PREPRATION OF ENVIRONMENTAL AND SOCIAL PROJECT BRIEF (EPB / PROSPECTUS) FOR THE EARLY WARNING SYSTEM (EWS) UNDER THE KARIBA DAM REHABILITATION PROJECT (KDRP)

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EXECUTIVE SUMMARY

The Zambezi River Authority (ZRA) is a bi-national organization jointly owned by the Governments of the Republic of Zambia and the Republic of Zimbabwe. It was established in 1987 under the Zambezi River Authority Act (Zambia) and the Zambezi River Authority Act (Zimbabwe), following the dissolution of the former Central African Power Corporation (CAPC).

The Authority is mandated to manage the Kariba Dam Complex and the shared water resources of the Zambezi River within the Kariba catchment on behalf of the two Governments. Its primary responsibility is to ensure the safe, sustainable, and efficient operation of the Kariba Dam while facilitating equitable utilization of the Zambezi River's water resources for hydroelectric power generation and other agreed purposes.

Project Raw Materials

The proposed project will utilize a variety of construction materials, electronic components, and ancillary equipment required for the installation and commissioning of the Early Warning System (EWS). Most of the specialized equipment will be imported by the contractor or sourced from approved international manufacturers, while standard construction materials will be procured locally where available.

The major raw materials required include:

Material	Purpose
Steel poles and galvanized mounting brackets	Mounting of monitoring stations and communication equipment
Reinforced concrete (cement, sand, aggregates, water)	Construction of equipment foundations and pole bases
Solar photovoltaic (PV) panels	Power supply for remote monitoring stations
Deep-cycle batteries	Energy storage for continuous operation during low sunlight conditions
Weatherproof equipment cabinets	Housing electronic components and communication devices
Water level sensors	Monitoring river and reservoir water levels
Rainfall gauges	Measurement of precipitation
River flow monitoring sensors	Monitoring discharge and flow conditions
Automatic weather stations	Collection of meteorological data including temperature, humidity, wind speed, wind direction, and atmospheric pressure
Data loggers	Collection and storage of field monitoring data
Telemetry equipment (GSM, Satellite, Radio or LoRa communication units)	Transmission of monitoring data to the central control system
Antennas and communication masts	Wireless communication between field stations and control centres
Electrical cables and connectors	Power distribution and data transmission

Material	Purpose
Earthing materials	Lightning protection and equipment grounding
Fencing materials	Protection of monitoring stations against vandalism and wildlife
Warning sirens and public address systems	Community flood warning and emergency notification
Reflective signposts and safety signage	Public awareness and equipment identification
Fuel (diesel/petrol)	Transportation of personnel, equipment, and construction machinery
Lubricants	Maintenance of installation equipment and vehicles

Consumables During Installation

The following consumables will also be required during construction and installation:

- Cement
- Sand
- Crushed stone aggregates
- Water
- Structural steel
- Bolts and nuts
- Welding electrodes
- Electrical conduit and cable ties
- Protective paints and anti-corrosion coatings
- Personal Protective Equipment (PPE)

Sources of Materials

Where feasible, ordinary construction materials such as cement, sand, aggregates, steel reinforcement, and water will be procured from licensed local suppliers in Zambia and Zimbabwe. Specialized monitoring instruments, telemetry systems, sensors, solar power units, and communication equipment will be sourced from reputable manufacturers meeting internationally recognized standards for hydrological and meteorological monitoring systems. This procurement approach will ensure the installation of reliable, durable, and high-quality equipment capable of operating under the environmental conditions prevailing within the Kariba Dam catchment and downstream areas.

Project Description

The proposed project involves the installation of an Early Warning System (EWS), which is an integrated system of tools that provides early warnings on floods and other natural disasters to reduce the risks. It disseminates information to communities through a network of key stakeholders that include national/provincial/local government authorities and local disaster management committees of communities for early warning and disaster management. A properly designed and implemented early warning system can save lives and reduce damage to property by increasing the lead time to prepare and respond to events.

Project Location

The proposed Early Warning System (EWS) project is located within the Middle Zambezi Basin, covering the stretch of the Zambezi River from the Kariba Dam to the confluence of the Zambezi and Luangwa Rivers at the ZambiaMozambique border, upstream of the Cahora Bassa Dam. The project area lies along the international boundary between Zambia and Zimbabwe, where the Zambezi River traverses the Gwembe Rift Valley and is regulated by the Kariba Dam, one of the world's largest man-made reservoirs by storage volume.

Description and processes involved in the Proposed Project

The proposed project will have a minimal physical footprint, with each Early Warning System (EWS) installation occupying approximately 4 m × 4 m (16 m^2), including the equipment foundation, solar power system, telemetry unit, and protective fencing where required. The compact size of each installation will minimize vegetation clearing, soil disturbance, and habitat disruption. Most activities will be confined to the designated installation sites and existing access routes, thereby reducing environmental impacts during both construction and operation. Consequently, the project is considered to be a low-impact infrastructure development aimed at enhancing flood monitoring, dam safety, and disaster preparedness for communities and infrastructure located downstream of the Kariba Dam.

The proposed Flood Early Warning System (EWS) will be operated through an integrated process of monitoring, analysis, forecasting, communication, and response. The system will continuously collects data on dam safety, hydrological, and meteorological conditions using monitoring instruments that measure structural behaviour, water levels, rainfall, river flows, and other environmental parameters. The data will be transmitted in real time to two central command control centres in Lusaka and Siavonga , where hydrological and hydraulic models are used to analyse current conditions and predict potential flood events. Predetermined threshold values will be applied to assess the level of risk and determine whether warning conditions have been reached. When a potential flood risk is identified, warning messages will be promptly disseminated to the Zambezi River Authority (ZRA), disaster management agencies, local authorities, and downstream communities through appropriate communication channels. This will enable timely preparedness and emergency response actions, thereby reducing the potential impacts of flooding on lives, property, infrastructure, and the environment.

Investment Cost

The estimated total investment cost for the proposed installation of the Early Warning System (EWS) is USD 7.45 million. This investment covers the complete design, procurement, installation, commissioning, and operationalization of the Early Warning System along the Kariba Dam and its downstream reach extending to the confluence of the Zambezi and Luangwa Rivers.

Of the total investment, approximately USD 3.0 million is allocated to project development activities, including the procurement and installation of monitoring stations, hydrological and meteorological sensors, telemetry equipment, solar power systems, communication infrastructure, civil works, and system commissioning.

The remaining USD 4.4 million is budgeted for associated implementation costs necessary for successful project delivery. These include international shipping and logistics for specialized equipment, labour and installation services, software acquisition and licensing, data management systems, communication bandwidth and connectivity services, training and capacity building, project management, testing and commissioning, contingency provisions, and other operational and administrative costs required to establish and sustain the Early Warning System.

Technology to be used and environmental concerns

Technology to be used

The proposed project will employ modern, automated, and renewable energy-powered technologies to facilitate real-time monitoring, data transmission, flood forecasting, and dissemination of early warnings. The EWS will comprise a network of strategically located monitoring stations equipped with hydrological and meteorological instruments, and warning systems integrated through telemetry and communication technologies.

The key technologies to be used include:

- Automatic water level monitoring sensors.
- River flow and discharge monitoring equipment.
- Automatic rainfall monitoring stations
- Solar photovoltaic (PV) systems with battery storage to provide continuous off-grid power.
- Data loggers and remote telemetry units for automated collection and transmission of monitoring data.
- Communication technologies, including GSM and satellite-based internet networks for real-time data transfer.
- Centralized monitoring software incorporating decision support tools.
- Warning dissemination systems, including SMS alerts, email notifications, and web-based dashboards.

The proposed technology is designed to operate continuously with minimal environmental disturbance while providing reliable, real-time information to support flood warnings and disaster risk management.

Environmental Concerns

The proposed project is expected to have relatively minor environmental impacts owing to the small footprint of each installation (approximately 4 m × 4 m) and the limited civil works involved. Nevertheless, several environmental concerns have been identified and will require appropriate management during construction and operation.

Potential environmental concerns include:

- Soil disturbance and erosion associated with excavation for equipment foundations.
- Dust generation and noise from construction activities and transportation of equipment.
- Generation of construction waste, including packaging materials and surplus construction materials.
- Risk of accidental fuel, oil, or lubricant spills from construction vehicles and equipment.

- Occupational health and safety risks to workers during installation and maintenance activities.
- Visual impacts associated with the installation of monitoring stations, communication masts, and warning sirens.
- Generation of electronic waste (e-waste), including batteries, sensors, and electronic components at the end of their service life.
- Potential community safety risks during construction if work areas are not adequately secured.

These potential impacts are expected to be localized, temporary, and of low significance. They will be effectively managed through the implementation of appropriate environmental and social management measures, including proper waste management, erosion control, spill prevention and adherence to occupational health and safety requirements. Consequently, the project is not anticipated to result in significant long-term adverse environmental effects while delivering substantial benefits in flood risk reduction, dam safety, and protection of downstream communities.

Waste Management

The proposed Early EWS project is expected to generate relatively small quantities of waste during the construction, installation, operation, and maintenance phases. Construction waste will mainly consist of packaging materials, surplus construction materials, excavated soil, and domestic waste generated by workers. During operation, waste will primarily comprise obsolete electronic components, damaged sensors, batteries, cables, and other end-of-life equipment (electronic waste). All waste will be managed in accordance with the waste hierarchy of reduce, reuse, recycle, and dispose. Recyclable materials will be separated and sent to licensed recycling facilities where feasible, while hazardous waste such as batteries and electronic components will be collected, stored safely, and disposed of through licensed waste management companies. Good housekeeping practices will be maintained at all installation sites to prevent pollution and ensure the protection of surrounding land, water resources, and ecosystems.

i. Water Resources

Concern: Minor water use during construction activities and the potential for contamination of nearby water bodies through accidental spills, improper waste disposal, or sediment runoff.

Mitigation:

- The project shall minimize water use by adopting efficient construction practices.
- Prevent fuel, oil, and chemical spills through proper storage and handling procedures.
- Dispose of construction waste appropriately to prevent pollution of rivers and streams.
- Implement erosion and sediment control measures at installation sites located near water bodies.

ii. Energy Consumption

Concern: Energy consumption associated with the operation of monitoring stations, telemetry systems, communication equipment, and data processing facilities.

Mitigation:

- Utilize solar photovoltaic (PV) systems with battery storage to provide renewable energy for remote monitoring stations.
- Install energy-efficient monitoring equipment and low-power communication devices.
- Conduct routine maintenance to ensure optimal energy efficiency and prolong equipment lifespan.
- Employ energy-efficient servers and data management systems at the central monitoring facility where applicable.

iii. Air Quality

Concern: Temporary dust emissions and exhaust gases generated by construction vehicles, equipment, and transportation during installation activities.

Mitigation:

- Minimize dust generation through good housekeeping and, where necessary, watering of disturbed surfaces.
- Ensure construction vehicles and equipment are regularly serviced to minimize exhaust emissions.
- Restrict unnecessary idling of vehicles and machinery.
- Complete installation works within the shortest practical time to reduce temporary air quality impacts.

iv. Biodiversity and Land Use

Concern: Localized soil disturbance, during installation of monitoring stations.

Mitigation:

- Limit each installation to the planned 4 m × 4 m (16 m^2) footprint to minimize land disturbance.
- Utilize existing access roads and previously disturbed areas wherever feasible.
- Rehabilitate disturbed areas after construction.
- Site monitoring stations away from environmentally sensitive habitats, protected areas, and critical breeding or nesting sites where practicable.
- Schedule construction activities to minimize disturbance to wildlife and surrounding ecosystems.

Project Lifespan

The proposed Early Warning System (EWS) is a long-term infrastructure project intended to provide continuous monitoring of dam safety, hydrological, and meteorological conditions along the Zambezi River downstream of the Kariba Dam. The system is expected to remain operational for approximately 20 years, subject to routine maintenance, periodic calibration, software upgrades, and replacement of individual components such as batteries, sensors, communication equipment, and telemetry devices as they reach the end of their service life. Continuous maintenance and technological upgrades will ensure the system remains reliable and effective throughout its operational life. A 20-year design life is consistent with international practice for hydrological and meteorological monitoring infrastructure.

The objective of the project

Undertaking the Environmental Project Brief (EPB) for the Early Warning System (EWS) for Kariba Dam and Downstream to Luangwa provides an opportunity to identify and evaluate the potential environmental and socio-economic impacts associated with the project and to develop appropriate mitigation and monitoring measures. The EPB has been prepared in accordance with the requirements of the Environmental Management Act No. 12 of 2011 (as amended by Act No. 8 of 2023) and the Environmental Assessment Regulations 2026 , which require the integration of environmental protection, sustainable natural resource management, and socio-economic considerations into project planning and implementation.

Relevant Legal Frameworks

The legal frameworks relevant to the project include;

- The Environmental Management Act No. 8 of 2023
- Statutory Instrument 3 of 2026 – Environmental Management (Environmental Impact Assessment) Regulations, 2026.
- Environmental Management (Licensing) Regulations, SI No. 112 of 2013.
- Zambia Wildlife Act No. 14 of 2015
- Standards Act No.4 of 2017
- The Petroleum Act No. 10 of 2008 and The Energy Regulation Act No. 12 of 2019
- Ensure to include the following legislation but not limited to: The Agriculture (Fertilisers and Feed) Act and The Food Safety No. 7 of 2019 Act.
- The Local Government Act No. 2 of 2019
- The National HIV/AIDS/STI/TB Act No. 10 of 2002
- The Road Traffic Act No. 28 of 2022
- The Urban and Regional Planning Act. No. 3 of 2015
- The Public Health Act No. 22 of 1995 and Statutory Instrument No. 22 Of 2020:
- The Employment Code Act No. 3 of 2019
- The Occupational Health and Safety Act No. 36 of 2010
- The Water Supply and Sanitation Act No. 28 of 1997
- Lands Act No. 20 of 2015
- The Water Resources Management Act No. 21 of 2011
- The Workers Compensation Act No. 10 of 1999
- The Investment, Trade and Business Development Act, No. 18 2022
- The Local Government Act 281 of 2019
- National Council for Construction Act No.10 of 2020;
- Solid Waste Regulations & Management Act No. 2 of 2018
- Metrology Act No. 6 of 2017

Zimbabwe legal frameworks

- Natural Resources Act [Chapter 20:13] – Conservation of soil, land, water, and natural resources.

- Regional, Town and Country Planning Act [Chapter 29:12] – Land-use planning and development control.
- Rural District Councils Act [Chapter 29:13] – Environmental management responsibilities of local authorities.
- Mines and Minerals Act [Chapter 21:05] – Environmental obligations relating to mining activities.
- Public Health Act [Chapter 15:17] – Protection against pollution affecting public health.

Relevant International Conventions and Treaties to which Zambia is a Party

- The Convention Concerning the Protection of the World's Cultural and Natural Heritage (1994) Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (1984)
- United Nation Convention to Combat Desertification (UNCCD) (1993)
- United Nations Framework Convention on Climate Change (UNFCCC) (1996)
- Convention on Biological Diversity (CBD), (1993)
- Ramsar Convention on Wetlands of International Importance especially a Waterfowl Habitat (1975)
- Kyoto Protocol to the United Nations Framework Convention on Climate Change Convention on Migratory Species and the African -Eurasian Water Bird Agreement (2016)
- Convention on Migratory Species and the African -Eurasian Water Bird Agreement (2006)

Project Alternatives

Several project alternatives were considered during the planning and design of the proposed EWS to ensure that the selected option provides the most effective, reliable, environmentally sustainable, and economically viable solution. The preferred alternatives are indicated in bold.

Project Location Alternatives Considered

The proposed project involves the installation of monitoring stations at strategic locations along the Zambezi River corridor. Alternative locations were evaluated based on hydrological significance, flood risk, accessibility, communication coverage, environmental sensitivity, and security.

- Existing ZRA monitoring locations
- Strategic locations along the Kariba Dam and downstream to the confluence of the Zambezi and Luangwa Rivers
- Community-based monitoring sites
- Tributary monitoring locations

Monitoring Technology Alternatives Considered

- Manual river level monitoring
- Staff gauges with manual data collection
- Automated water level sensors with real-time telemetry

- Remote sensing and satellite monitoring only

Meteorological Monitoring Alternatives

- Manual rainfall gauges
- Stand-alone weather stations
- Automatic rainfall monitoring stations
- Satellite-derived weather information only

Communication System Alternatives

- GSM mobile network
- Radio communication
- Satellite communication
- Hybrid communication system (GSM, Radio and Satellite) to ensure system redundancy and reliability

Power Supply Alternatives

- National electricity grid
- Diesel generators
- Wind energy
- Solar photovoltaic (PV) systems with battery storage
- Hybrid solar-grid systems where grid electricity is available

Warning Dissemination Alternatives

- Community notice boards
- Local radio broadcasts
- Public address systems
- SMS messaging
- Mobile applications
- Integrated warning dissemination system incorporating SMS alerts, electronic sirens, and coordination with disaster management authorities

Construction Alternatives

- Conventional reinforced concrete foundations
- Steel platform installations
- Small reinforced concrete foundations (4 m × 4 m footprint) with minimal vegetation clearance
- Elevated mounting structures in flood-prone areas where necessary

Pollution Prevention Alternatives Considered

- Good housekeeping during construction
- Spill prevention and fuel management
- Proper waste segregation and recycling
- Use of existing access roads to minimize land disturbance
- Rehabilitation of disturbed areas after installation
- Routine environmental monitoring during construction and operation

Waste Management Alternatives Considered

- Disposal at licensed waste disposal facilities
- Recycling of scrap metal and packaging materials
- Collection and recycling of electronic waste (e-waste)
- Safe storage and disposal of used batteries through licensed handlers
- Integrated waste management based on the principles of Reduce, Reuse, Recycle, and Responsible Disposal

No Project Alternative

The "No Project" alternative was considered but was not preferred because it would maintain the current limitations in flood monitoring and early warning capabilities downstream of the Kariba Dam. Without the proposed Early Warning System, communities, critical infrastructure, and ecosystems along the Zambezi River would remain more vulnerable to flooding and other water-related hazards. The absence of a modern, real-time monitoring and warning system would reduce the capacity of the Zambezi River Authority (ZRA) and disaster management agencies to provide timely warnings and coordinate effective emergency response. Consequently, implementation of the proposed project represents the most appropriate option for enhancing dam safety, disaster preparedness, and the protection of lives, property, and the environment while minimizing adverse environmental impacts through its small installation footprint and use of renewable energy technologies.

Hydrology and Hydrogeology

Hydrological and hydrogeological assessments were undertaken to understand the environmental conditions along the proposed project corridor extending from the Kariba Dam to the confluence of the Zambezi and Luangwa Rivers. The assessment included desktop studies, GIS analysis, review of hydrological records, catchment characterization, and field reconnaissance of the proposed monitoring station locations.

Geographic Information Systems (GIS) and Digital Elevation Model (DEM) data were used to delineate the drainage network, river catchments, flood-prone areas, and the strategic locations for the installation of monitoring stations. The project area lies within the Middle Zambezi Basin, encompassing the Kariba Reservoir and the downstream reaches of the Zambezi River, including major tributaries such as the Kafue and Luangwa Rivers.

The assessment established that the project will have minimal interaction with groundwater resources, as each monitoring station occupies a footprint of only 4 m × 4 m (16 m^2) and requires only shallow excavation for equipment foundations. No abstraction of groundwater is proposed during either the construction or operational phases. Nevertheless, appropriate construction practices will be implemented to prevent accidental contamination of surface water and groundwater from fuel, lubricants, or construction waste

Air Quality and Noise Assessment

Ambient air quality and noise assessments indicate that the proposed project area is generally characterized by good environmental quality, with pollutant concentrations and ambient noise levels largely influenced by natural conditions, local settlements, road traffic, and existing activities around the Kariba Dam and downstream communities. Given the nature of the proposed project, construction activities will be limited in duration and scale, resulting in only temporary and localized dust emissions and vehicle exhaust during equipment installation. Similarly, temporary noise will arise from excavation works, transportation of equipment, and the use of light construction machinery. Since each installation occupies a small footprint and construction activities are short-term, noise impacts are expected to be negligible and confined to the immediate vicinity of the installation sites. Routine maintenance activities during operation will generate insignificant noise levels.

