benefits of the project to regulators and other stakeholders.

The Faculty of Engineering and School of Hydraulic Engineering play a key role in the knowledge sharing aspects of the project including capacity building activities. They also provide technical inputs on the consequence modelling (WP5) and sustainability activities (WP9) and are supporting the Monitoring & Evaluation and user requirement activities.

Solution development journey

A comprehensive set of user requirements was defined to inform the technical development. In order to identify the user needs the project team undertook a number of tasks, including in country research trips to understand the challenges faced by stakeholders, identify opportunities for interventions, and gain a better understanding of the potential value of said opportunities.

Key challenges

- having up to date reliable weather data (e.g. live data on rainfall);
- difficulty in getting data on mines that are in remote locations, especially in adverse weather;
- a need to work more smoothly and efficiently with other organisations during emergency response;
- difficulty in getting real-time awareness of safety and stability of dams because organisations may have limited resources and are not frequently in the field;
- in case of an emergency, to quickly and objectively assess the situation even before getting to the site;
- in case of an emergency, to know what caused the accident (for example operations or rainfall), where the accidents originated from and the extent of how much area was affected;
- a need for clear and timely communication between organisations involved in the operation and supervision of sites.

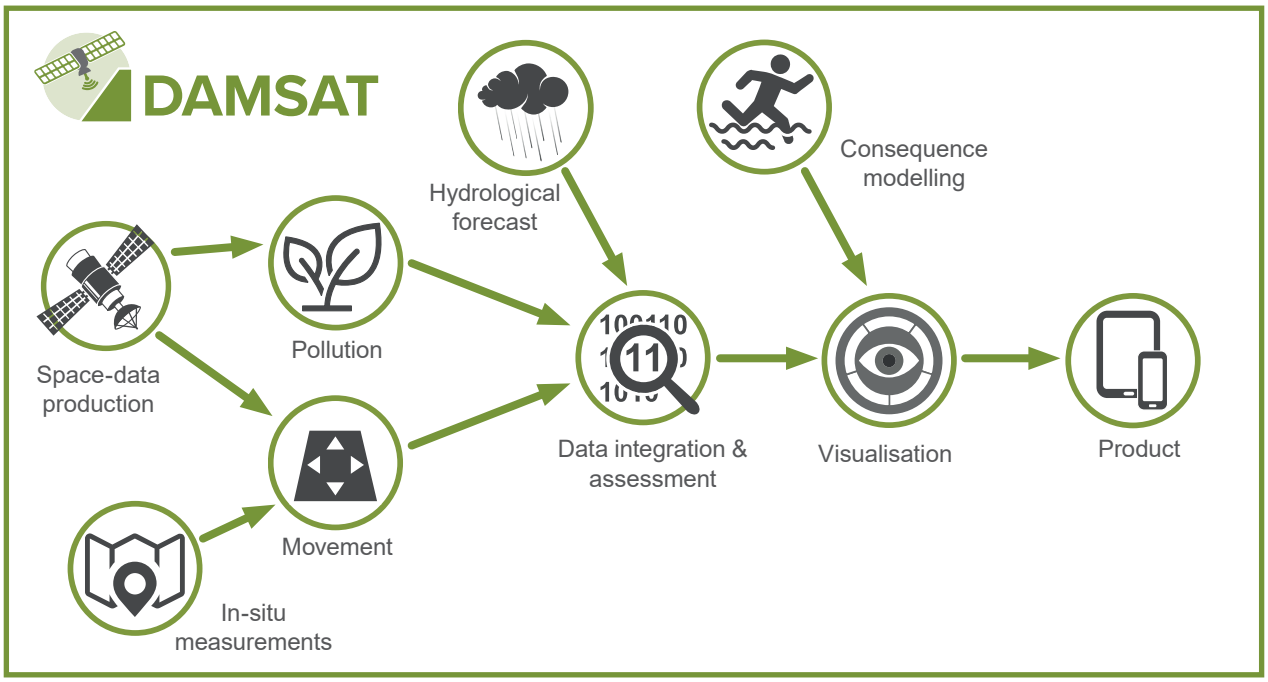
DAM Monitoring from Satellite's (DAMSAT) was developed to address these challenges. DAMSAT uses satellite technology to remotely monitor water and tailings dams and other tailings deposit areas. The system helps to reduce the risk of failure of these structures and the consequent risk to population and damage to ecosystems downstream upon which many vulnerable communities rely for both their source of water and livelihoods. The interface is web-based and can be accessed by multiple users and/or organisations.

DAMSAT has been developed as a series of modules that monitor different aspects of dam behaviour.

DAMSAT modules

	DAMSAT modules
General information	Site information is stored here such as the site name, location, including grid reference and a general description of the site.
Warnings	Warnings are triggered when the results provided by the Movement Detection, Leakage and Hydrometeorological forecast exceed a certain threshold, fixed by the DAMSAT user. Depending on the threshold values three levels are considered: No warning, Medium and High. Each warning contains information of when it was created and modified, the origin and reason of the warning and any other additional information required by the user. Warnings can be managed to lower or raise their level based on additional information or actions taken on the ground. Selected users can modify the threshold values, which are set for each different module and for each particular site.
Visualisation	Allows users to do visual inspection of sites by comparing a current image with previous images. The purpose is to assists users to detect possible changes in the areas of interest such as changes in populated areas or infrastructures. The images are obtained from the satellite Sentinel 2 (2A and 2B) and they are RGB images with 10 m spatial resolution. The images are updated approximately every 5 days.
Movement detection	Provides information about possible movements at the sites of interest and nearby areas. The information is obtained from three different sources: ◢ Automatized InSAR analysis of Sentinel-1 imagery. ◢ Supervised InSAR analysis of COSMO-SkyMed imagery. ◢ GNSS (SUMMIT SHM) based motion monitoring system that provides up to millimetre-level accuracy in real and near real-time. The movement is presented as velocity maps in the line of sight of the satellite and as graphs of point movements for different areas at the dam. We are using the SUMMIT-SHM, Telespazio monitoring system based on GNSS technology that delivers 3D motion monitoring up to millimetre-level accuracy in real-time. The system is composed of two elements: the GNSS monitoring stations with a reference station, with Real-Time Kinematic processing that are installed on the points of interest, and the SUMMIT-SHM central processing unit.
Leakage	This module provides information about changes in two indicators, iron oxide and vegetation health, in areas downstream of the sites of interest. The analysis of the changes of these two indicators by the DAMSAT user can help to identify possible leakages or pollution incidents from the sites. The changes are estimated analysing images from the Sentinel-2 Level 2A product.
Hydrometeorological forecast	This module presents the rainfall forecast for the site and, when applicable, the estimated water discharge and change in water levels in the ponds behind the dams. Updates of meteorological forecasts and subsequent estimations are produced every 6 hours. The rainfall forecasts are obtained from NOAA GFS (with 4 daily predictions up to 10 days) and ECMWF (4 daily predictions from ensemble models at high spatial resolution 3 days into the future and 2 daily predictions up to 10 days).
Emergency planning	This module provides information to support the development of emergency plans, helping to improve the understanding of the risks downstream if a failure of the dam occurs. The results provided in this module are obtained from the consequence modelling approach followed, which considers the simulation of the outflow from the water or tailings dam if there is a failure (the breaching of the structure), its spread downstream, and how it impacts people living in the area downstream. A suite of consequence related models is used to create these simulations. With this information, estimations of economic and environmental damages are also quantified.