Impact Assessment and Mitigation Measures

i. Envisaged Positive Impacts of the Proposed Project
ii. The proposed Early Warning System is expected to generate significant environmental and socio-economic benefits, including:
iii. Improved Flood Forecasting and Disaster Preparedness: The project will strengthen the ability of the Zambezi River Authority (ZRA) and disaster management institutions to detect and forecast flood events, enabling timely warnings and reducing disaster risks.
iv. Protection of Lives and Property: Early warning information will enable downstream communities to prepare for flood events, thereby reducing potential loss of life, damage to infrastructure, and destruction of property.
v. Employment Creation: Temporary employment opportunities will be created during the installation and commissioning phases, while specialized technical positions will support operation and maintenance of the monitoring system.
vi. Capacity Building and Technology Transfer: The project will enhance local technical capacity through training in monitoring technologies, data analysis, equipment maintenance, and emergency response procedures.
vii. Strengthened Environmental Monitoring: Continuous monitoring of hydrological and meteorological conditions will improve water resources management, dam safety, and climate resilience within the Zambezi River Basin.
viii. Support to National Disaster Risk Management: The project will improve coordination among ZRA, Disaster Management and Mitigation Unit (DMMU), Civil Protection Authorities, local authorities, and downstream communities.

Envisaged Negative Impacts of the Proposed Project

Although the project has a relatively small physical footprint, several potential environmental impacts may arise during construction and operation.

a. Vegetation Disturbance

Minor vegetation clearing may be required at individual monitoring station locations.

Mitigation

- Restrict clearing to the approved 4 m × 4 m installation footprint.
- Utilize existing access roads where possible.
- Reinstate disturbed areas after installation.

b. Dust and Air Emissions

Construction vehicles and excavation activities may generate temporary dust and exhaust emissions.

Mitigation

- Minimize exposed surfaces during construction.
- Maintain construction vehicles in good operating condition.
- Limit unnecessary vehicle idling.

c. Noise Generation

Temporary noise will result from excavation equipment and transportation activities.

Mitigation

- Restrict construction activities to normal daytime working hours.
- Maintain equipment to reduce excessive noise.
- Provide hearing protection for workers where necessary.

d. Soil Disturbance and Erosion

Minor excavation may disturb soils around installation sites.

Mitigation

- Minimize excavation areas.
- Reinstate disturbed ground immediately after installation.
- Implement erosion control measures where necessary.

e. Water Pollution

Accidental spills of fuels, oils, or lubricants could affect nearby rivers and streams.

Mitigation

- Store fuels and lubricants appropriately.
- Maintain spill response kits at construction sites.
- Prohibit discharge of waste into watercourses.

f. Solid and Electronic Waste

Construction waste and end-of-life electronic equipment may be generated.

Mitigation

- Segregate recyclable and non-recyclable waste.
- Dispose of waste through licensed waste management contractors.
- Recycle electronic waste and batteries through approved facilities.

g. Occupational Health and Safety

Workers may be exposed to construction-related hazards.

Mitigation

- Provide appropriate Personal Protective Equipment (PPE).
- Implement site safety procedures.

- Conduct regular safety training and toolbox meetings.
- Provide first aid facilities at work sites.

Environmental Management and Monitoring Plan

To ensure environmentally sustainable implementation, an Environmental Management and Monitoring Plan (EMMP) will be implemented throughout the project lifecycle. The plan will focus on monitoring air quality, noise, waste management, soil disturbance, erosion control, water quality, occupational health and safety, biodiversity protection, and community health and safety. Regular environmental inspections and compliance monitoring will be undertaken to verify the effectiveness of mitigation measures and ensure adherence to national environmental legislation and project-specific commitments.

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1 INTRODUCTION

1.1 Background

The Kariba Dam is a major hydropower and water-resources facility on the Zambezi River, situated in the Kariba Gorge between Zambia and Zimbabwe. It is a double-curvature concrete arch dam constructed between 1956 and 1959 and forms Lake Kariba, one of the largest man-made reservoirs in the world. The dam and reservoir are operated by the Zambezi River Authority (ZRA) on behalf of Zambia and Zimbabwe. In addition to hydropower generation, the dam and reservoir support water management, flood regulation, fisheries, tourism and other economic activities in the region.

The dam is about 128 m high and has a crest length of approximately 617 m. Lake Kariba extends for about 280 km upstream and has a large storage capacity. Six spillway gates are provided for controlled releases from the reservoir, particularly during periods of high inflows. The operation of the spillway is therefore important for managing reservoir levels and downstream flows along the Zambezi River.

After more than 60 years of operation, dam safety and the condition of key infrastructure have become important concerns. Repeated high-volume spillway releases have resulted in erosion of the plunge pool downstream of the dam. The continued development of this erosion towards the dam foundation, together with the condition and operational limitations of the spillway gates, led to the need for rehabilitation of these facilities.

The Kariba Dam Rehabilitation Project (KDRP) was developed to address these concerns and improve the safety and reliability of the Kariba Dam Hydro-Electric Scheme. The project is supported by international development partners, including the World Bank and African Development Bank. The main interventions include rehabilitation and reshaping of the plunge pool to address downstream erosion and rehabilitation of the six spillway gates to improve the safe control of reservoir releases. KDRP also includes measures related to dam-safety management and operation of the dam.

The proposed Installation of an Early Warning System (EWS) for Flood Risk Management in the Downstream Areas of Kariba Dam up to the Confluence of the Zambezi and Luangwa Rivers is intended to complement these measures. KDRP focuses mainly on the structural and operational safety of the dam, while the EWS will strengthen downstream monitoring, warning and emergency preparedness. The system will help provide timely warnings to communities and other potentially affected receptors in the downstream areas, including infrastructure, livelihoods and environmentally sensitive locations.

When KDRP was being prepared, rehabilitation of an existing dam was not specifically listed as a scheduled activity under the applicable environmental legislation in Zambia and Zimbabwe. ZRA nevertheless committed to undertaking a comprehensive Environmental and Social Impact Assessment (ESIA) and agreed with the Zambia Environmental Management Agency (ZEMA) and Environmental Management Agency (EMA) to follow a harmonised process addressing the requirements of both countries and relevant international standards, including those of the World Bank and African Development Bank.

The ESIA process started in 2015. The joint Scoping/Prospectus Report was approved by ZEMA on 27 February 2015 (Ref. ZEMA/INS/101/04/1) and by EMA on 2 March 2015 (Ref. 17/1/1/3A). The findings and commitments from the ESIA subsequently formed the basis for the Environmental and Social Management Plan (ESMP) and the associated environmental and social management measures.

Against this background, the purpose of this Environmental and Social Project Brief is to fulfil the applicable national environmental and social regulatory and safeguard requirements for the proposed EWS and to support Zambezi River Authority's commitment to environmentally and socially responsible project implementation. The ESPB provides a framework for describing the proposed project, establishing baseline environmental and socio-economic conditions, identifying and assessing potential environmental and social risks and impacts, and defining appropriate mitigation, monitoring and management measures through the Environmental and Social Management Plan. It also aims to ensure that the project is implemented in accordance with applicable national legislation, World Bank requirements, and relevant good international industry practices and guidelines, while protecting communities, livelihoods, biodiversity and environment.

1.2 Need of the Early Warning System

Although rehabilitation and improved operation of the Kariba Dam will reduce the likelihood and potential consequences of dam-safety incidents, emergency preparedness and response arrangements are still needed for residual risks. These may include major spillway or hydropower releases, extreme inflows to the reservoir and potential dam-failure scenarios. The downstream area extends through Zambia and Zimbabwe towards the Mozambique border and includes communities, settlements, infrastructure, tourism facilities, agricultural areas, protected areas and wildlife habitats.

The EWS has been planned using the findings of technical studies commissioned by ZRA. These studies provide the basis for identifying flood hazards, forecasting releases, assessing potential inundation and planning emergency response. The main studies considered are the *Zambezi River Dam Break Analysis* (Mott MacDonald, 2020), *Zambezi River Early Warning System Project - Baseline Assessment Report* (Jomiso JV, 2024/2025) and *Hydraulic Modelling and Flood Mapping Report* (Jomiso JV, 2025).

The studies considered different scenarios, including controlled releases from the Kariba and Kafue Gorge Lower powerhouses, spillway releases, extreme floods equivalent to the 1-in-10,000-year design flood, and hypothetical Kariba Dam failure under both normal ("sunny day") and extreme flood conditions. The hydraulic modelling and flood-inundation maps provide information on potential flood depths, flow velocities, inundation extents and hazard classifications, as well as downstream communities and infrastructure that could be affected.

The findings from these assessments provide the technical basis for planning and configuring the EWS, including monitoring requirements, critical locations, warning arrangements and emergency-response needs. The EWS will add a non-structural measure to the wider Kariba Dam safety framework by linking real-time monitoring and hazard information with timely warnings and emergency response. It will complement, and not replace, structural rehabilitation, dam surveillance, operational controls and existing emergency preparedness arrangements. The system will strengthen the ability of ZRA, emergency-management authorities, local authorities and downstream communities to receive timely warnings and take appropriate preparedness, protective and evacuation actions.

The EWS is consistent with internationally recognised dam-safety and emergency-preparedness principles promoted by the International Commission on Large Dams (ICOLD), which emphasise dam-safety management, surveillance, emergency preparedness and public safety throughout the dam life cycle[1]. It is also aligned with the World Bank Good Practice Note on Dam Safety (2020), which promotes a risk-based approach covering risk assessment, monitoring, emergency preparedness, downstream inundation assessment and reliable warning arrangements. [2] World Bank and IFC good practice guidance also recognises the importance of linking meteorological and flood monitoring with early warning systems and establishing clear arrangements for emergency detection, notification and response. The EWS will therefore form an important part of the wider KDRP dam-safety framework and provide timely warnings to responsible authorities and potentially affected downstream communities.

1.3 Brief Project Description and Location

The proposed project, "Installation of an Early Warning System (EWS) for Flood Risk Management in the Downstream Areas of Kariba Dam up to the Confluence of the Zambezi and Luangwa Rivers," involves establishing an integrated EWS for the Zambezi River downstream of Kariba Dam. The system will bring together hydrological and meteorological monitoring, water-level and flow measurements, relevant dam-safety information, data transmission and processing, flood forecasting, decision support and warning dissemination. The aim is to improve preparedness and emergency response in potentially affected areas of Zambia and Zimbabwe.

The project includes 20 Automatic Rain Gauge (ARG) stations, 10 radar-type Automatic Water Level Recorder (AWLR) stations, 7 non-contact discharge/flow monitoring stations, 10 large omni-directional sirens and 40 mini sirens, together with two Main Command and Control Centres. Communication systems, power supply, data management and SCADA/decision-support infrastructure will also be provided to support operation of the EWS.

The EWS will link flood monitoring and forecasting with decision-making, warning dissemination and emergency response. It will provide timely information and warnings to ZRA, emergency-management authorities, local authorities and potentially affected communities. This will support preparedness and appropriate protective or evacuation actions and help reduce potential impacts of flooding on people, livelihoods, infrastructure

[1] International Commission on Large Dams (ICOLD), Bulletin 154: Dam Safety Management: Operational Phase of the Dam Life Cycle, 2017
[2] World Bank, Good Practice Note on Dam Safety, 2020, Good Practice Note on Dam Safety (Vol. 1 of 7), Washington, D.C.

and the environment. The system will operate through defined warning protocols, institutional responsibilities, community awareness and coordination among the relevant authorities in Zambia and Zimbabwe.

The proposed EWS Project covers the Middle Zambezi Basin, including the Kariba Dam and its upstream catchment, and extending downstream along the Zambezi River to the confluence with the Luangwa River at the Zambia-Mozambique border, immediately upstream of the Cahora Bassa Reservoir in Mozambique. The system therefore covers both the upstream and downstream areas of Kariba Dam. The upstream component will provide information on rainfall, reservoir water levels and inflows, while the downstream network will support river-level and flow monitoring, flood assessment and warning dissemination along potentially affected area.

On the Zambian side, the broader project area includes Siavonga, Chirundu, Luangwa and Kafue Districts, with particular attention to settlements and activities located close to the Zambezi and areas potentially exposed to flood hazards. The project stretch encompasses several vulnerable downstream settlements and strategic locations, including Kariba, Chirundu, Chiawa, Kavalamanja and Luangwa, where monitoring stations, warning infrastructure and emergency communication systems are proposed to strengthen flood preparedness and response. The EWS will also cover potentially affected communities, lodges, resorts, tourism facilities and other downstream activity areas along the Zambezi. At the Zambezi-Luangwa confluence, the project reach terminates at the Zambia-Mozambique border, beyond which the Zambezi continues into Mozambique and flows into the Cahora Bassa Reservoir.

The downstream system also considers the influence of major tributaries, particularly the Luangwa River, including potential backwater/backflow conditions during high Zambezi River levels. Rainfall, river levels and flows along the reach between Kariba and the Luangwa confluence are therefore important components of the EWS.

The proposed EWS locations have been selected based on flood-risk and hydraulic assessments, monitoring requirements, potential inundation areas, population and activity distribution, accessibility, communication requirements and the need to achieve effective warning coverage. The public warning infrastructure, particularly the sirens, is primarily located in downstream areas where people and activities may be exposed to flood risks. Most siren locations are planned within or close to existing community settlements, lodges, resorts, tourism facilities and other established activity areas. Where installations are required within or near national parks, ZimParks areas, protected areas or biodiversity-sensitive locations, existing modified or developed areas, such as park offices or other already disturbed sites, are preferred wherever practicable. This approach will help avoid or minimise vegetation clearance, habitat disturbance and impacts on wildlife.

The physical footprint of individual EWS installations will be very small. For the siren installations, the typical fenced site is expected to occupy approximately 4 m × 4 m (about 16 m^2), including the area required for the 15-m-high MS mast/pole, siren, associated equipment, solar/power system, fencing and other accessories. Construction will therefore be limited to a small foundation and associated installation works within the defined footprint. The ARG, AWLR and flow-monitoring installations will similarly have site-specific and generally very small footprints, with most equipment being prefabricated/procured and installed with limited civil works. The Command-and-Control Centres will be established within existing buildings of ZRA, wherever planned, and therefore are not expected to require major new building construction or significant additional land take.

1.4 Project Rationale

The proposed project will establish an integrated EWS for the Zambezi River downstream of Kariba Dam up to the confluence with the Luangwa River, covering potentially affected areas in Zambia and Zimbabwe. The system is intended to strengthen preparedness for flood conditions associated with Kariba Dam spillway and gate operations, hydropower releases, extreme catchment inflows and downstream flooding, as well as, in the unlikely event, dam-failure scenarios. Particular attention will be given to areas that may experience backwater or backflow conditions from the Luangwa River, where elevated Zambezi River levels could influence downstream flooding.

The EWS will use hydrological and meteorological observations, water-level and flow monitoring, hydraulic modelling and relevant dam-safety information to support timely assessment and warning. It will strengthen the ability of ZRA, disaster-management authorities, local authorities and downstream communities to understand developing flood conditions and take appropriate preparedness, protective and evacuation measures.

The project will also improve coordination and information sharing between relevant authorities in Zambia and Zimbabwe, particularly in relation to dam and spillway operations, downstream flood conditions, warning activation and emergency response. The EWS will complement existing dam-safety, surveillance, operational and emergency-preparedness arrangements under KDRP and will be implemented in accordance with applicable national legislation and relevant international good practice, including World Bank requirements and guidance and applicable ICOLD principles and guidelines.

Key expected outcomes

- Improved monitoring and forecasting of flood conditions downstream of Kariba Dam.
- Timely warning of potentially hazardous conditions resulting from dam releases, spillway/gate operations, extreme floods and potential dam-failure scenarios.
- Improved understanding and warning of backflow/backwater flooding affecting the Luangwa River and adjacent areas.
- Strengthened emergency preparedness, coordination and response in Zambia and Zimbabwe.
- Reduced risks to life, livelihoods, infrastructure, tourism, agriculture and environmentally sensitive areas.
- Improved institutional capacity for flood-risk management and emergency communication.

1.5 Objective of the Project

The overall objective of the proposed EWS is to strengthen flood-risk management, downstream public safety and emergency preparedness from Kariba Dam to the Zambezi-Luangwa confluence by providing timely, reliable and actionable information and warnings on potentially hazardous flood conditions.

1.5.1 Operational Objectives

- Establish an integrated EWS for monitoring rainfall, river water levels and flows and providing timely warnings of potentially hazardous conditions downstream of Kariba Dam.
- Improve detection and forecasting of flood conditions associated with dam and spillway/gate operations, hydropower releases, extreme rainfall and catchment inflows, including potential dam-related emergencies.
- Improve identification and warning of backwater or backflow flooding in the Luangwa River and other downstream areas.
- Integrate hydrological, meteorological, hydraulic and relevant dam-safety information into a centralised decision-support and warning system.
- Provide reliable power supply, communication, backup, testing, maintenance and emergency activation arrangements to support continuous operation during emergencies.
- Strengthen coordination, information sharing and decision-making among ZRA, disaster-management authorities and other relevant institutions in Zambia and Zimbabwe.

1.5.2 Social and Community Objectives

- Reduce risks to lives, livelihoods, property and critical infrastructure in potentially affected downstream areas through timely and reliable warnings.
- Strengthen the preparedness and resilience of downstream communities to floods, major dam releases and other dam-related emergencies.
- Improve community understanding of flood risks, warning signals and appropriate preparedness, protective and evacuation actions.
- Ensure that warning messages and communication arrangements are accessible and understandable to local communities, including vulnerable groups and people who may require additional assistance during emergencies.
- Strengthen coordination between responsible authorities, communities and other stakeholders during warning and emergency response.
- Support effective coordination between Zambia and Zimbabwe for downstream flood warning, preparedness and emergency response.

1.5.3 Sustainability, Institutional Capacity and Good Practice

- Establish clear roles and responsibilities for operation, management, maintenance and emergency activation of the EWS.

- Strengthen the technical and institutional capacity of responsible agencies to operate, maintain and use the EWS effectively.
- Establish arrangements for routine testing, inspection, maintenance and periodic review to maintain system reliability throughout its operational life.
- Ensure compliance with applicable regulatory requirements and relevant good international industry practice, including applicable World Bank requirements and ICOLD dam-safety principles.

1.6 Project Benefits

The EWS will strengthen flood monitoring, warning and emergency preparedness downstream of Kariba Dam. The main benefits are expected to relate to public safety, community preparedness, institutional coordination and protection of infrastructure, livelihoods and environmentally sensitive areas in Zambia and Zimbabwe.

1.6.1 Disaster Risk Reduction and Public Safety

The EWS will improve flood monitoring, forecasting and warning, supporting timely action to protect lives, livelihoods, property and critical infrastructure and reduce potential losses associated with floods, dam releases and other emergency situations.

1.6.2 Emergency Preparedness and Response

The system will improve coordination among ZRA, DMMU, DCP, local authorities, emergency responders and other relevant institutions in Zambia and Zimbabwe. This will support timely decision-making, warning dissemination and emergency response.

1.6.3 Community Resilience and Awareness

Clear and timely warning information will improve community awareness and preparedness and support downstream communities, including vulnerable groups, in taking appropriate protective and evacuation actions.

1.6.4 Climate and Flood Resilience

Improved real-time monitoring and forecasting will help authorities respond to extreme rainfall, changing hydrological conditions, dam releases and other flood-related risks and strengthen overall flood-risk management.

1.6.5 Institutional and Technical Capacity

The project will strengthen capacity for hydrometeorological monitoring, flood forecasting, warning dissemination and emergency management. It will also improve information sharing and coordination between institutions in Zambia and Zimbabwe.

1.6.6 Environmental and Economic Protection

Timely warning and preparedness can help reduce potential impacts on agriculture, tourism, businesses, public infrastructure, protected areas, wildlife habitats, water resources and other environmentally sensitive areas.

1.6.7 Compliance with Good International Industry Practice and Guidelines

The project will be implemented in line with relevant **Good International Industry Practice (GIIP)** for dam safety, flood-risk management and emergency preparedness, including applicable World Bank guidance and ICOLD principles. These provide a framework for risk-based monitoring, reliable warning and communication, emergency preparedness, community safety, institutional coordination, and appropriate operation and maintenance of the EWS. The EWS will complement the existing safety, surveillance, operational and emergency-preparedness arrangements for Kariba Dam.

1.7 Project Investment

The total estimated investment for the proposed Project is USD 7.4 million. Of this amount, approximately USD 3 million will be allocated to the development of the Early Warning System, including the design, procurement, installation, testing, and commissioning of the system and its associated infrastructure. The remaining USD 4.4 million will cover project implementation costs, including shipping and logistics, labour, software licensing, communication bandwidth, system integration, training and capacity building, statutory approvals, operational support, and other associated implementation expenses required for the successful delivery of the project.

1.8 Contact Person and Details

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1.9 Particulars of Shareholders

The Zambezi River Authority (ZRA) is a binational organization jointly owned by the Governments of Zambia and Zimbabwe. It was established under the Zambezi River Authority Act/Agreement of 1987 to manage the Kariba Dam and the Zambezi River stretch forming the common border between the two countries.

The principal stakeholders/shareholders are:

1. **Government of the Republic of Zambia** (50% ownership)
2. **Government of the Republic of Zimbabwe** (50% ownership)

The two governments are represented through their respective ministries responsible for energy and appoint members to the **ZRA Council**, which provides policy direction and oversight to the Authority.

1.10 Track Record of the Developer

The Authority was established in 1987 with the responsibility for the operation, maintenance and management of the Kariba Dam Complex and of those water resources of the Zambezi River which jointly border both countries. ZRA has command of dam safety management, water resources management, hydrological and environmental monitoring, and transboundary water governance expertise developed over many years. The Authority has successfully coordinated the operation of Kariba Dam, ensuring reliable hydropower generation in Zambia and Zimbabwe, whilst meeting high standards of both dam safety and environmental stewardship.

The ZRA has also implemented significant infrastructure and technical projects, including the Kariba Dam Rehabilitation Project (KDRP), comprising rehabilitation of the plunge pool and refurbishment of spillway gates to improve the long-term structural integrity and safety of the dam. In addition, the Authority developed comprehensive flood hydrology analysis, flood modelling studies (including dam break assessments), environmental monitoring programmes and disaster risk preparedness plans in a bid to mitigate risks along the Zambezi River.

Over the past few years ZRA has undertaken steps to develop a state-of-the-art EWS to enhance flood forecasting, emergency planning and communication with downstream communities in Zambia and Zimbabwe. This project is based on previous extensive baseline studies, hydraulic modelling, flood mapping and engagement with stakeholders targeting to improve resilience against the threat of floods impact or wider dam related emergencies. ZRA has evolved into one of Africa`s premier transboundary river basin authorities for the safe, sustainable and equitable management of the Zambezi River Infrastructure and Kariba Dam Infrastructure in particular drawing from its long technical expertise, its strong institutional capacity to work with both national governments and regional institutions as well as international development partners.

1.11 Proposed Implementation Dates

Production is scheduled to start as soon as installation is done by December 2026. Installation of the equipment of the plant will only commence once we get the ZEMA approval letter.

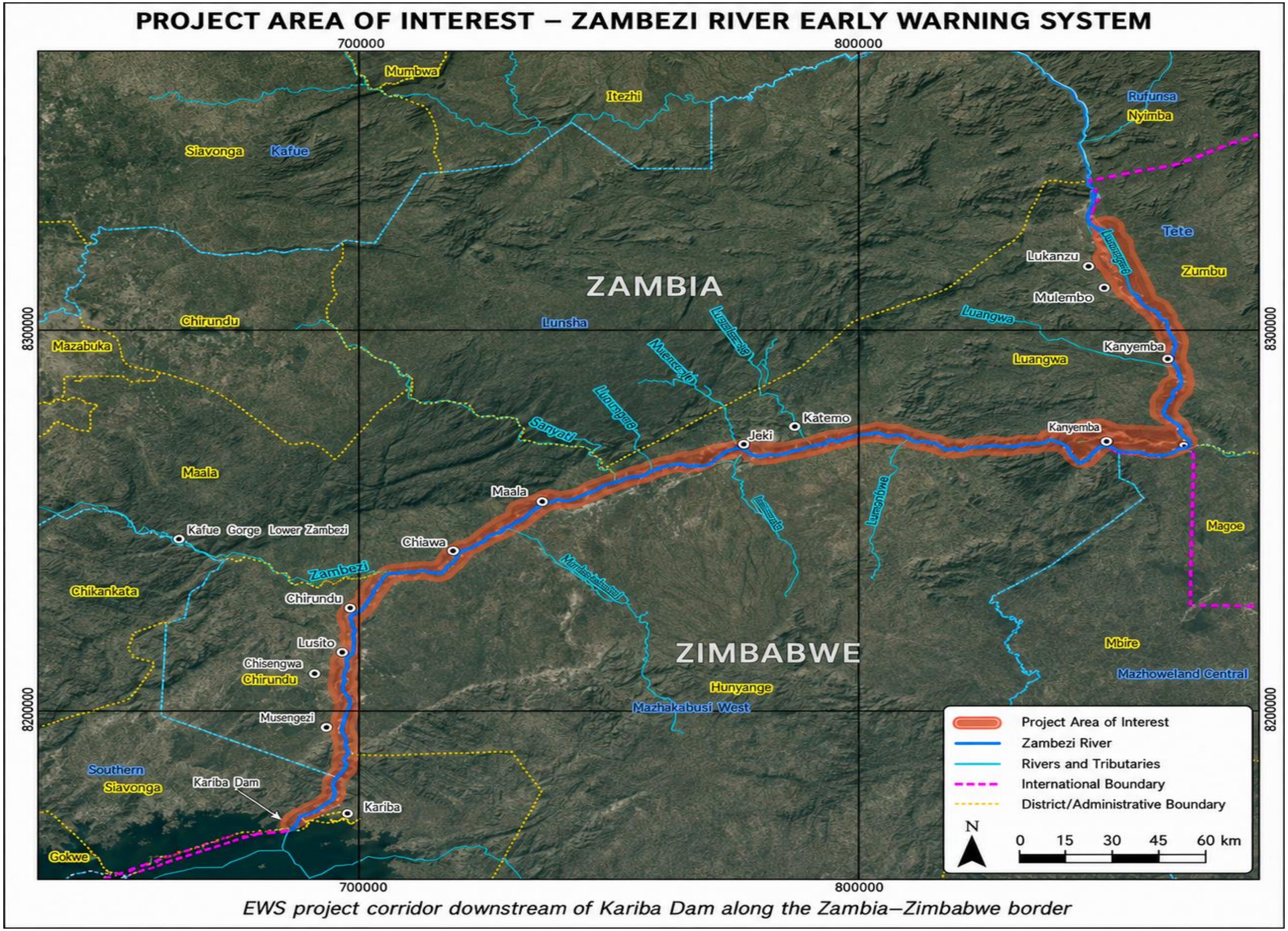

Figure 1: Google satellite image of the proposed project's location

2 LEGAL FRAMEWORK

2.1 Brief Historical Background of the Legal, institutional and Policy Framework in Zambia and Zimbabwe

The legal, institutional, and policy frameworks governing environmental management and disaster risk management in Zambia and Zimbabwe have evolved over several decades in response to increasing environmental challenges, rapid socio-economic development, and the growing need for sustainable natural resource management. Both countries have progressively strengthened their legislative and institutional arrangements to integrate environmental protection, disaster risk reduction, climate resilience, and sustainable development into national planning and decision-making.

In Zambia, the Government recognised the need to balance environmental protection with economic development and social well-being during the early 1980s. This led to the adoption of the National Conservation Strategy (NCS) in 1985, which provided the country's first comprehensive framework for environmental conservation and sustainable natural resource management. Building upon the NCS, the Government prepared the National Environmental Action Plan (NEAP) in 1992, which broadened environmental planning by incorporating pollution control, biodiversity conservation, natural resource management, and sustainable development principles. The NCS and NEAP laid the foundation for modern environmental legislation and policy in Zambia.

The implementation of these national strategies culminated in the enactment of the Environmental Protection and Pollution Control Act (EPPCA), Cap 204 of the Laws of Zambia, in 1990, which established the Environmental Council of Zambia (ECZ) as the country's principal environmental regulatory institution. The EPPCA provided the legal framework for environmental protection, pollution prevention, environmental impact assessment, and environmental monitoring. In 2011, the EPPCA was repealed and replaced by the Environmental Management Act No. 12 of 2011, which remains Zambia's principal environmental legislation. The Act transformed the Environmental Council of Zambia into the Zambia Environmental Management Agency (ZEMA) and significantly strengthened environmental governance by introducing broader provisions on environmental management, strategic environmental assessment, pollution control, climate change considerations, public participation, environmental restoration, and compliance enforcement.

Complementing the Environmental Management Act are sector-specific laws governing water resources, disaster risk management, forestry, wildlife, fisheries, cultural heritage, public health, and local government administration. Institutions such as the Water Resources Management Authority (WARMA), Disaster Management and Mitigation Unit (DMMU), the Department of Meteorology, and the Zambezi River Authority (ZRA) play important roles in implementing these laws and supporting environmental management, flood forecasting, and disaster preparedness.

In Zimbabwe, environmental governance has similarly evolved through a series of legislative and institutional reforms aimed at promoting sustainable development and environmental protection. Prior to 2002, environmental management responsibilities were dispersed among several government departments operating under different sectoral laws, often resulting in fragmented regulation and overlapping mandates. Recognising the need for a more integrated environmental management framework, the Government enacted the Environmental Management Act [Chapter 20:27] in 2002. This legislation established the Environmental Management Agency (EMA) as the country's lead environmental regulator responsible for environmental protection, pollution control, environmental impact assessment (EIA), environmental monitoring, and the enforcement of environmental standards.

Zimbabwe's environmental legal framework is further supported by several sector-specific statutes, including the Water Act [Chapter 20:24], the Zimbabwe National Water Authority (ZINWA) Act [Chapter 20:25], the Civil Protection Act [Chapter 10:06], the Parks and Wildlife Act [Chapter 20:14], the Forestry Act [Chapter 19:05], and other legislation relating to land, biodiversity, public health, and cultural heritage. These laws collectively promote sustainable management of natural resources while strengthening national capacity for disaster preparedness, climate adaptation, and environmental protection.

Both Zambia and Zimbabwe are also parties to numerous international and regional environmental agreements, including the Convention on Biological Diversity (CBD), the United Nations Framework Convention on Climate Change (UNFCCC), the Paris Agreement, the Ramsar Convention on Wetlands, the World Heritage Convention, and the Southern African Development Community (SADC) Protocol on Shared Watercourses. These international commitments have significantly influenced national legislation and policies by promoting integrated water resources management, transboundary environmental cooperation, disaster risk reduction, and sustainable development.

Given that the proposed Early Warning System (EWS) is a transboundary initiative implemented jointly by the Zambezi River Authority (ZRA), its planning and implementation are guided by the legal, institutional, and policy frameworks of both Zambia and Zimbabwe. These frameworks provide the legal basis for environmental protection, water resources management, disaster risk reduction, public participation, emergency preparedness, and cross-border cooperation necessary for the effective implementation and long-term sustainability of the project.

2.2 The Environmental Management Act No. 8 of 2023

The Act was immediately preceded by the Environmental Protection and Pollution Control Act No. 12 of 1990. Provisions of the Environmental Management Act require that all new projects begin with an Environmental Impact Assessment (EIA) and thereafter, licensing, auditing and compliance inspections follow.

The Environmental Management Act No. 12 of 2011 as amended by Environmental Management (Amendment) Act No. 8 of 2023. Formerly Environmental Council of Zambia) draws its mandate is the principal environmental Act in Zambia which integrates environmental management, protection, conservation and sustainable use of resources. In its Preamble it declares that '*Subject to the constitution, where there is any inconsistency between the provision of this Act and the provision of any other written law relating to environmental protection and management, which is not a specific subject related to law on a particular environmental subject, the provisions of this Act shall prevail to the extent of the inconsistency*.'' ZEMA will enforce the provisions of the Environmental Management Act and the subsidiary Statutory Instruments (SIs). The EMA is the principal environmental legislation in Zambia and is only subject to the constitution. As far as environmental management is concerned, any other law that is inconsistent with the provisions of this act shall be declared null and void to the extent of the inconsistency.

In relation to this project, the applicability of this Law is that it dictates the functions of ZEMA including reviewing environmental impact assessment reports, and undertake environmental auditing and monitoring. In particular, section 29 of the Act states that *"A person shall not undertake any project that may have an effect on the environment without the written approval of the Agency, and except in accordance with any conditions imposed in that approval"*.

Relevance: The project will cause environmental impacts on the environment.

Compliance: The project shall comply with EIA regulations of the EMA.

Below are the subsidiaries SIs of the EMA that are relevant to the proposed project:

- Environmental Management Act and its subsidiary legislation, the Environmental Management (Licensing) Regulations, Statutory Instrument No. 112 of 2013
- The Air and Water Pollution Control Regulations, 2013.
- Ozone Depleting Substances Regulations, 2013
- Hazardous Regulations, 2013
- Pesticides and Toxic Substances Regulations, 2013.
- Waste Management (Waste Transportation and Waste Disposal Sites) Regulations, 2013.

2.3 Environmental Management Act [Chapter 20:27] (Zimbabwe)

The Environmental Management Act [Chapter 20:27] is Zimbabwe's principal environmental legislation governing environmental protection, natural resource conservation, pollution control, and sustainable development. The Act was enacted in 2002 and came into force in 2003, replacing fragmented environmental legislation with a comprehensive legal framework for integrated environmental management. It established the Environmental Management Agency (EMA) as the country's lead environmental regulatory authority responsible for coordinating environmental management across all sectors of the economy.

The overall objective of the Act is to promote sustainable development by ensuring that economic growth, infrastructure development, and natural resource utilization are undertaken in a manner that protects the environment and safeguards public health for present and future generations. It provides the legal basis for preventing environmental degradation, promoting responsible use of natural resources, conserving biodiversity, controlling pollution, and ensuring that development projects incorporate environmental considerations throughout their planning, implementation, operation, and decommissioning phases.

One of the key provisions of the Act is the establishment of the Environmental Management Agency (EMA), which is mandated to implement environmental policies, enforce environmental legislation, regulate activities that may affect the environment, undertake environmental monitoring, coordinate environmental education and public awareness programmes, and advise Government on environmental matters. EMA is also responsible for reviewing Environmental Impact Assessment (EIA) reports, issuing environmental licences and permits, conducting environmental inspections, and taking enforcement action against individuals or organisations that fail to comply with environmental requirements.

A fundamental component of the Act is the Environmental Impact Assessment (EIA) process. The Act requires that any project likely to have significant environmental, social, or economic impacts must undergo an Environmental Impact Assessment before implementation. The EIA process ensures that potential environmental impacts are identified, assessed, and mitigated during project planning. It also promotes informed decision-making by requiring project developers to consider alternative project designs, consult affected stakeholders, and incorporate environmental management measures into project implementation.

The Act further provides for the preparation and implementation of Environmental Management Plans (EMPs) to ensure that environmental mitigation measures identified during the EIA process are effectively implemented throughout the life of a project. Developers are required to monitor environmental performance and comply with conditions attached to environmental approvals issued by EMA.

The Environmental Management Act also establishes comprehensive provisions for pollution prevention and control. It regulates pollution affecting air, water, land, and the atmosphere by setting environmental quality standards and requiring industries, municipalities, and project developers to prevent or minimise pollution arising from their activities. The Act prohibits the discharge of untreated waste, hazardous substances, toxic chemicals, and other pollutants into the environment without appropriate authorisation. It also promotes waste minimisation, recycling, cleaner production technologies, and environmentally sound waste disposal practices.

Another important objective of the Act is the conservation and sustainable management of natural resources. The legislation provides for the protection of forests, wetlands, rivers, lakes, soils, biodiversity, wildlife habitats, and ecologically sensitive ecosystems. It encourages the sustainable utilisation of renewable natural resources while preventing land degradation, deforestation, erosion, desertification, and the destruction of fragile ecosystems.

The Act also contains provisions for the protection of public health by ensuring that environmental pollution does not create unacceptable risks to human health and safety. It regulates hazardous waste management, chemical handling, environmental emergencies, and activities that may expose communities to harmful pollutants or environmental hazards.

Public participation is another cornerstone of the Environmental Management Act. The legislation recognises the right of communities and interested stakeholders to participate in environmental decision-making. Developers are therefore required to consult affected communities, local authorities, government institutions, and other stakeholders during the Environmental Impact Assessment process. Public consultation promotes transparency, accountability, and the incorporation of local knowledge into environmental planning.

The Act also provides mechanisms for environmental monitoring, compliance, and enforcement. Environmental inspectors appointed by EMA have powers to inspect facilities, investigate environmental offences, issue compliance orders, suspend environmentally harmful activities, and institute legal proceedings against offenders. Failure to comply with the provisions of the Act may result in administrative penalties, fines, restoration orders, suspension of operations, or criminal prosecution.

In relation to the proposed Zambezi River EWS Project, the Environmental Management Act [Chapter 20:27] provides the primary legal framework governing environmental assessment, pollution prevention, biodiversity conservation, stakeholder consultation, environmental monitoring, and sustainable project implementation within Zimbabwe. Since the project is transboundary in nature and involves the installation of monitoring stations, communication infrastructure, and associated facilities within environmentally sensitive riverine ecosystems, compliance with the Act is essential to ensure that potential environmental impacts are identified, mitigated, and managed in accordance with Zimbabwean environmental legislation and internationally accepted best practices

2.4 Water Resources Management Authority Act No. 21 of 2011

The **Water Resources Management Authority (WARMA)** is a statutory body established under the **Water Resources Management Act No. 21 of 2011** to regulate, manage, and protect Zambia's water resources. WARMA is responsible for ensuring the sustainable allocation, development, conservation, and utilization of surface and groundwater resources in accordance with the principles of Integrated Water Resources Management (IWRM).

In relation to the proposed Early Warning System (EWS), WARMA plays a critical role in monitoring river water levels, stream flows, and hydrological conditions through a network of manual and automated gauging stations located across major river systems, including the Zambezi, Kafue, Luangwa, and Chongwe Rivers. The Authority collects, analyses, and disseminates hydrological data that supports flood forecasting, water resources planning, and emergency preparedness. These real-time hydrological datasets will be integrated into the EWS command centre to improve flood prediction accuracy and provide timely warnings to downstream communities. WARMA also collaborates with the Zambezi River Authority (ZRA), national meteorological agencies, local authorities, and disaster management institutions in managing water-related hazards and promoting sustainable water resources governance.

2.5 Zimbabwe National Water Authority Act [Chapter 20:25]

The **Zimbabwe National Water Authority (ZINWA)** is a parastatal organisation established under the **Zimbabwe National Water Authority Act [Chapter 20:25]**. ZINWA is mandated to develop, manage, and conserve Zimbabwe's water resources while ensuring equitable and sustainable water allocation for domestic, agricultural, industrial, and environmental purposes.

Within the context of the proposed Early Warning System, ZINWA is responsible for monitoring river flows, reservoir levels, and other hydrological parameters across Zimbabwe's river basins. The Authority operates hydrological monitoring stations that provide essential real-time information on river conditions, particularly within the Zimbabwean catchments that contribute runoff to the Middle Zambezi Basin.

The hydrological information generated by ZINWA will complement data obtained from WARMA and meteorological agencies to strengthen flood forecasting models and enhance transboundary flood risk management between Zambia and Zimbabwe. ZINWA's participation is therefore essential in ensuring coordinated management of shared water resources and effective dissemination of flood warnings.

2.6 Disaster Management and Mitigation Unit

The Disaster Management and Mitigation Unit (DMMU) is the Government of Zambia's lead institution responsible for coordinating disaster risk management, emergency preparedness, response, recovery, and resilience-building activities. The Unit operates under the Office of the Vice President and coordinates disaster management activities across national, provincial, district, and community levels.