DAMSAT module network



Promotion of DAMSAT

Over the course of the project the team has developed different mediums of promotion, including several capacity building activities:

- DAMSAT has a project website www.damsat.org which is in both English and Spanish.
- we provide monthly newsletters in Spanish to the Peruvian stakeholders.
- we prepared brochures and short videos explaining the project in both English and Spanish.
- we signed an MoU with CONIDA, the Peruvian Space Agency.
- we delivered a dedicated 2-day training course and other workshop activities.
- we participated in conferences and events in the UK and Peru and also worldwide.
- we published papers in journals.
- we had one to one meetings with the different stakeholders during several trips to Peru.

Capacity building

A dedicated training course was designed to be of interest to all organisations involved with the DAMSAT project, as the course presented the methods and technologies that support the tool, but also to members of public and private organisations involved in monitoring or risk management that wanted to have an overview of satellite-based observations techniques and modelling-based approaches. A total of 23 different organisations participated in the training course. The ones with the biggest presence were public Peruvian institutions in charge of managing the environmental and infrastructure assets and national risk. Mining stakeholders, private engineering companies, university representatives and risk management organisations also attended the training scheme.

General stakeholder meeting

In addition to the individual meetings with stakeholders the project team organised a general meeting at the British Embassy with some of the main potential end-users: MINEM (the Ministry of Energy and Mines), OSINERGMIN (in charge of supervision of mining sector), OEFA (environmental body) and CONIDA (the Peruvian Space Agency). This meeting was an important step forward for the future sustainability of the project as it was discussed the role of each organisation, the importance of confidentiality of information and how this would be managed among stakeholders.

Innovations

DAMSAT provides a one-stop portal to access information on the performance of the monitored dams by combining the use of satellite derived data with other techniques resulting in the ability to:

- monitor deformation of the retaining structure with the use of near real time InSAR data and real time in-situ data from SUMMIT-SHM, a Telespazio monitoring system based on GNSS technology that delivers 3D motion monitoring;
- use forecasting tools and consequence modelling to issue warnings of unusual behaviour or weather conditions that could lead to failure;
- use optical data imagery to monitor pollution indicators;
- integrate and assess data providing real-time monitoring accessible on a web platform;
- use high and low resolution satellite imagery allowing DAMSAT to cater for different needs and budgets;
- develop the EMBREA-MUD model, an innovation in the dynamic simulation of breaching of tailings embankments; the model represents water and dam material using three different layers, which is a scientific and technological advance as this type of model was not previously available;
- apply for the first time the Life Safety Model (one of the most technically advanced methods) to simulate loss of life resulting from the failure of a tailings dams (rather than water dams). The model, used in the consequence modelling approach developed, performed well when applied to historical failures.

This combination of services combined with the expertise of project partners makes the DAMSAT offering unique.

Palcash 2, a water dam in Pasco

Village of Shelby downstream Palcash water dam

Community meeting at Shelby to present DAMSAT

Sustainability model

The services

The services DAMSAT provides are based around a Basic Package offering, which is considered the minimum leave behind, which uses freely distributed satellite data that will generally be of low resolution, and the option of a Premium Package, which includes in-situ monitoring equipment, high resolution satellite imagery or risk modelling. Users can tailor the DAMSAT package to suit their needs and requirements.

DAMSAT basic package

Module	Source of information	Comment
Warnings	DAMSAT	Allows quick visualization of warning and their management.
Visualisation	Sentinel 2, with a 10m resolution	Allows manual inspection of sites. Comparison of a current image with historic images to assist users to detect interesting changes that occur on site.
Movement detection	InSAR Sentinel-1	Provides an indication of displacements at the structure and in nearby points.
Leakage	Sentinel 2, with a 10m resolution	Analysing sequences of optical data for signs of changes in iron oxide that could indicate locations of potential pollution events.
	Sentinel 2, with a 10m resolution	Analysing sequences of optical data for signs of vegetation health variations that could indicate locations of potential pollution events.
Hydrometeorological forecast	NOAA GFS	NOAA GFS provides 4 daily forecasts of precipitation up to 10 days into the future with a spatial resolution of 0.25°. The data is analysed to also provide estimations of runoff and variations of water levels in the ponds behind the dams (if applicable).