DMMU's mandate includes disaster risk assessment, contingency planning, early warning dissemination, emergency coordination, humanitarian assistance, evacuation planning, and post-disaster recovery. The Unit works closely with sector ministries, local authorities, cooperating partners, and community disaster management committees to reduce disaster risks and improve national preparedness.

Under the proposed Early Warning System, DMMU will receive and evaluate flood warnings generated by the ZRA EWS Command Centre and coordinate the dissemination of warning information to provincial administrations, district disaster management committees, emergency services, and vulnerable communities. The Unit will also coordinate evacuation procedures, search and rescue operations, emergency shelter management, and post-disaster response where required. DMMU is therefore a key institutional partner in ensuring that early warning information results in timely action that protects lives, livelihoods, and critical infrastructure.

2.7 Department of Civil Protection (DCP), Zimbabwe

The **Department of Civil Protection (DCP)** is Zimbabwe's national institution responsible for disaster risk management and emergency response. The Department operates under the

Ministry of Local Government and Public Works and coordinates disaster preparedness, response, recovery, and mitigation activities throughout the country.

The DCP is mandated to coordinate national disaster management planning, facilitate emergency response operations, promote disaster risk reduction initiatives, and strengthen institutional and community preparedness for natural and human-induced hazards. The Department works in collaboration with government ministries, provincial and district civil protection committees, emergency services, humanitarian organisations, and local communities. For the proposed Early Warning System, the DCP will play a central role in receiving flood forecasts and warning information generated through the EWS, coordinating warning dissemination within Zimbabwe, activating emergency response mechanisms, and overseeing evacuation and relief operations in flood-prone communities downstream of Kariba Dam.

The DCP will work closely with the ZRA, ZINWA, DMMU, meteorological agencies, and local authorities to ensure a coordinated transboundary approach to flood preparedness and emergency management. Its participation is fundamental to the effective implementation of the EWS and to safeguarding lives and property in downstream communities affected by flood events.

Table 1: Applicable Regulations to the proposed project

Act/Policy	Relevance to the Proposed EWS Project	Compliance Requirements
Environmental Management Act No. 12 of 2011 (as amended by Act No. 8 of 2023), Zambia	The Act provides the legal framework for environmental protection, pollution prevention, Environmental and Social Impact Assessments (ESIAs), public participation, environmental monitoring, and sustainable development. The EWS project involves installation of monitoring stations, communication towers, and associated infrastructure that require environmental assessment.	This ESIA has been prepared in accordance with the Environmental Management Act and will be submitted to ZEMA for review and approval before project implementation. All mitigation measures contained in the ESMP shall be implemented.
Environmental Management Act [Chapter 20:27], Zimbabwe	Zimbabwe's principal environmental legislation governing environmental protection, Environmental Impact Assessments, pollution control, biodiversity conservation, and sustainable development. The Act applies to all project components implemented within Zimbabwe.	The project shall comply with the requirements of EMA Zimbabwe, including environmental approvals, stakeholder consultation, environmental monitoring, and implementation of mitigation measures where applicable.
Environmental Management (Licensing) Regulations, SI No. 112 of 2013 (Zambia)	Regulates waste management, wastewater disposal, emissions, hazardous substances, and environmental licensing during construction and operation.	All wastes generated during installation and maintenance shall be managed in accordance with the Regulations. Hazardous materials shall be stored, transported, and disposed of through licensed service providers.

Act/Policy	Relevance to the Proposed EWS Project	Compliance Requirements
Water Resources Management Act No. 21 of 2011 (Zambia)	Provides for the sustainable management, protection, and allocation of Zambia's water resources. The EWS relies on hydrological monitoring and integration of river level information from WARMA.	The project shall coordinate with WARMA regarding hydrological monitoring stations, river monitoring activities, and protection of water resources during installation and operation.
Zimbabwe National Water Authority Act [Chapter 20:25]	Establishes ZINWA and provides for sustainable management of Zimbabwe's water resources. The Authority is responsible for hydrological monitoring that supports the EWS.	The project shall collaborate with ZINWA in integrating hydrological data and ensure compliance with national water resource management requirements.
Disaster Management Act / Disaster Management Framework (Zambia - DMMU)	Provides the framework for disaster preparedness, emergency response, coordination, and warning dissemination. The EWS is directly intended to strengthen disaster risk reduction.	The project shall operate in collaboration with the Disaster Management and Mitigation Unit (DMMU) to ensure effective dissemination of warnings and coordinated emergency response.
Civil Protection Act [Chapter 10:06], Zimbabwe	Establishes the Department of Civil Protection (DCP) and provides the legal framework for disaster preparedness, emergency response, evacuation, and disaster coordination.	The project shall coordinate with DCP in warning dissemination, emergency preparedness, and flood response activities within Zimbabwe.
Occupational Health and Safety Act No. 36 of 2010 (Zambia)	Construction and maintenance activities expose workers to electrical, mechanical, working-at-height, and transportation risks.	Contractors shall provide Personal Protective Equipment (PPE), training, safe work procedures, emergency response plans, and comply with occupational health and safety requirements.
Labour Act / Employment Code Act No. 3 of 2019 (Zambia)	Governs employment conditions, workers' rights, remuneration, working hours, and welfare during project implementation.	All workers employed during construction and operation shall be engaged in accordance with the provisions of the Act.
Labour Act [Chapter 28:01], Zimbabwe	Provides minimum labour standards, occupational rights, dispute resolution mechanisms, and employee welfare requirements.	Any personnel employed within Zimbabwe shall be engaged in compliance with Zimbabwean labour legislation.
Urban and Regional Planning Act No. 3 of 2015 (Zambia)	Installation of communication towers, monitoring stations, and associated infrastructure requires planning approval from local planning authorities.	The Developer shall obtain all necessary planning approvals and development permits before commencement of construction.
Regional, Town and Country Planning Act [Chapter 29:12], Zimbabwe	Regulates land use planning, development control, and infrastructure siting within Zimbabwe.	Construction activities shall comply with planning requirements and approvals issued by the relevant planning authorities.
Local Government Act No. 2 of 2019 (Zambia)	Local Authorities regulate development, environmental health, waste management, and public	The project shall obtain all relevant local authority approvals

Act/Policy	Relevance to the Proposed EWS Project	Compliance Requirements
	infrastructure within their jurisdictions.	and comply with council by-laws during implementation.
Road Traffic Act No. 11 of 2002 (Zambia) / Road Traffic Act [Chapter 13:11] (Zimbabwe)	Equipment, monitoring stations, communication infrastructure, and construction materials will be transported using public roads.	Contractors shall comply with road traffic legislation, engage licensed drivers, observe axle load limits, and implement road safety measures.
National Heritage Conservation Commission Act No. 11 of 1989 (Zambia)	Installation of EWS infrastructure may encounter archaeological or cultural heritage resources.	Chance Finds Procedures shall be implemented, and NHCC shall be notified immediately if archaeological materials are discovered.
National Museums and Monuments Act [Chapter 25:11], Zimbabwe	Protects archaeological, historical, and cultural heritage resources within Zimbabwe.	Any heritage resources encountered during project implementation shall be reported to the National Museums and Monuments of Zimbabwe (NMMZ), and works suspended until clearance is granted.
Forests Act No. 4 of 2015 (Zambia) and Forest Act [Chapter 19:05] (Zimbabwe)	Limited vegetation clearance may be required during installation of monitoring stations and communication infrastructure.	Vegetation clearance shall be minimised, and disturbed areas shall be rehabilitated following construction.
Zambia Wildlife Act No. 14 of 2015 and Parks and Wildlife Act [Chapter 20:14], Zimbabwe	Portions of the project corridor traverse ecologically sensitive habitats supporting wildlife.	Project activities shall minimise disturbance to wildlife and protected habitats, particularly within protected areas and wildlife corridors.
Workers' Compensation Act No. 10 of 1999 (Zambia)	Protects employees against occupational injuries or fatalities.	All eligible workers shall be registered with the Workers' Compensation Fund Control Board, and statutory contributions shall be paid.

2.8 International Conventions Protocols and Guidelines

Zambia and Zimbabwe are signatories to numerous international environmental conventions, treaties, and agreements that guide sustainable environmental management and conservation. These include, among others, the Stockholm Declaration on the Human Environment (1972), the Rio Declaration on Environment and Development (1992), the Convention on Biological Diversity (CBD), the United Nations Framework Convention on Climate Change (UNFCCC), the United Nations Convention to Combat Desertification (UNCCD), the Ramsar Convention on Wetlands, and the Convention Concerning the Protection of the World Cultural and Natural Heritage (World Heritage Convention). Collectively, these international instruments establish internationally recognized principles and best practices for environmental protection, sustainable development, biodiversity conservation, climate change mitigation and adaptation, and the protection of cultural and natural heritage. The principles embodied in these conventions should be considered and complied with, as applicable, during the planning, construction, operation, and decommissioning phases of the proposed development to ensure alignment with national legislation and international environmental obligations.

Table 2: Relevant International Conventions and Treaties to which Zambia is a Party

Date of Ratification (Zambia /Zimbabwe)	Convention / Protocol	Key Provisions	Relevance to the Proposed EWS Project	Compliance
1984 (Zambia); 1991 (Zimbabwe)	Convention Concerning the Protection of the World Cultural and Natural Heritage (1972)	Promotes the identification, protection, conservation, presentation, and transmission of cultural and natural heritage of Outstanding Universal Value (OUV).	Installation of monitoring stations and associated infrastructure has the potential to affect cultural heritage resources or archaeological sites if not properly managed. Although no World Heritage property will be directly affected, the project shall avoid adverse impacts on any cultural heritage resources encountered during implementation.	Any chance archaeological or cultural heritage discoveries shall be managed in accordance with the Convention and national heritage legislation of Zambia and Zimbabwe. Appropriate Chance Finds Procedures shall be implemented during construction activities.
1993 (Zambia); 1994 (Zimbabwe)	Convention on Biological Diversity (CBD)	Promotes the conservation of biological diversity, sustainable use of biological resources, and fair sharing of benefits arising from genetic resources.	The project traverses environmentally sensitive riverine ecosystems that support important flora and fauna. Project implementation should minimise disturbance to biodiversity and ecological processes.	Vegetation clearance shall be minimised, sensitive habitats avoided where possible, and disturbed areas rehabilitated. Environmental Management Plans shall incorporate biodiversity protection measures.
1993 (Zimbabwe); 1994 (Zambia)	United Nations Framework Convention on Climate Change (UNFCCC)	Establishes the international framework for addressing climate change through mitigation, adaptation, resilience building, and international cooperation.	The proposed EWS is fundamentally a climate adaptation initiative designed to improve resilience to climate-induced flooding and hydrological extremes.	The project enhances climate resilience by improving flood forecasting, monitoring, preparedness, and emergency response for downstream communities.

Date of Ratification (Zambia /Zimbabwe)	Convention / Protocol	Key Provisions	Relevance to the Proposed EWS Project	Compliance
2016 (Zambia & Zimbabwe)	Paris Agreement (2015)	Strengthens global efforts to limit climate change while enhancing adaptive capacity, resilience, and low-carbon sustainable development.	The EWS contributes directly to climate adaptation by improving preparedness for extreme weather events and strengthening institutional resilience to climate-related disasters.	Project implementation supports the climate adaptation objectives contained within the Nationally Determined Contributions (NDCs) of both Zambia and Zimbabwe.
2015	Sendai Framework for Disaster Risk Reduction (2015-2030)	Promotes understanding disaster risk, strengthening disaster governance, investing in resilience, and enhancing preparedness for effective disaster response and recovery.	The Early Warning System directly supports all four priorities of the Sendai Framework through improved risk assessment, forecasting, communication, and emergency preparedness.	The project has been designed to strengthen disaster risk reduction by integrating flood forecasting, early warning dissemination, institutional coordination, and community preparedness.
1991 (Zambia); 2013 (Zimbabwe)	Ramsar Convention on Wetlands of International Importance	Promotes the conservation and wise use of wetlands and their ecological functions.	The Zambezi River corridor contains wetlands and floodplains that provide critical ecological services and biodiversity habitats. Installation activities should avoid unnecessary disturbance of these ecosystems.	Construction activities shall minimise impacts on wetlands, riverbanks, and floodplain ecosystems, while rehabilitation measures shall be implemented where disturbance cannot be avoided.
2000 (SADC Revised Protocol)	SADC Protocol on Shared Watercourses (Revised Protocol on Shared Watercourses, 2000)	Promotes equitable and reasonable utilisation, protection, conservation, and coordinated management of shared watercourses	The proposed EWS is a transboundary initiative operating on the shared Zambezi River between Zambia and Zimbabwe and therefore directly supports the objectives of the Protocol.	The project shall promote information sharing, joint flood monitoring, coordinated warning dissemination, and cooperative management of shared water

Date of Ratification (Zambia /Zimbabwe)	Convention / Protocol	Key Provisions	Relevance to the Proposed EWS Project	Compliance
		among SADC Member States.		resources between Zambia and Zimbabwe.
2011 (Agreement entered into force)	Zambezi Watercourse Commission (ZAMCOM) Agreement	Establishes ZAMCOM to promote integrated water resources management, sustainable development, and cooperation among riparian states of the Zambezi River Basin.	The EWS contributes to basin-wide cooperation by strengthening hydrological monitoring, data sharing, flood forecasting, and disaster preparedness across the Middle Zambezi Basin.	The project shall support regional cooperation through harmonised monitoring systems, information exchange, and coordinated flood management consistent with ZAMCOM principles.

3 DESCRIPTION OF THE PROJECT

The proposed project, “Installation of an Early Warning System (EWS) for Flood Risk Management in the Downstream Areas of Kariba Dam up to the Confluence of the Zambezi and Luangwa Rivers,” is being implemented by the Zambezi River Authority as a disaster-risk reduction and dam-safety initiative. The project is intended to strengthen preparedness, emergency response and resilience to flood and dam-related hazards along the Zambezi River downstream of Kariba Dam, extending to the Zambezi-Luangwa confluence.

The proposed EWS will establish an integrated system for real-time monitoring, assessment and communication of potentially hazardous conditions, supported by rainfall, river water-level and flow monitoring, relevant dam operational information, communication infrastructure and warning facilities. The system will provide timely information to ZRA, disaster-management authorities, local authorities, emergency responders and potentially affected downstream communities to support appropriate preparedness and response actions.

The EWS has been planned based on the existing flood-risk assessments, hydraulic modelling and flood-inundation mapping undertaken for the project area. These studies have considered relevant scenarios, including controlled releases associated with dam and powerhouse operations, spillway releases, extreme flood events and hypothetical catastrophic Kariba Dam failure scenarios. The results provide the technical basis for identifying potentially affected areas and determining appropriate monitoring and warning coverage.

The project is also aligned with the UN/ISDR (2006)[3] early warning approach, which identifies four interconnected elements of an effective, people-centred EWS: risk knowledge; monitoring and warning services; warning dissemination and communication; and preparedness and response capability.[1] The EWS also supports the broader dam-safety and emergency-management principles promoted by the International Commission on Large Dams (ICOLD[4]), including the need for systematic dam-safety management, monitoring, emergency preparedness and protection of downstream populations throughout the operational life of a dam.[2]

Accordingly, the proposed EWS is designed as an end-to-end flood-risk and emergency-warning system, rather than simply an equipment-installation project. It will link existing risk information and monitoring arrangements with warning dissemination and emergency-response mechanisms, thereby strengthening downstream public safety, institutional preparedness and community resilience while complementing the existing structural and operational dam-safety measures at Kariba Dam.

[3] UN/ISDR (2006), Developing Early Warning Systems: A Checklist – Third International Conference on Early Warning (EWC III), Bonn, Germany, 27–29 March 2006, United Nations International Strategy for Disaster Reduction, Geneva.
[4] ICOLD, Dam Safety Management: Operational Phase of the Dam Life Cycle, ICOLD Bulletin 154, International Commission on Large Dams, Paris.

3.1 Project Location

The proposed EWS Project covers the Middle Zambezi Basin, including the Kariba Dam, selected areas of its upstream catchment and the downstream Zambezi River corridor up to the confluence of the Zambezi and Luangwa Rivers at the Zambia-Mozambique border, immediately upstream of the Cahora Bassa Reservoir in Mozambique. The system includes selected monitoring locations upstream of Kariba Dam and monitoring and warning facilities along the downstream river corridor.

The EWS therefore covers both upstream and downstream areas. The upstream monitoring network will provide information on rainfall, reservoir water levels and inflows that is relevant to Kariba Dam operations and downstream flood conditions. The downstream network will monitor river levels and flows and support flood assessment and warning in areas that could be affected. The project is transboundary, with installations proposed in both Zambia and Zimbabwe.

On the Zambian side, the broader project area includes Siavonga, Chirundu, Luangwa and Kafue Districts, with particular attention to settlements and activities along or close to the Zambezi River and areas that may be exposed to flood hazards. Important locations along the project corridor include Kariba, Chirundu, Chiawa, Kavalamanja and Luangwa, where monitoring, warning and emergency communication infrastructure is proposed to strengthen flood preparedness and response.

The EWS will also cover potentially affected communities, lodges, resorts, tourism facilities, public facilities and other activity areas along the Zambezi. Priority will be given to locations where people may be exposed to flood risks and where warning infrastructure can provide effective coverage. The system also takes into account the influence of the Luangwa River, including possible backwater or backflow conditions when Zambezi River levels are high. The project reach ends at the Zambezi-Luangwa confluence at the Zambia-Mozambique border, beyond which the Zambezi continues through Mozambique towards the Cahora Bassa Reservoir.

3.1.1 Spatial Extent of the Project

Administrative /Geographical Unit	Project Area / Description
Countries	Zambia and Zimbabwe
River Basin	Zambezi River Basin- Middle Zambezi Basin
Upstream Area	Selected rainfall, reservoir inflow and water-level monitoring locations upstream of Kariba Dam
Downstream Area	Zambezi River corridor from Kariba Dam to the Zambezi-Luangwa River confluence at the Zambia-Mozambique border
Kariba Reservoir and Dam	Kariba Dam and Reservoir, including monitoring locations relevant to reservoir levels, inflows and dam operations
Zambian Area	Selected locations in and around Siavonga, Chirundu, Luangwa and Kafue Districts, including communities and strategic downstream receptors
Zimbabwean Area	Selected locations along the Zambezi corridor including communities, tourism facilities and other strategic receptors

Key Downstream Locations	Kariba, Chirundu, Chiawa, Kavalamanja, Luangwa and other potentially affected settlements and activity areas
Warning Infrastructure	10 large omni-directional sirens and 40 mini sirens
Hydrometeorological Monitoring	20 ARG stations, 10 radar-type AWLR stations and 7 non-contact flow/discharge monitoring stations
Control Infrastructure	2 Command and Control Centre

The current installation plan provides for 50 sirens, comprising 10 large sirens and 40 mini sirens, with 39 installations in Zambia and 11 in Zimbabwe. The siren network is primarily intended for downstream areas where communities and other receptors may be exposed to flood hazards. The proposed EWS is a distributed, small-footprint project rather than a single continuous construction site. Most installations will be located within or close to existing communities, public/institutional facilities, lodges, resorts and tourism establishments. Where installations are required within or near national parks, ZimParks areas, protected areas or biodiversity-sensitive locations, preference will be given, wherever practicable, to existing modified or developed areas such as park offices or other disturbed sites. This approach will minimise vegetation clearance, habitat disturbance and other environmental impacts.

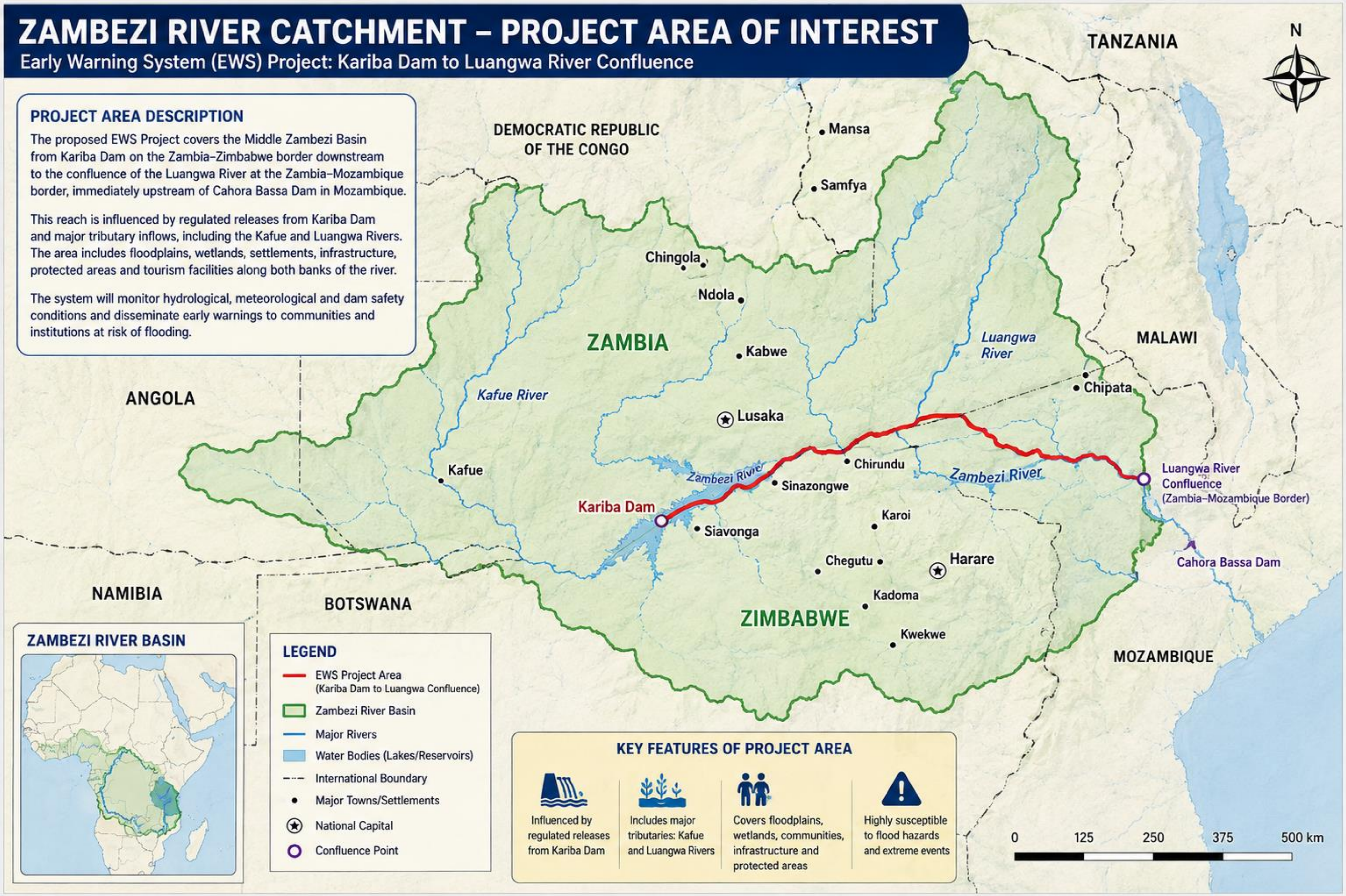

Figure 2 Zambezi River catchment and project area of Interest:

3.1.2 Project Sites and Individual Installation Footprint

The proposed EWS is a distributed, small-footprint project rather than a single continuous construction site. Most installations will be located within or close to existing communities, public/institutional facilities, lodges, resorts and tourism establishments. Where installations are required within or near national parks, ZimParks areas, protected areas or biodiversity-sensitive locations, preference will be given, wherever practicable, to existing modified or developed areas such as park offices or other disturbed sites. This approach will minimise vegetation clearance, habitat disturbance and other environmental impacts.

The proposed EWS is a distributed, small-footprint project comprising 10 large omni-directional sirens and 40 mini sirens. The sirens will be strategically located within or near communities, public/institutional facilities, lodges, resorts and tourism establishments, and where required, within or near protected areas. Preference will be given to existing disturbed or developed areas to minimise vegetation clearance and habitat disturbance. A typical siren installation will occupy approximately 4 m × 4 m (16 m^2), including the fenced area, 15-m-high mast, siren, solar/power system and control equipment.

The hydrometeorological monitoring network will comprise 20 Automatic Rain Gauge (ARG) stations, 10 radar-type AWLR stations and 7 non-contact flow/discharge monitoring stations. These installations will have small, site-specific footprints and will generally require only limited civil works for foundations, mounting structures and equipment. The use of prefabricated equipment and non-contact monitoring technologies will further minimise ground disturbance and impacts on river channels and surrounding areas. The project will also include two Command and Control Centres proposed to be accommodated within existing suitable facilities at Siavonga and Lusaka, respectively. These centres will primarily involve installation of monitoring, communication, control and backup power systems within existing buildings and are therefore not expected to require significant new construction or additional land acquisition. The geographical coordinates of the proposed siren, AWLR and AWR stations are provided in Table 3 and depicted in Figure 3.

Table 3: Geographical Location of Proposed Large and Mini Siren

No.	Country	Latitude	Longitude	Instrument	Proposed location
1	Zambia	16°09'38.16" S	28°49'39.00" E	Large Siren	Chisamu Village-Pambaza, near Chipepo Health Post
2	Zambia	16°07'09.48" S	28°50'41.64" E	Large Siren	Behind Sitinkwi Primary School
3	Zambia	16°03'54.72" S	28°50'43.44" E	Mini Siren	Siabulembo/Malangi Village
4	Zambia	15°40'41.88" S	29°28'44.40" E	Mini Siren	Sausage Tree Lodge, Lower Zambezi
5	Zambia	15°39'29.16" S	30°13'27.12" E	Mini Siren	Kingfisher Lodge
6	Zimbabwe	16°02'49.20" S	28°51'12.60" E	Large Siren	Behind Chirundu Border
7	Zambia	15°55'43.68" S	28°58'06.96" E	Mini Siren	Kabwadu Village
8	Zambia	15°36'47.88" S	30°15'34.92" E	Large Siren	Kavalamanja Village
9	Zimbabwe	15°37'31.08" S	29°54'47.52" E	Mini Siren	Kapirinhengo, ZimParks Workers' Camp
10	Zambia	16°18'43.92" S	28°49'00.84" E	Mini Siren	Manyepa, near Manyepa SDA Church, Siavonga
11	Zambia	16°17'06.00" S	28°49'37.92" E	Mini Siren	Chalokwa Village
12	Zambia	16°15'18.72" S	28°50'38.04" E	Mini Siren	KaGodhi Village

No.	Country	Latitude	Longitude	Instrument	Proposed location
13	Zimbabwe	15°58'09.84" S	28°54'56.52" E	Mini Siren	Tamarind Camp
14	Zambia	15°57'44.28" S	28°46'24.96" E	Mini Siren	Katuma Village near Gota Gota, Chiawa, Kafue
15	Zambia	15°56'04.92" S	28°56'18.24" E	Mini Siren	Entrance to Chiawa Zambeef Farm
16	Zambia	15°41'01.68" S	29°24'47.16" E	Mini Siren	Chiawa Camp
17	Zimbabwe	15°40'17.40" S	29°34'43.68" E	Mini Siren	Chikwenya Island, Mana Pools National Park
18	Zambia	15°37'50.52" S	29°41'25.80" E	Mini Siren	Old Mondoro, Chiawa Safaris, Lower Zambezi National Park
19	Zambia	15°38'26.88" S	30°19'13.08" E	Mini Siren	Amoro Village, Luangwa
20	Zambia	15°36'21.60" S	30°24'00.72" E	Mini Siren	Kamoba Village, near Luangwa Airstrip
21	Zambia	15°34'49.44" S	30°22'30.00" E	Mini Siren	Chiendeende Village
22	Zambia	15°23'33.00" S	30°22'17.40" E	Mini Siren	Nyaukwindi Village, Kapoche Ward, Luangwa
23	Zambia	15°21'07.56" S	30°21'43.20" E	Mini Siren	Kanemela Village
24	Zambia	16°02'11.04" S	28°50'43.08" E	Large Siren	Apollo Road Truck Park
25	Zambia	15°56'28.68" S	28°50'08.52" E	Mini Siren	Chaledzela/Kashiki Village, Gota Gota Primary School
26	Zambia	15°56'36.60" S	28°52'28.20" E	Large Siren	Mafurusa Village, Kafue Bridge, Chiawa
27	Zambia	15°53'26.16" S	29°02'30.84" E	Large Siren	Chiawa SDA Church
28	Zambia	15°49'57.36" S	29°06'35.28" E	Large Siren	Mugurameno Primary School
29	Zimbabwe	15°39'28.08" S	30°21'45.36" E	Large Siren	Chinembiri Hill, opposite Kanyenze
30	Zambia	15°37'15.96" S	30°24'16.92" E	Large Siren	Yellow Shop, Luangwa
31	Zambia	16°21'00.72" S	28°50'06.72" E	Mini Siren	Muskowe Health Clinic, Namoomba
32	Zimbabwe	16°01'34.68" S	28°52'38.28" E	Mini Siren	Jecha/Jeki Camp, Chirundu
33	Zambia	15°54'37.80" S	29°01'48.00" E	Mini Siren	Chilimanga Village, Chiawa
34	Zambia	15°47'22.20" S	29°10'55.56" E	Mini Siren	Kaira Lodge, Lower Zambezi National Park
35	Zambia	15°49'29.28" S	29°07'10.20" E	Mini Siren	Chimusambo Village, Chapanga, Chiawa
36	Zimbabwe	15°46'19.56" S	29°14'54.96" E	Mini Siren	Mana Pools Safari Lodge
37	Zambia	15°44'52.80" S	29°16'41.52" E	Mini Siren	Zambezi Grande
38	Zambia	15°43'38.28" S	29°18'52.92" E	Mini Siren	Royal Zambezi Lodge
39	Zimbabwe	15°43'16.32" S	29°21'47.52" E	Mini Siren	Nyamepi Camp, Sapi Safari Area, Mana Pools National Park
40	Zambia	15°36'42.12" S	29°46'00.84" E	Mini Siren	Dulini Anabezi Lodge
41	Zimbabwe	15°36'53.64" S	29°51'06.48" E	Mini Siren	Tafika Zambezi Lodge
42	Zimbabwe	15°38'43.08" S	29°59'20.04" E	Mini Siren	Big Five Lodge
43	Zambia	15°39'04.68" S	30°20'35.52" E	Mini Siren	Chikumbi Village
44	Zambia	15°38'52.80" S	30°21'48.60" E	Mini Siren	Kanyenze Village
45	Zimbabwe	15°38'39.84" S	30°23'57.12" E	Mini Siren	Kanyemba Meteorological Station
46	Zambia	15°37'54.48" S	30°23'54.96" E	Mini Siren	Chidada/Hotela Village
47	Zambia	15°33'17.28" S	30°21'11.88" E	Mini Siren	Fungulani Village
48	Zambia	15°26'44.52" S	30°22'03.36" E	Mini Siren	Zavedo, Chapitambiri, Njerekadza and Chabhoka villages, Mhuka Chiefdom
49	Zambia	15°18'23.40" S	30°19'03.36" E	Mini Siren	Undi Village, Luangwa

No.	Country	Latitude	Longitude	Instrument	Proposed location
50	Zambia	15°16'41.52" S	30°16'27.84" E	Mini Siren	Chilukusha Village, near Luangwa High School

Table 4: Location of the Automated Rain Gauges

No.	Country	Latitude	Longitude	Proposed location
1	Zambia	14°00'00.0"S	30°19'48.0"E	Class A priority site
2	Zimbabwe	17°19'48.0"S	28°22'48.0"E	Class A priority site
3	Zambia	13°31'48.0"S	25°51'00.0"E	Class A priority site
4	Zambia	14°57'00.0"S	22°42'00.0"E	Class B priority site
5	Zambia	16°51'00.0"S	27°03'36.0"E	Class B priority site
6	Zambia	17°27'36.0"S	24°18'00.0"E	Class B priority site
7	Zimbabwe	17°38'56.4"S	27°18'50.4"E	Class B priority site
8	Zambia	14°24'36.0"S	28°28'48.0"E	Class B priority site
9	Zambia	16°31'19.2"S	28°45'43.2"E	Class B priority site
10	Zambia	11°45'00.0"S	24°25'48.0"E	Class B priority site
11	Zambia	13°31'48.0"S	23°06'36.0"E	Class B priority site
12	Zambia	15°37'26.4"S	30°24'46.8"E	Class B priority site
13	Zambia	14°58'48.0"S	27°03'36.0"E	Class B priority site
14	Zimbabwe	18°55'58.8"S	29°48'28.8"E	Class C priority site
15	Zambia	11°40'40.8"S	32°46'15.6"E	Class C priority site
16	Zambia	15°24'36.0"S	28°18'36.0"E	Class C priority site
17	Zambia	10°15'28.8"S	33°00'21.6"E	Class C priority site
18	Zambia	14°53'09.6"S	25°23'16.8"E	Class C priority site
19	Zimbabwe	20°09'07.2"S	28°35'13.2"E	Class C priority site
20	Zambia	17°51'14.4"S	25°51'18.0"E	Class C priority site

Table 5: Locations of Automatic Water Level Recorder

No.	Zambia	14°58'01.2"S	30°12'54.0"E	Class A priority site
1	Zambia	15°16'12.0"S	23°04'12.0"E	Class A priority site
2	Zambia	16°09'07.2"S	28°50'34.8"E	Class A priority site
3	Zambia	17°54'36.0"S	25°50'24.0"E	Class B priority site
4	Zambia	17°28'58.8"S	24°16'58.8"E	Class B priority site
5	Zambia	16°31'19.2"S	28°45'43.2"E	Class B priority site
6	Zambia	15°56'27.6"S	28°54'46.8"E	Class B priority site
7	Zambia	16°06'36.0"S	23°17'24.0"E	Class B priority site
8	Zambia	15°37'26.4"S	30°24'46.8"E	Class B priority site
9	Zambia	14°22'48.0"S	23°14'24.0"E	Class B priority site

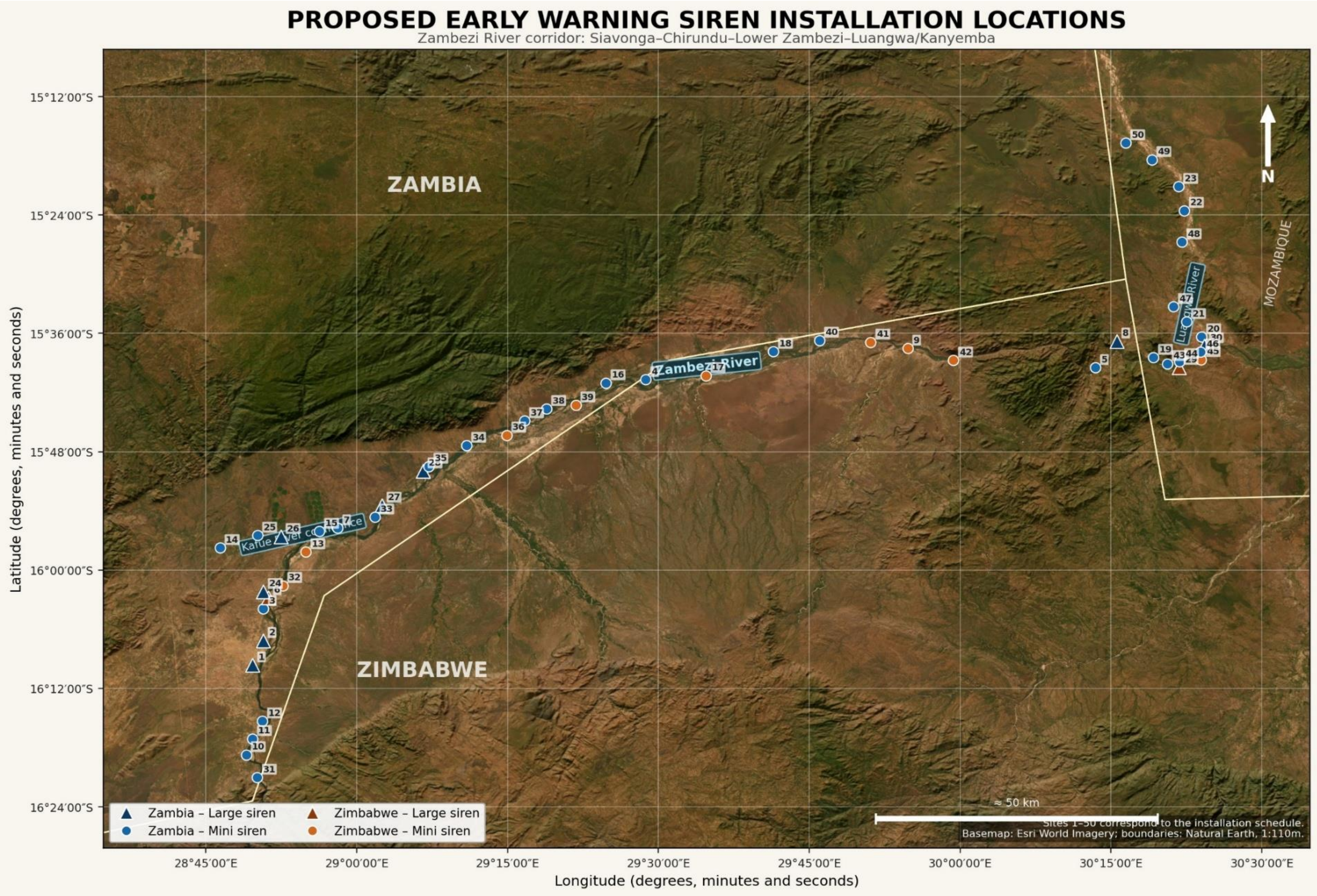

Figure 3: EWS Proposed Siren installation locations

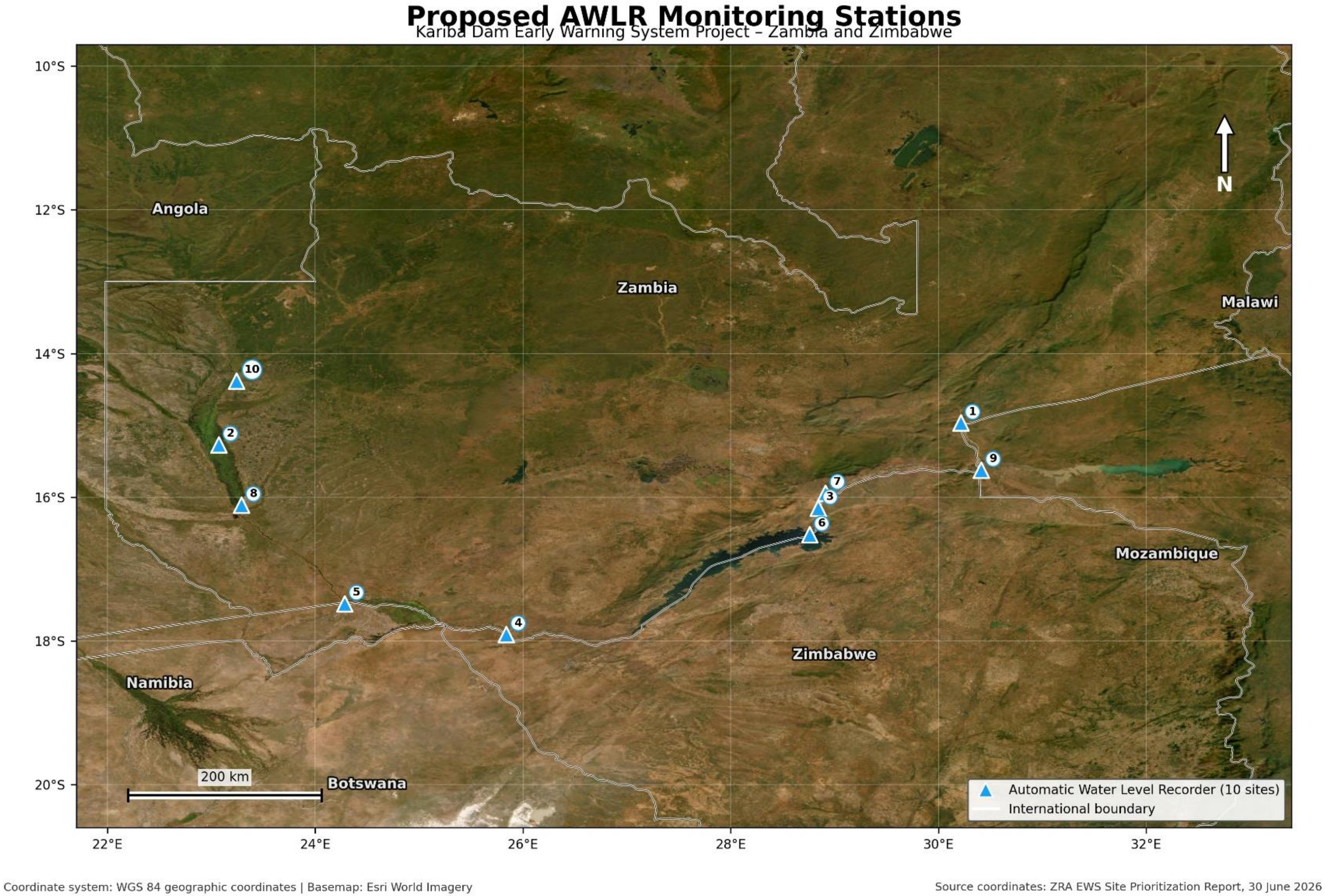

Figure 4: EWS Proposed AWLR installation locations

3.1.3 Site Features, Land Ownership and Site-Access Arrangements

The proposed EWS installations will generally be located on existing public, institutional, community, tourism-related or government-managed sites in Zambia and Zimbabwe. The principal land-administering and managing institutions include the Water Resources Management Authority (WARMA), Department of National Parks and Wildlife, Zimbabwe Parks and Wildlife Management Authority, Zambezi River Authority, and other relevant government and local authorities. Some installations will also be located within or adjacent to tourism facilities, including lodges, resorts and safari camps operating on land leased from or otherwise administered by relevant government institutions.