DAMSAT premium package

Module	Source of information	Comment
Basic package +		
Movement detection	InSAR COMSO-SkyMed (CSK)1	Provides an indication in high resolution of displacements at the structure and in nearby points. Visualization tools are provided to analyse this data. InSAR provides differences between two measurements of the same point with a precision of few millimetres.
Movement detection	SUMMIT-SHM	SUMMIT-SHM, a Telespazio's monitoring system based on GNSS technology that delivers 3D motion monitoring up to millimetre-level accuracy in real-time.
Hydrometeorological forecast	ECMWF	ECMWF data provides 4 daily predictions from ensemble models at high spatial resolution (of 0.1° and 0.2°) 3 days into the future and 2 daily predictions up to 10 days. The data is analysed to also provide estimations of runoff and variations of water levels in the ponds behind the dams (if applicable).
Emergency planning	A suit of mathematical models	Provides information to support the development of emergency plans, helping to improve the understanding of the risks downstream if a failure of the dam occurs. The models, which are also known as consequence models, simulate the breach of the water or tailings dam, the spread of the release downstream and the impacts on people living in the area downstream. With this information, economic and environmental damages are also quantified.

Customers and users

To increase the chance of sustainability, this project sought to appeal to a wide range of end-users. This was approached firstly by selecting a portfolio of sites for the project that covers the interests of as many end users as possible. Secondly, by offering the flexibility of different types of services to different end-users (depending on the DAMSAT modules they select).

Key customers and end-users of DAMSAT

- Ministry of Energy and Mines (MEM)
- Supervisory Agency for Investment in Energy and Mining (OSINERGMIN)
- Agency for Environmental Assessment and Enforcement (OEFA)
- Water Administrative Authority (ANA)
- CIEMAM, mining and environmental research and consultancy company
- SIMSA, a mining company

The Department for Natural Resources and Environment of the Regional Governments of Cajamarca and Pasco are also interested in DAMSAT although mining and water dams are not in their areas of responsibility. National, state and province emergency response agencies are also involved in the project as they are interested in the Emergency Planning Module of DAMSAT.

In addition, CONIDA (Peruvian Space Agency) and CEVAN (the Amazonic and National Monitoring Centre) are institutions involved in the generation and assessment of Earth Observation information for the Peruvian government institutions and therefore, they are key institutions involved in the DAMSAT project that can have an important role in the sustainability of the project. The project has already identified their willingness to own the platform themselves at the end of the project and has signed an Agreement with CONIDA.

Key customers and end-users of future commercial versions of DAMSAT

- International mining groups, mine owners and operators (companies with direct environmental liabilities)
- Water companies
- Smaller national mining companies (with direct environmental liabilities)
- Mineral processing operators/asset owners (companies with direct environmental liabilities)
- Tailings dam construction EPC contractors
- Tailings dam remediation or monitoring consultants
- Insurance and risk industry (catastrophe risk industry)
- International donor funded agencies e.g. UNEP
- Institutional Investment Funds
- Equator Principal Financial Institutions (EPFIs)
- Development Banks

At present, we believe that all end-users will value services more highly if they have invested in it, and hence no completely free version is planned. The costing of each level of service has been carefully developed around a sustainable business case, and the cost of the ‘Basic Package’ needs to be minimised as far as possible to encourage uptake.

Across the government organisations, it was recognised that DAMSAT could save valuable time in the decision making process and sharing of information. Assessment time can be reduced when trying to detect problems and visual inspection programmes can be more informed based on the information provided by the service. The risk-based approach to inspections could be more refined, based on live data rather than historic out of date information. All the organisations were also very interested in the opportunities of improving their capacities that the DAMSAT project provided.

Minimum leave behind

The project is naturally aiming for a high level of sustainability. The 'Basic Package' is the 'minimum leave behind' in case the modules requiring higher resolution images and paid services become unviable in the long term for the current project stakeholders.