The proposed EWS network comprises large and mini sirens, AWLRs, ARGs, weather and other monitoring instruments, together with associated solar panels, communication equipment and minor supporting infrastructure. Proposed locations include villages and community areas, schools, health facilities, police and border-control facilities, meteorological and monitoring stations, tourism facilities, national parks and wildlife-management areas, transport infrastructure and other government-administered locations. Examples include Chisamu Village, Sitinkwi Primary School, Kabwadu Village, Kingfisher Lodge, Sausage Tree Camp, Kavalamanja Village and the Chirundu Border area, among other strategic locations along the project corridor.

Site Selection and Finalisation of Installation Locations

The proposed EWS sites have been identified through a combination of flood inundation modelling, warning-coverage requirements, technical site assessment and field-level evaluation. The modelling has been used to identify areas requiring effective flood warning coverage, while site assessments have considered proximity to potentially affected populations and facilities, accessibility, availability of suitable infrastructure, site security, environmental sensitivity, safety and ease of operation and maintenance. The locations shown in the project mapping therefore represent the proposed locations identified through the technical assessment and modelling process.

The identified locations are further verified and reassessed. This is to ensure that the final installation point is technically suitable and does not create unnecessary inconvenience, safety risks or environmental and social impacts. Where the originally identified, point is found to have a practical constraint, the final installation location may be shifted within an indicative radius of up to approximately 100 m, where technically feasible. Such minor adjustments may be made to avoid obstruction of existing access routes, buildings, community activities or tourism operations; maintain safe distances from people and existing infrastructure; avoid sensitive vegetation, habitats, drainage features or other environmentally sensitive areas; and facilitate safe access for installation, inspection, maintenance and repair.

Any adjustment within the indicative 100 m radius will remain within the same general proposed site and will not normally constitute a new project site or require additional land acquisition. The final position will be selected in consultation with the relevant landowner, land administrator, facility operator or responsible authority, as applicable. Where a shift beyond the indicative 100 m radius becomes necessary, the alternative location will undergo additional technical and environmental and social screening and obtain the relevant approvals before installation. This flexible approach will allow the EWS design to retain the required warning coverage while responding appropriately to site-specific conditions identified during implementation.

Use of Modified and Disturbed Land/Habitat to Minimise Land Disturbance and Impact

Wherever practicable, the proposed EWS installations are planned to be located on existing developed, modified or previously disturbed land and habitat to minimise new land disturbance, vegetation clearance and environmental and social impacts. Site selection has been guided by flood inundation modelling, warning-coverage requirements and site assessments, with consideration of accessibility, safety, existing infrastructure, security, maintenance requirements and environmental sensitivity. The identified locations are being further verified before installation, and the final position may be adjusted within an indicative radius of up to approximately 100 m where necessary to avoid inconvenience, safety risks, sensitive habitat, vegetation, existing services or other site-specific constraints without compromising the required warning coverage.

The EWS installations will have relatively small physical footprints and will generally require only minor civil works. Sirens will typically require a small foundation or mounting structure, with an indicative footprint of approximately 4 m × 4 m (16 m^2). AWLRs will be installed along existing streams and watercourses and, where technically feasible, existing structures such as bridges will be used to mount or support the equipment, thereby minimising disturbance to stream banks and channels. ARGs and other monitoring equipment will generally comprise instruments, poles or mounting structures, solar panels, communication equipment and minor ancillary components, requiring limited ground disturbance. Solar panels and associated equipment will be positioned to minimise the footprint and avoid unnecessary vegetation clearance.

The proposed installations will generally be located within or near existing villages, public and community facilities, transport infrastructure, tourism establishments, monitoring stations and other developed or managed locations along the project corridor. These include established settlements and facilities in the Siavonga, Chirundu, Chiawa, Lower Zambezi-Mana Pools, Luangwa and Kanyemba areas, as well as corresponding locations on the Zimbabwean side. Existing infrastructure such as the Kafue Bridge, meteorological and monitoring stations, access roads, tourism facilities, park facilities and other previously disturbed areas will be utilised wherever technically suitable.

Tourism and protected-area locations will receive particular attention to minimise disturbance to natural habitats. Where EWS installations are required within or near national parks, wildlife-management areas or other biodiversity-sensitive locations, existing developed facilities such as park offices, camps, monitoring stations, lodge areas or other modified sites will be prioritised wherever practicable. Necessary permissions and approvals will be obtained from the relevant authorities, and final locations will be selected to avoid sensitive vegetation, habitats, drainage features and other environmental constraints. The use of existing modified and disturbed land/habitat, together with the small footprint and flexibility to make minor site adjustments, will minimise the need for new land clearance, earthworks and construction. The project is not expected to require demolition of buildings, significant land acquisition or substantial alteration of existing land uses. Final installation locations will be confirmed through site-level verification and consultation with the relevant landowner, land administrator, institution or facility operator, with appropriate environmental, social and safety measures incorporated into implementation.

Land Ownership and Access Arrangements

The project will not require the purchase or compulsory acquisition of land for the EWS installations. Existing ownership, leasehold and land-use rights will remain with the respective landowner, leaseholder or responsible institution. ZRA will obtain the necessary right to use the identified locations for installation, operation and maintenance of the EWS through a No Objection Certificate (NOC), site-access agreement, lease arrangement or other appropriate written authorisation, as applicable.

Prior to installation, written consent or site-access authorisation will be obtained from the relevant landowner, leaseholder, institution or lawful land administrator. The access arrangements will cover installation, operation, inspection, maintenance, repair and, where necessary, replacement of the EWS equipment. For installations located within tourism facilities, consultation and agreement will be undertaken with both the relevant land-administering authority and the facility operator.

The proposed installations are intended to serve as public and community safety infrastructure and will provide flood warnings to residents, visitors, workers, tourists and other potentially affected users. Landowners, facility operators and surrounding communities will be encouraged to support the protection of the installations and to report vandalism, damage or malfunction.

Several tourism facilities are located within or adjacent to the Lower Zambezi National Park, Mana Pools National Park, the Sapi Safari Area and other wildlife-management areas. Development in these areas is generally limited and dispersed, and access may depend on unpaved roads, boats or seasonal tracks. Telecommunications coverage may also be intermittent. The EWS will therefore provide an additional means of communicating flood warnings to lodge staff, tourists, park employees and nearby communities.

Where installations are proposed within or near national parks, protected areas, wildlife-management areas or other biodiversity-sensitive locations, existing developed or modified sites, such as park offices, existing camps, monitoring stations or other established facilities, will be prioritised wherever practicable. Necessary permissions and approvals from the relevant authorities will be obtained before installation. Site-specific environmental, biodiversity and social requirements will be incorporated into the implementation arrangements, and final locations will be selected to avoid or minimise disturbance to sensitive habitats and vegetation.

3.2 Nature of the Project

The proposed project is an Early Warning System (EWS) for flood and dam-related emergencies. It is primarily an electronic monitoring, communication and public-warning infrastructure project and does not involve manufacturing, processing or extraction of natural resources.

The project will involve the installation and commissioning of distributed monitoring and warning equipment, including warning sirens, Automatic Rain Gauges (ARGs), Automatic Water Level Recorders (AWLRs), non-contact flow/discharge monitoring stations, solar power systems, communication equipment and associated minor supporting civil works. The EWS will function as an integrated network for receiving and transmitting hydrometeorological information, supporting assessment of potential flood conditions and disseminating timely warnings to downstream communities and relevant authorities.

The EWS design is informed by existing hydraulic modelling and flood-mapping studies, including scenarios associated with Kariba Dam operational/gate releases, spillway releases, extreme flood conditions and catastrophic dam-failure scenarios. These existing studies provide the hazard and flood-risk basis for determining warning requirements and identifying areas requiring warning coverage.

The project does not involve construction or modification of Kariba Dam, river diversion, water abstraction, or any alteration of the existing operating regime of the dam. The project is limited to monitoring, communication and warning infrastructure required to improve preparedness and emergency response.

3.2.1 Project Components

The proposed EWS will comprise a distributed network of monitoring, communication and public-warning infrastructure designed to detect and transmit relevant hydrometeorological information and disseminate timely flood and dam-related warnings to downstream communities and responsible authorities. The procurement requirements provide for 20 Automatic Rain Gauge (ARG) stations, 10 radar-type Automatic Water Level Recorder (AWLR) stations and 7 non-contact discharge/flow monitoring stations, together with 10 large omni-directional sirens and 40 mini omni-directional sirens. The system will also include two Main Command and Control Centres and two Backup Control Centres, supported by communication, power supply, data-logging and site-protection infrastructure. The field equipment will generally be powered by solar panels and batteries, with AC compatibility where specified, and will require only minor site-specific civil works and equipment mounting arrangements.

The principal physical components of the EWS are summarised below.

Table 6: Project components

Component	Quantity	Description
Large omni-directional sirens	10	High-power, 360° warning sirens mounted on approximately 15 m galvanized MS poles, with foundations, working platforms, protective fencing, solar power, battery backup, communication and control systems.
Mini omni-directional sirens	40	Localised 360° audible warning sirens for communities and strategic facilities, with supporting poles, foundations, fencing,

Component	Quantity	Description
		solar power, battery backup and communication/control equipment.
Automatic Rain Gauge (ARG) stations	20	Automated rainfall monitoring stations comprising approximately 2 m galvanized masts, rain-gauge sensors, data loggers, power supply and telemetry equipment.
Automatic Water Level Recorder (AWLR) stations	10	Non-contact radar-based water-level monitoring stations for continuous measurement of river/watercourse levels, with data logging, communication and power systems.
Non-contact flow/discharge monitoring stations	7	Radar-based systems for non-contact measurement of water velocity and level and calculation of river discharge, including data logging, telemetry, solar power and validation camera.
Main Command and Control Centres	2	Central facilities for receiving, monitoring and managing field data and EWS warning communications.
Site protection and ancillary infrastructure	As required	Minor foundations, equipment mounting structures, fencing/gates, earthing and lightning protection, solar panels, batteries, equipment enclosures, cables, communication equipment and other site-specific supporting infrastructure.

The EWS will therefore consist predominantly of electronic monitoring and communication equipment with small supporting structures, rather than major civil infrastructure. The detailed technical specifications for each component are presented in the Tables below while typical schematic of Siren installation, Arrangement of Rain Gauge, Water level sensor and Water level recorders are depicted in the table that follows.

Table 7: Component and Specification of Omni Directional Siren (Large Siren)

Omni Directional Siren (Large Siren)	
Components	**Specification**
Mast for Siren	• 15m high galvanized MS pole with appropriate Civil foundation work • Working platform for Siren • 2-meter-high GI MS fencing with top secured with Barbed Wire. • Earthing for LA & Electronics. • Lightning arrestor, Beacon Light mounted on top of the Siren Platform. • AV Camera for intrusion / Fire detection & Sound feedback
Siren	• Outdoor 5 cell Omnidirectional modular speaker cells assembled in a vertical column with separate amplifiers for each cell. • 360° High sound output throughout the entire frequency range. Sound output accuracy shall be +/- 1.5 db©. A Third-Party Type Test report for the offered Siren series shall be submitted for the support of the sound propagation within accuracy limit. • 6 warning tones, 10 pre-recorded messages. • Live Voice Message facility • Public Address System Interface • STI intelligibility index 0,99 • Siren Cells Made of non-corrosive carbon fibre reinforced polymer. Hooter / Motorised sirens not allowed. • Sound Pressure Limit @ 1 Meter - 153 db© • Sound Pressure Limit @ 30 Meters - 123 db©

	• Sound attenuation - 10 db© per doubling distance as per FEMA guidelines. • Sound feedback to control room when siren is operational.
Siren Control System	• Remote Control Station at Siren End to ensure following functions- 1. To establish Bi-Directional Communication with Main Control Centre and Backup Control centre. 2. PLC based Modular control system having control processor and I/O Cards. On board RAM - Min. 1MB Redundancy Support Media Redundancy Protocol (MRP) Ethernet Communications - SRTP Client/Server (Max 8 Connections), Modbus TCP/IP (Max 8 Connections), OPC-UA Server (Max 8 Clients), EDG (Max 16 Exchanges), PROFINET (Max 8 IO Devices) USB - 1x USB-A 2.0 Ethernet Port - 1x 10/100, 1x 3-port switch 10/100 Other Interface 1x RS-232 Operating Temp.: -40 to 70 Deg C. High-quality corrosion resistant aluminium cabinet.
Power Supply	• Battery with solar panel/ Charging System support minimum 30 minutes backup post three sunless days. • Siren system shall also be able to operate on 220 VAC Single-phase power supply.
Communication System	GSM/GPRS enabled communication
Fencing	Secure fencing around siren installation
Camera	• Outdoor Bullet IP Camera and accessories with Suitable enclosure • Operating -Temperature Range -40º C to +60º C • Image Processer 5MP • Camera Operating Mode: Full Feature/High Frame rate • Power Source: PoE: 12V DC Aux • IP camera shall be weatherproof (IP67) • Memory 1 GB Ram, 512 MB flash • Onboard Storage: micro-SD/micro SDXC slot • Provide at least 512 GB micro-SD/micro SDXC video speed card class V10 or better • Audio reception on Camera • RTC battery back :3V manganese lithium • Support Analytics events, Remote Zoom, focus and auto focus cut filter • Certifications-ROHS • Safety: IEC 62368-1, IEC 62471 • IP rating: IP 67 or better

Table 8: Component and Specification of Omni Directional Siren (Mini Siren)

Omni Directional Siren (Large Siren)	
Components	**Specification**
Mast for Siren	• 15m high galvanized MS pole with appropriate Civil foundation work • Working platform for Siren • 2-meter-high GI MS fencing with top secured with Barbed Wire. • Earthing for LA & Electronics. • Lightning arrestor, Beacon Light mounted on top of the Siren Platform. • AV Camera for intrusion / Fire detection & Sound feedback
Siren	• Outdoor 1 cell Omnidirectional modular speaker cells assembled in a vertical column with separate amplifiers for each cell.

	• 360° High sound output throughout the entire frequency range. Sound output accuracy shall be +/- 1.5 db©. A Third-Party Type Test report for the offered Siren series shall be submitted for the support of the sound propagation within accuracy limit. • 6 warning tones, 10 pre-recorded messages. • Live Voice Message facility • Public Address System Interface • STI intelligibility index 0,99 • Siren Cells Made of non-corrosive carbon fibre reinforced polymer. Hooter / Motorised sirens not allowed. • Sound Pressure Limit @ 30 Meters - 109 db© • Sound attenuation - 10 db© per doubling distance As per FEMA guidelines. • Sound feedback to control room when siren is operational.

Siren Control System	• Remote Control Station at Siren End to ensure following functions-
	  ○ To establish Bi-Directional Communication with Main Control Centre and Backup Control centre.
	  ○ PLC based Modular control system having control processor and I/O Cards.
	  ○ On board RAM - Min. 1MB
	  ○ Redundancy Support Media Redundancy Protocol (MRP)
	  ○ Ethernet Communications - SRTP Client/Server (Max 8 Connections), Modbus TCP/IP (Max 8 Connections), OPC-UA Server (Max 8 Clients), EDG (Max 16 Exchanges), PROFINET (Max 8 IO Devices)
	  ○ USB - 1x USB-A 2.0
	  ○ Ethernet Port - 1x 10/100, 1x 3-port switch 10/100
	  ○ Other Interface 1x RS-232
	  ○ Operating Temp.: -40 to 70 Deg C.
	  ○ High-quality corrosion resistant aluminium cabinet.

Power Supply	• Battery with solar panel/ Charging System support minimum 30 minutes backup post three sunless days. • Siren system shall also be able to operate on 220 VAC Single-phase power supply.
Communication System	GSM/GPRS enabled communication
Fencing	Secure fencing around siren installation
Camera	• Outdoor Bullet IP Camera and accessories with Suitable enclosure • Operating -Temperature Range -40° C to +60° C • Image Processer 5MP • Camera Operating Mode: Full Feature/High Frame rate • Power Source: PoE: 12V DC Aux • IP camera shall be weatherproof (IP67) • Memory 1 GB Ram, 512 MB flash • Onboard Storage: micro-SD/micro SDXC slot • Provide at least 512 GB micro-SD/micro SDXC video speed card class V10 or better • Audio reception on Camera • RTC battery back :3V manganese lithium • Support Analytics events, Remote Zoom, focus and auto focus cut filter • Certifications-ROHS • Safety: IEC 62368-1, IEC 62471 • IP rating: IP 67 or better

Discharge Monitoring Station	
Components	**Specification**
Radar Level, Velocity and Discharge System	• Non-contact radar for velocity & level; RS485 interface/ 4-20 mA DC output. • **Specification of non-contact Radar flow meter**

	• Ambient Temperature: From -5 to +60 ^{0}C
	• Humidity: 0-100%
	• Altitude: 0-2000 m
	• **Water Level Radar Type Sensor**
	  ○ Sensor Type: Microwave non-contact sensor
	  ○ Power: <0.5W
	  ○ Response Time: <2s
	  ○ Frequency: 76 - 81 Ghz
	  ○ Range: 0 -70m
	  ○ Resolution: 1 mm
	  ○ Accuracy: +- 2mm
	  ○ Repeatability: +- 1mm
	  ○ Protection: IP 67
	  ○ Electrical Connection: 2xM20*1.5(cable diameter 9-13mm)/ 1/2NPt
	  ○ Signal Output: 4 - 20mA/RS485
	• **Velocity Measurement Sensor Non-Contact Radar Type**
	  ○ Sensor Type: Microwave non-contact sensor
	  ○ Non- contact measurement
	  ○ Flow velocity, liquid level, flow output at the same time
	  ○ IP68 waterproof design
	  ○ Small and compact appearance
	  ○ Integrated anti- reverse connection
	  ○ Supports Modbus- RTU protocol
	  ○ Supports Bluetooth debugging on mobile phones
	• **Parameters Details:**
	  ○ **Speed range:** 0.1 m/s ~30m/s
	  ○ **Speed measurement accuracy:** ±0.01m/s
	  ○ **Blind area:** 8cm
	  ○ **Maximum range:** 60m
	  ○ **Level antenna beam angle:** 6°
	  ○ **Power supply range:** 9 ~ 28VDC
	  ○ **Working** current: 25mA@12V
	• **Communication Interface:** RS485
	  ○ **Operating temperature:** (-)30 ~ 70°C
	  ○ **Shell material:** Aluminium alloy , PBT
	  ○ **Protection level:** IP68
	  ○ **Installation method:** Bracket

Discharge Measurement Computing System	• **Discharge Measurement Computing System**
	  ○ **Method:** Velocity-Area method and refined using In-built Index-velocity rating. This system shall be fully integrated as flow meter to calculate the discharge based on the Velocity and the wetted area.
	  ○ **Accuracy:** The accuracy of velocity measurement shall be 0.5% of mean velocity reading < ± 3 % of discharge reading (under normal flow conditions)
	  ○ **Resolution:** The resolution of velocity measurement should be 1mm/s.
	• **Accuracy and Discharge Enhancing Feature:**
	  ○ Velocity-Index Discharge Rating curve.
	  ○ Actual flow meter measurement, at various water levels.
	• **Ability to define cross section:**
	  ○ The system shall have features to configure the cross-section
	  ○ dimensions of measurement site. The area may be natural channel cross- section (irregular shape) in unlined areas.
	• **Parameterization:** The system should provide Flow Display with following parameters: -
	  ○ Velocity and mean velocity in the flow area. Velocity

	○ distribution in the horizontal and the vertical panel in the cross section. ○ Water Level in the flow area. ○ Wetted area - cross section in the area of flow Discharge ○ Cumulative Discharge ○ Signal strength/amplitude in dB. ○ Geometry of the cross section ○ Last entered sludge level/silt level • **Data Output:** Real-time Discharge rate, total volume, Level, wetted area
Level Sensor	• **Water Level Radar Type Sensor** ○ Sensor Type: Microwave non-contact sensor ○ Power: <0.5W ○ Response Time: <2s ○ Frequency: 76 - 81 Ghz ○ Range: 0 -70m ○ Resolution: 1 mm ○ Accuracy: +- 2mm ○ Repeatability: +- 1mm ○ Protection: IP 67 ○ Electrical Connection: 2xM20*1.5(cable diameter 9-13mm)/ 1/2NPt ○ Signal Output: 4 - 20mA/RS485
Enclosure and Accessories	• Protection: IP65 or better • NEMA4 or IP67 or better • Sensor Mounting support, cables and other accessories as required. Sensor cable shall be as per site requirement. • IP Bullet camera (Min 5 MP) for validation of Level.
Power Supply	• Solar panel with battery backup and AC compatible (Single-phase AC power supply may be provided.)
Data Logger	• 7” Colour TFT display options • Suitable for Complex applications, trending, alarms, logging, IEC 61131-3 programming environment • Recipe Management, VNC Server, Email, MQTT • eMMC: 4GB, RAM: 512MB • Approvals: CE, UL Class I Div 2, IP66 • Resolution: 800 x 480 • Touch: Analog Resistive • Panel Cutout: 175.0x127.0 mm • CPU: 32-bit RISC Processor • Power Supply: 24 VDC (±15%) • Isolation: Yes • RTC: Built-in • Communication: ○ Serial-2x RS485 ○ USB Device: 1x micro 2.0 ○ USB Host: 1x 2.0 ○ Ethernet: 1x 10/100Mbps ○ SD Card Slot: 1xmicro SDHC • Operating Temp: -10~60°C* • Humidity: 10~90% non-condensing • Mathematical functions
Communication System	Transmitter with GSM/GPRS enabled communication Ambient Temperature: From -5 to +60 °C Humidity: 5 to 100 % Altitude: 0 to 3100 m **Serial Port for Sensor Interface:** RS-485 for sensor Interface port

	Input-Output Interfaces: **Data Transfer:** USB Stick Option for Data Transfer / WI-FI option for data transfer **Port for Configuration**: One Serial Port (USB / wireless LAN support) for communication with Laptop for programming **IP communication:** Yes **Telemetry**: Communication with Telemetry (GSM, GPRS)
Camera	• Outdoor Bullet IP Camera and accessories with Suitable enclosure • Operating -Temperature Range -40º C to +60º C • Image Processer 5MP • Camera Operating Mode: Full Feature/High Frame rate • Power Source: PoE: 12V DC Aux • IP camera shall be weatherproof (IP67) • Memory 1 GB Ram, 512 MB flash • Onboard Storage: micro-SD/micro SDXC slot • Provide at least 512 GB micro-SD/micro SDXC video speed card class V10 or better • Audio reception on Camera • RTC battery back :3V manganese lithium • Support Analytics events, Remote Zoom, focus and auto focus cut filter • Certifications-ROHS • Safety: IEC 62368-1, IEC 62471 • IP rating: IP 67 or better

Table 9: Component and Specification of Automatic Rain Gauge Station (ARG)

Automatic Rain Gauge	
Components	**Specification**
Mast for Rain Gauge	• 2 m mast with Hot dipped Galvanized steel material to withstand in extreme harsh climate in accordance with ASTM A123 and ASTM A153 Standards. • GI coating - Approx 85 microns. • Necessary fabrication and Civil work for mounting arrangements (Site Specific and to be provided at site)
Rain Gauge Sensor	• Tipping Bucket Rain Gauge (TBRG) sensor or with better Technology • Collector Diameter: Specified collection area should be between 200 to 325 cm2. Height above funnel should be sufficient to accumulate rain during heavy rainfall as per WMO guideline. • Switch shall be Rugged Magnetic Proximity • Resolution: 0.5 mm per tip • Accuracy: ±2% or better, for rain rate up to 25 mm/hr ±3% or better, for rain rate between 25 mm/hr. to 50 mm/hr. ±4% or better, for rain rate between 50 mm/hr. to 100 mm/hr. ±5% or better, for rain rate>100 mm/hr. • Rust proof housing • Suitable leveling adjustment screws and circular sprit level must be provided on the basis of TBRG for leveling the tripping bucket mechanism. • Switch Closer Time: 135 ms or better • Suitable (wire mesh) debris protection filter should be provided inside the collector
Data Logger	• 7” Color TFT display options

	• Suitable for Complex applications, trending, alarms, logging, IEC 61131-3 programming environment • Recipe Management, VNC Server, Email, MQTT • eMMC: 4GB, RAM: 512MB • Approvals: CE, UL Class I Div 2, IP66 • Resolution: 800 x 480 • Touch: Analog Resistive • Panel Cutout: 175.0x127.0 mm • CPU: 32-bit RISC Processor • Power Supply: 24 VDC (±15%) • Isolation: Yes • RTC: Built-in • Communication: Serial-2x RS485 USB Device: 1x micro 2.0 USB Host: 1x 2.0 Ethernet: 1x 10/100Mbps SD Card Slot: 1xmicro SDHC • Operating Temp: -10~60°C* • Humidity: 10~90% non-condensing

Table 10: Component and Specification of Automatic Water Level Station (AWLR)

Automatic Water Level Sensor	
Components	**Specifications**
Measuring Principle	Non-Contact Radar
Measuring Range	50m
Accuracy	±2 mm (0.003 feet) or better
Operating temperature	-20˚C to 70˚C
Protection	IP68
Transmitting Frequency	26 GHz
Response Time	≤ 3s or better
Humidity	0 to 100 %
Altitude	0 to 2500 m
Bluetooth	Optional
Bluetooth range	15 m
Power Supply	9 to 30 VDC
Beam Angle	8° x 8° (azimuth by elevation)
Communication Interface	SDI-12/Modbus / Wi-Fi/Bluetooth
Data Logger	7" Color TFT display options Suitable for Complex applications, trending, alarms, logging, IEC 61131-3 programming environment Recipe Management, VNC Server, Email, MQTT eMMC: 4GB, RAM: 512MB Approvals: CE, UL Class I Div 2, IP66 Resolution: 800 x 480 Touch: Analog Resistive Panel Cutout: 175.0x127.0 mm CPU: 32-bit RISC Processor Power Supply: 24 VDC (±15%) Isolation: Yes RTC: Built-in Communication: Serial-2x RS485

	USB Device: 1x micro-2.0 USB Host: 1x 2.0 Ethernet: 1x 10/100Mbps SD Card Slot: 1xmicro SDHC Operating Temp: -10~60°C* Humidity: 10~90% non-condensing