The 'Basic Package' has a minimum 'run and maintain' cost to keep the solution operating and generating impact including the existing software maintenance and data storage. Any future additions to the system such as new dams or tailings deposits or software features need to be costed separately.

Achieving the minimum sustainability objective requires:

- a handover of the deployed system to the relevant government regulator/operational body;
- sufficient institutional capacity building within this end-user to ensure the future effective operation and maintenance of the solution;
- guaranteed coverage of all the associated running costs by the end-user, either by revenues or from local government budgets;
- that the GNSS "SUMMIT" hardware boxes installed in two tailings dam sites as part of the project testing (one in a closed site in Cajamarca and one in an active dam in Junin), will remain on site at the end of the project. If requested, this will allow the service there to constinue with CIEMAN and SIMSA.

In addition, the minimum leave behind will also include increased knowledge on the use of Earth Observations techniques to support the management and monitoring of vital infrastructure and raised awareness of approaches and techniques to understand the risks posed by possible tailings and water dam failures. These 'soft' knowledge transfer aspects were addressed through workshops, presentations and training sessions in Peru and the UK and will continue in the project with further workshops, training and dissemination events.

Expansion strategy

DAMSAT could potentially be exported worldwide in both high and low-income countries. This offers a route for the UK associated consortium partners into a potentially multi-million pound global market.

The expansion of the project is based on the provision of the services to similar end-users in other key territories around the world with significant dam populations. The project team would like to start engaging with those possible users in 2020.

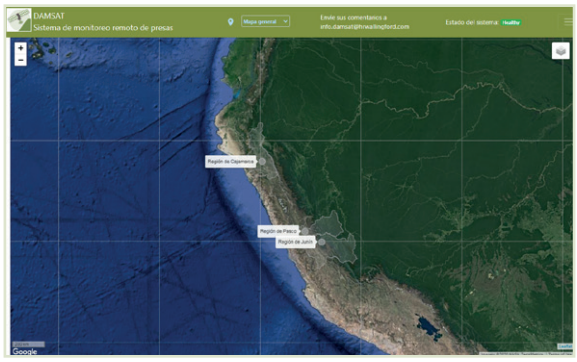
The project team would also explore the provision of a similar monitoring service for different infrastructures such as steep road or railway cuttings or remote oil and gas pipelines within the next 2-4 years.

Mining site of El Brocal in Pasco

Results so far

The project is now at the mid-point stage of implementation and has successfully delivered the majority of the intended milestones. We:

- have version 4 of the DAMSAT system that was very well received by our stakeholders in Peru; the system is running in 31 sites in Cajamarca, Pasco and Junín;



DAMSAT interface

- installed SUMMIT-SHM equipment in one closed tailings deposit and are planning, when possible, to install another one in an active dam;

Installation of SUMMIT-SHM equipment at Colquirrumi

- delivered a successful training course in Peru about Earth Observation techniques and provided further capacity building to stakeholders in dedicated workshops;
- have presented DAMSAT at a number of conferences and events;
- published reports and papers, including marketing material and a dedicated website about DAMSAT with all the information;
- successfully engaged with several stakeholders in Peru and a have pre-agreement of the handover of the tool to CONIDA (the Peruvian Space Agency) to allow access to Peruvian government institutions once the project ends.

The project conducted a formal evaluation baseline to understand the starting conditions in country before any intervention by the project. A midline process assessment has recently been conducted to explore whether the project activities have taken place as expected, capturing risks and opportunities that may affect the achievement of outputs, outcomes and impacts. To collect this information key informant interviews and focal group discussions were conducted in Peru with various government and commercial stakeholders, and interviews were held with consortium members in the UK to discuss the functioning of the consortium. The project will also carry out an endline impact evaluation to measure the results of the project intervention since the baseline evaluation.The midline evaluation stated that the project is on track to meet the main impacts the DAMSAT project is trying to achieve, which are:

- 10% risk reduction of the annual loss of life in communities downstream;
- a reduction in the vulnerability of land downstream of dams to significant pollution and/or flooding incidents;
- increase the number of people benefiting from space driven solutions;
- improve the availability and sustainable management of water.

Several events presenting DAMSAT

Key findings from the midline evaluation were as follows:

- There is consensus amongst consortium partners and stakeholders that there is a very high likelihood the project will result in the development of an effective dam monitoring tool that can be used by Government authorities to improve the monitoring of dams and reduce the risks of dam failures.
- A commercially viable product is an achievable goal, but there are hurdles to overcome which include the management of sensitive data and related to that the buy-in for and trust of DAMSAT by the private sector mining companies.
- The project could benefit from approaching the different potential beneficiaries and end users in a more structured way in order to obtain institutional buy-in. While organisational and individual buy-in for DAMSAT are necessary steps in Peru to formalise agreements, these agreements do not have the required institutional support unless they are followed by a convention or written agreement.
- Continuous staff changes in government are a challenging factor that increases the risks of having to renew the buy-in process with organisations and to obtain the interest of the new officials.
- Progress is being made on several output areas. As DAMSAT is only anticipated to be fully operational in August 2020 no effect can yet be detected for some outcome areas and for all impact areas.

Gender equality

Gender equality is an important part of the project and measurement indicators are tracked through the project cycle and reported on at impact evaluations to understand the effect the project has had.

Within the project team there is a split of males and females working on key aspects of DAMSAT. Many of the women have key responsibilities within the project, including overall project management, technical development and work package leads.

There were females attending all meetings with stakeholders and 20% of attendees to our training course were also females.

DAMSAT training course organised with CEVAN at Lima

Conclusions and lessons learnt

The DAMSAT project is currently at the approximate mid implementation point, and to date had progressed mainly to plan, although some issues have been encountered and lessons learnt. However the project is on track overall to deliver the impact it set out to achieve. The development of DAMSAT has largely benefitted from the continuous engagement with stakeholders in-country that steered the updating process and the development of the different versions of the system.

- In order to work towards the sustainability of the project we developed pre-agreements with partners for the future commercialisation of DAMSAT and with stakeholders in Peru to take ownership of the system beyond the project;
- Continuous staff changes in government are a challenging factor that increases the risks of having to renew the buy-in process with organisations and to obtain the interest of the new officials; the visits in country have highlighted the importance of stakeholder engagement and allowed for good working relationships to develop, which have eased the pressures when there have been staff changes;
- It was necessary to commit to lengthy and constant in-country engagement to identify the right individuals that could take decisions at institutional level to support the project and to map the relationships between stakeholders;
- Capacity building is an activity very well received by all types of organisations that are willing to improve staff skills;
- A positive spirit of collaboration and willingness to find solutions among all project partners was fundamental to overcome some of the challenges affecting the functioning of the team;
- The fact that active tailings dams are continuously being raised during their life time, restricts the ability to install fixed monitoring equipment on the dam. This means that close engagement with site owners is essential and fixed monitoring assets need to be closely managed;
- It's important to engage closely with in-country personnel and partners to allow the shipment of equipment (e.g. the fixed monitoring equipment), into the country to happen smoothly;
- The comparison of the results in the Movement Detection module from different sources of information such as satellite imagery, in-situ instrumentation and manual measurements from site owners has not been possible yet, due to the difficulties in getting permission to install instruments on active mine sites;
- Monitoring tailings dam displacements is still a young discipline and we have been learning about its implementation into a warning system; there is still room for improvement in the understanding of the links between failure modes and precursors of movement;
- Some of the technical work in the Emergency module depends on having good information about the sites. Data for individual sites has been difficult to come by and slow at times; it required a long process to map the bureaucratic structures to follow that could provide information; in some cases, information was not publicly available or didn't exist.

DAMSAT

www.damsat.org

Closed tailings dam deposits of El Dorado in Cajamarca.

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