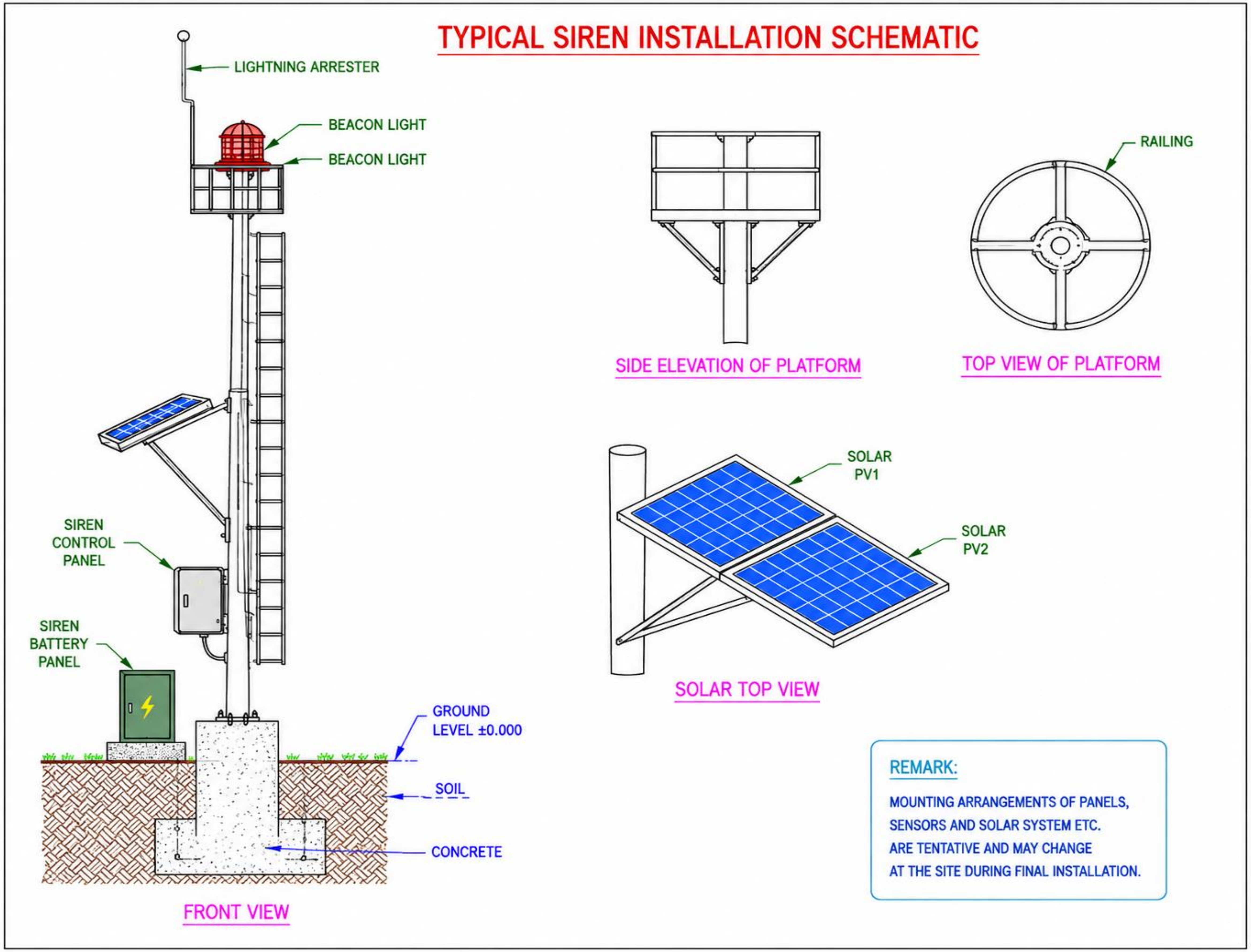

Figure 5: Typical Siren Installation Schematic

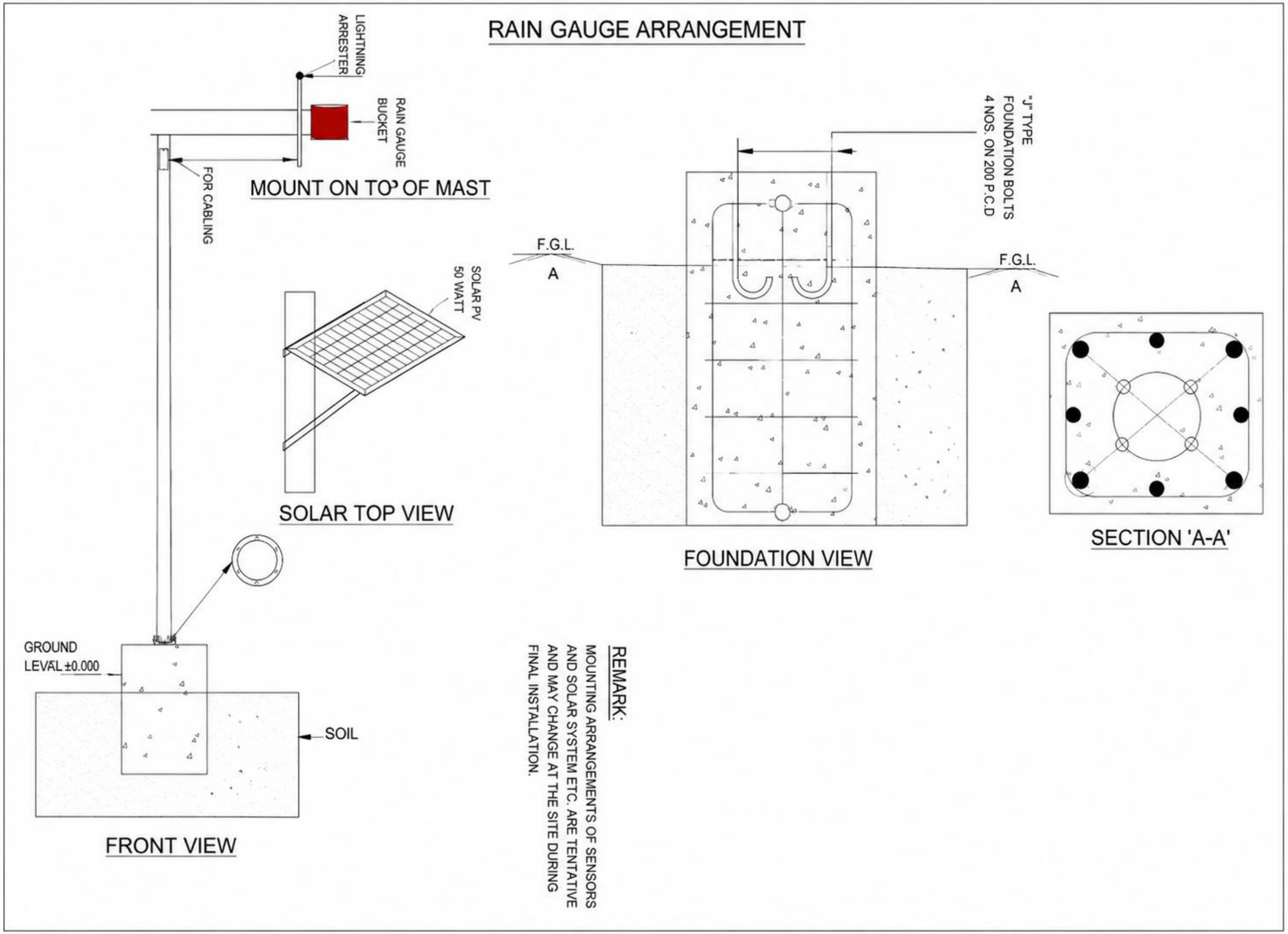

Figure 6: Typical Rain Gauge Arrangement

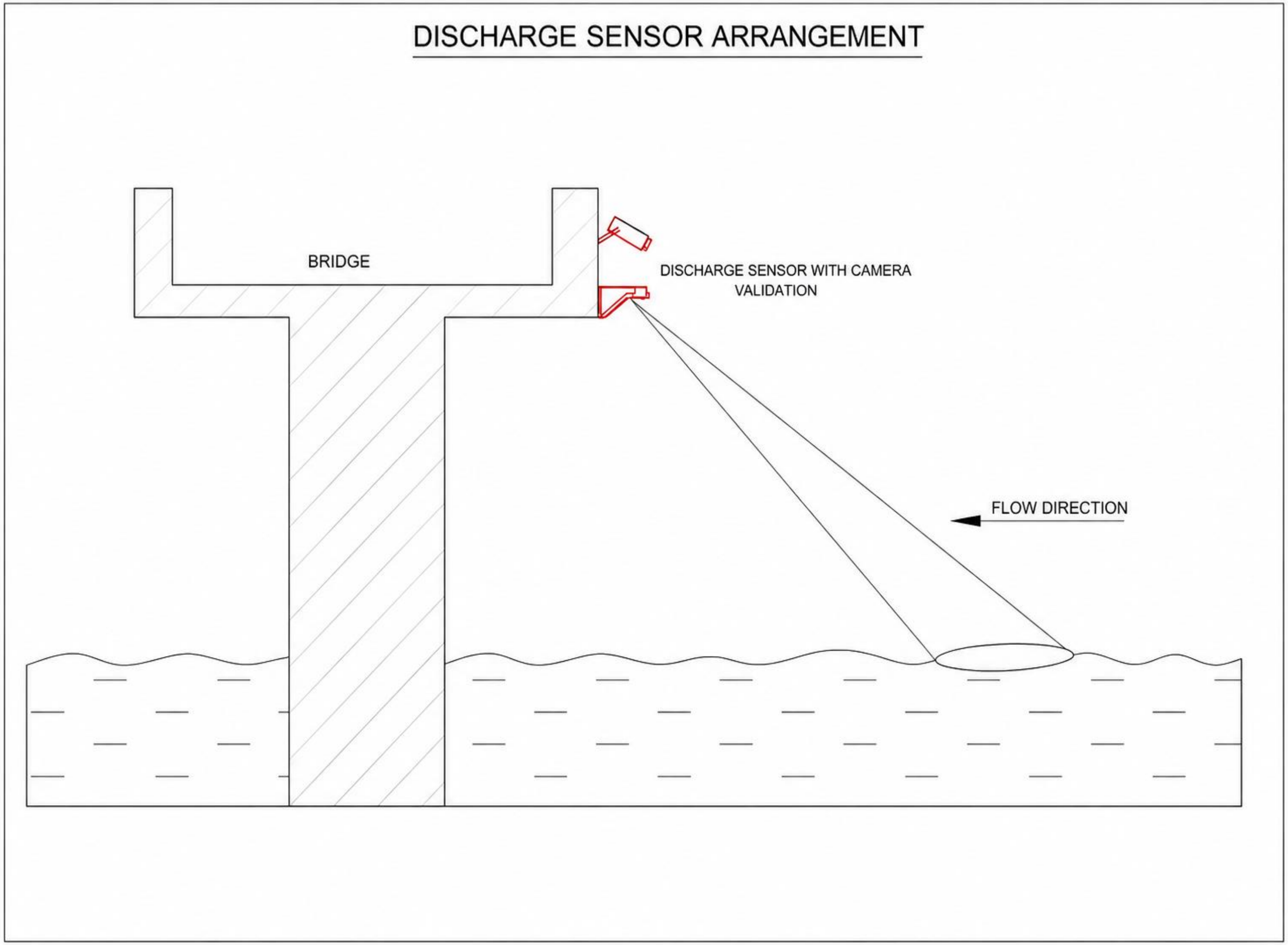

Figure 7: Discharge Sensor Arrangement

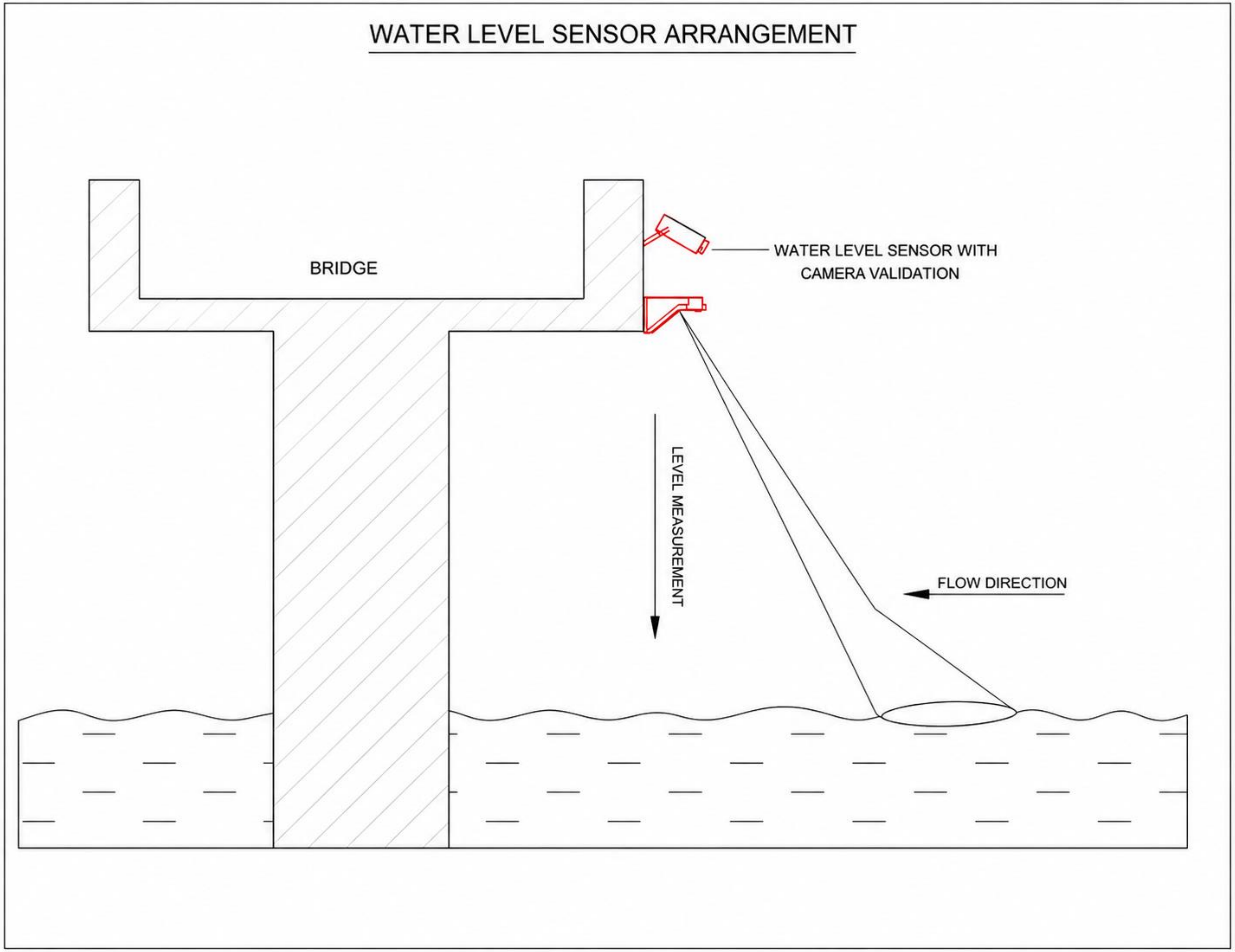

Figure 8: Typical Water Level Sensor Arrangement

3.2.2 Process Flow and Technology

The project does not involve an industrial production process. The field monitoring network will include rainfall, water-level and flow/discharge monitoring equipment. Remote equipment will generally use data loggers, communication equipment and solar-powered systems. The warning infrastructure will comprise remotely controlled large and mini sirens. The siren systems will include communication, power supply and control equipment. A simplified process diagram for EWS Flood Warning and Emergency Response Process is depicted below in Fig.

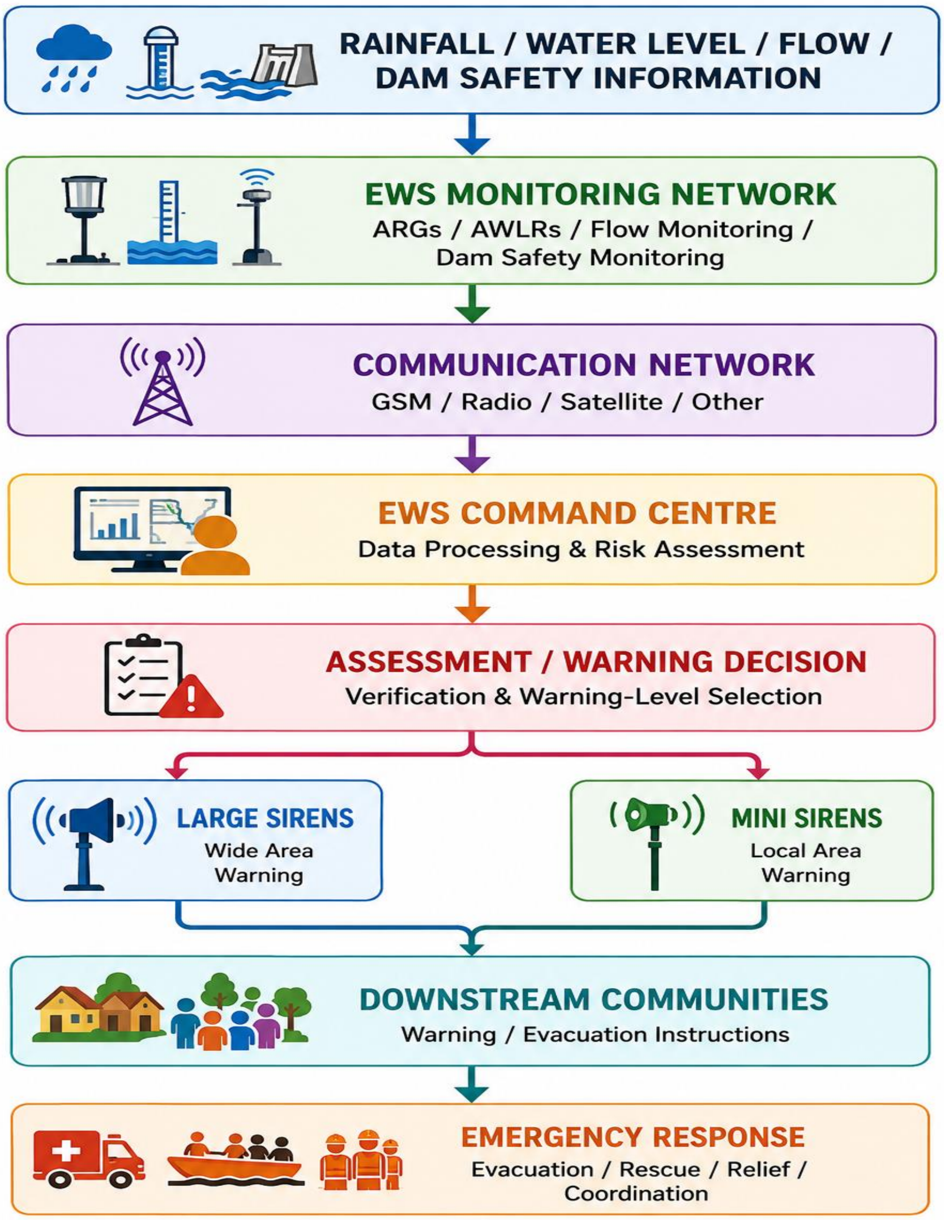

Figure 9: Simplified EWS Flood Warning and Emergency Response Process

3.3 Technology to be used for EWS Data Collection & Warning Dissemination

The proposed Early Warning System (EWS) will comprise an integrated network of hydrometeorological monitoring equipment, communication and telemetry systems, data-management and decision-support technology, and public-warning devices. The system will continuously collect information on rainfall, river water levels, river discharge and relevant dam-safety parameters; transmit the information to designated control centres; support analysis, forecasting and flood-risk assessment; and facilitate timely dissemination of warnings to downstream communities, emergency-response agencies and other responsible authorities. The proposed technology will include 20 Automatic Rain Gauge (ARG) stations, 10 radar-based Automatic Water Level Recorder (AWLR) stations, 7 non-contact flow/discharge monitoring stations, 10 large omni-directional sirens and 40 mini omni-directional sirens, supported by Main and Backup Control Centres, telemetry, data loggers, solar power and battery systems.

3.3.1 Design and Operational Principles

The EWS is designed as a people-centred, multi-hazard and integrated flood-warning system, addressing the principal elements of effective early warning: risk knowledge; monitoring, detection and forecasting; warning dissemination and communication; and preparedness and response. The system will address riverine flood risks associated with controlled operational releases, uncontrolled releases, extreme hydrological events and potential dam-failure scenarios.

The system will be designed to provide timely, reliable and actionable information to ZRA, emergency-response agencies, local authorities and downstream communities. Warning coverage will be planned to reach people within potentially affected areas, including communities, tourism facilities, public institutions and other strategic locations. Particular consideration will be given to people who may have limited access to mobile phones, electricity, internet, television or radio, as well as older persons, children and persons with disabilities.

The EWS will use multiple and complementary communication channels so that failure or limited availability of one communication method does not prevent warnings from reaching affected populations. The system will complement existing flood-warning, dam-safety and emergency-management arrangements in Zambia and Zimbabwe rather than duplicate them. Clear institutional responsibilities, standard operating procedures, warning approval arrangements and communication protocols will be established before the system becomes operational.

The system will be designed to be practical, reliable and cost-effective to operate and maintain and will be appropriate to the environmental, telecommunications and operational conditions of the project area. It will also allow future expansion and technological upgrades, including additional monitoring stations, extension of warning coverage, integration of additional hydrological information and adaptation to changing flood risks and communication technologies.

3.3.2 Overall EWS Warning Process

The proposed EWS will operate as a continuous cycle linking hazard monitoring, data transmission, data analysis, forecasting, warning generation, communication and emergency response. The overall process will comprise the following stages:

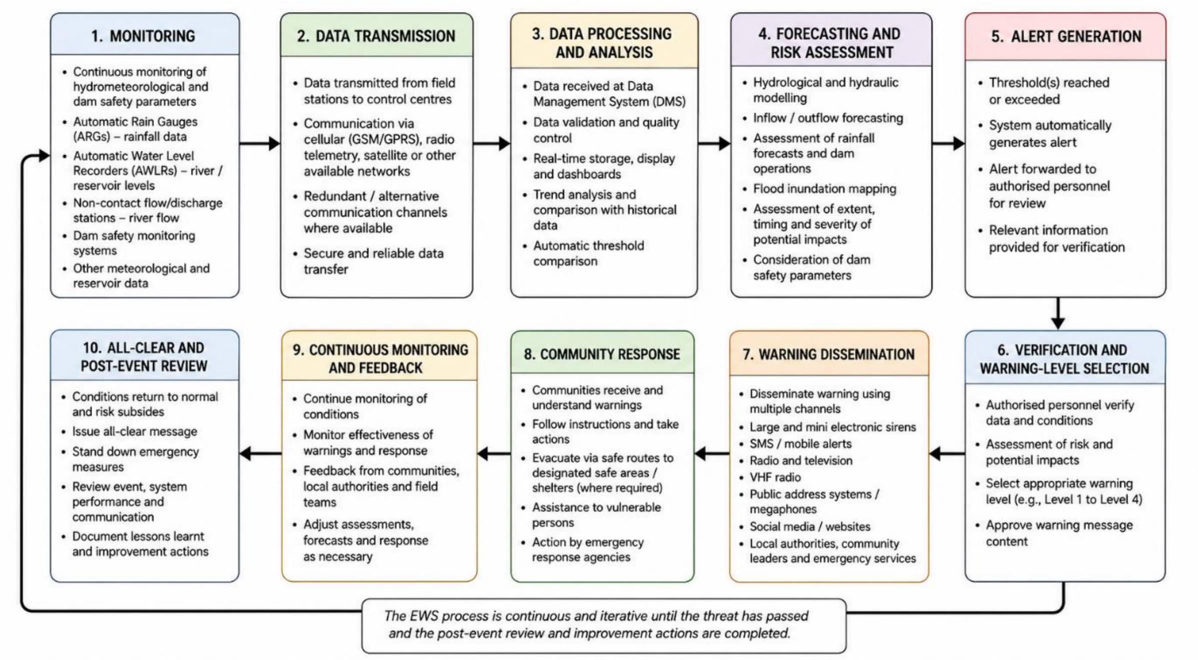

Figure 10: Overall Early Warning System (EWS) Warning and Response Process

The process will operate continuously during periods of elevated flood risk. Monitoring and feedback will continue throughout an emergency, while information obtained from actual events, system tests and emergency exercises will be used to improve warning thresholds, communication arrangements and response procedures.

3.3.3 EWS Technology and System Components

The EWS will comprise a distributed network of automated monitoring stations, communication systems, data-management facilities and warning devices. The principal field components will include ARGs, radar-based AWLRs, non-contact flow/discharge monitoring stations, large and mini omni-directional sirens, solar power and battery systems, telemetry equipment and associated minor supporting infrastructure. The 20 ARG stations will provide automated rainfall monitoring; the 10 AWLR stations will provide non-contact radar-based water-level monitoring; and the 7 flow/discharge stations will provide non-contact measurement of river velocity, water level and discharge. The warning network will comprise 10 large omni-directional sirens and 40 mini omni-directional sirens. The system will be supported by Main and Backup Control Centres, data loggers, communication systems, solar photovoltaic systems and battery storage.

The equipment will generally be installed with relatively small physical footprints and will require only minor site-specific civil works, equipment foundations or mounting arrangements. Existing developed or modified infrastructure will be used wherever technically feasible to minimise land disturbance.

3.3.4 Hydrometeorological Monitoring

ARGs will continuously measure rainfall at selected locations. The stations will record rainfall intensity and cumulative rainfall and transmit observations to the central EWS platform. Rainfall information will provide an early indication of intense or prolonged rainfall that may contribute to increased river flows, reservoir inflows and downstream flooding. AWLRs will continuously monitor water levels along the Zambezi River and relevant tributaries. The proposed AWLRs will use non-contact radar technology, thereby avoiding the need for submerged mechanical sensors. Where technically feasible, AWLR equipment may be mounted on existing structures such as bridges to minimise disturbance to riverbanks and channels.

The non-contact flow/discharge monitoring stations will measure water velocity and water level using radar technology and calculate river discharge using the velocity-area and index-velocity approach. These stations will provide information on the magnitude and movement of river flows and strengthen the information available for flood forecasting and warning decisions.

The EWS will also incorporate relevant information from existing hydrological and meteorological monitoring networks operated by responsible agencies in Zambia and Zimbabwe. This may include reservoir levels, upstream rainfall, river flows, downstream water levels and other information relevant to flood prediction.

3.3.5 Dam Safety Monitoring and Integration

The EWS will support the integration of relevant Kariba Dam safety-monitoring information with hydrological and meteorological observations. The existing dam-safety monitoring programme includes parameters such as deformation, seepage, piezometric conditions, structural cracks, uplift, spillway-gate performance, foundation and abutment behaviour, plunge-pool conditions and other structural and geotechnical indicators. Where these monitoring systems are automated or connected to the EWS, information will be transmitted to the designated control centre for assessment against predefined operational and safety thresholds. Where monitoring remains manual, information may be entered into the appropriate digital system by authorised personnel.

The integration of dam-safety, hydrological and meteorological information will enable the EWS to consider both flood hazards and potential dam-related emergencies within a common decision-support framework. The EWS itself will not modify the operation of Kariba Dam or replace the existing dam-safety management arrangements.

3.3.6 Data Transmission and Communication

Data collected from the field monitoring stations will be transmitted to the designated control centres through available telecommunications and telemetry systems. Depending on site conditions and network availability, communication may utilise GSM/GPRS, radio, satellite or other suitable communication channels.

The communication system will be designed to provide reliable transmission of monitoring information and warning commands. Where practicable, alternative communication arrangements will be provided for critical locations to reduce the risk of communication loss during power failures, severe weather or network interruptions.

3.3.7 Data Management, Analysis and Decision Support

The Data Management System (DMS) will serve as the central platform for receiving, processing, storing and displaying information from the field monitoring network. It will provide authorised personnel with real-time information, historical records, trends, alarms and other decision-support functions.

Incoming observations will be compared with predefined rainfall, water-level, discharge and other relevant warning thresholds. The system will identify abnormal or rapidly changing conditions and generate alerts for review by authorised personnel. The EWS will utilise available hydraulic and hydrological modelling and flood-inundation mapping to assess the likely extent, timing and severity of downstream flooding under different scenarios, including operational releases, spillway releases, extreme flood conditions and potential dam-failure scenarios. The prediction and warning process will combine observed conditions with relevant forecast and dam-operational information, including reservoir levels, upstream inflows, rainfall forecasts, planned powerhouse releases, potential spillway discharges and other information required to estimate downstream flows and flood propagation.

3.3.8 Flood Prediction and Risk Assessment

Flood prediction will combine real-time observations with available hydrological and hydraulic modelling, forecast rainfall, reservoir conditions, river flows and dam-operational information. The assessment will consider:

- observed rainfall and rainfall trends;
- reservoir and river water levels;
- upstream and downstream river flows;
- predicted inflows and discharges;
- dam operational conditions and planned releases;
- potential spillway or uncontrolled releases;
- dam-safety monitoring information;
- hydrological and hydraulic model predictions;
- flood-inundation maps; and
- expected timing, extent and severity of downstream impacts.

The assessment will provide the technical basis for determining whether a monitored condition represents a potential flood or dam-related emergency and whether an alert should be escalated to a formal warning.

3.3.9 Alert Generation and Warning-Level Selection

Flood warnings will be generated through a combination of automatic monitoring, threshold-based alerts, modelling and verification by authorised personnel. When rainfall, river level, discharge, reservoir conditions or other relevant parameters reach or exceed established thresholds, the system will generate an alert. The alert will be reviewed by authorised personnel, who will verify the information, assess prevailing conditions and determine the appropriate warning level in accordance with the approved Emergency Preparedness Plan and standard operating procedures. The four emergency alert levels will provide the basis for determining the appropriate response.

Table 11: Alert Generation and Warning-Level Selection

Alert level	Classification	Required action	Description
Level 1	Abnormal or potentially hazardous event	Increased monitoring and investigation	An abnormal event is occurring, but there is no immediate threat to the operation or structural integrity of the dam. The condition is generally developing slowly and should be closely monitored.
Level 2	Unusual event that may lead to downstream flooding	Notify responsible authorities and prepare response measures	Conditions are outside the normal operating range and may develop rapidly. Although there may not yet be an immediate threat to the dam's structural integrity, failure to take corrective action could result in downstream flooding or contribute to dam failure.
Level 3	Potential dam failure or serious uncontrolled discharge	Prepare downstream communities for evacuation	Conditions are developing rapidly and could lead to dam failure. This level also applies where uncontrolled releases through the spillway or outlet works are likely to cause downstream flooding, but buildings, roads and public safety have not yet been significantly affected.
Level 4	Dam failure is imminent or already occurring	Declare an emergency and order immediate evacuation	The dam has failed, is failing or is expected to fail. Because it may not be possible to predict how quickly a complete breach will occur, a Level 4 alert must be issued as soon as failure is considered unavoidable. Emergency authorities should apply the worst-case assumption that failure has already occurred when initiating evacuation.

The warning level will be selected based on the assessed severity, extent and timing of the hazard and its potential consequences for downstream communities, infrastructure and other receptors.

3.3.10 Warning Dissemination and Communication

Once the appropriate warning level has been verified and authorised, the warning will be disseminated through multiple complementary communication channels. The principal public-warning infrastructure under the project will comprise large and mini electronic sirens.

Large omni-directional sirens will provide wider-area audible warning coverage, while mini sirens will provide more localised coverage for communities, settlements and strategic facilities. The sirens will be remotely controlled from designated control centres and will be capable of transmitting warning tones and pre-recorded or live voice messages.

The siren network will be supplemented, as appropriate, by:

- SMS and mobile-phone notifications;
- radio and television
- VHF radio
- public-address systems and megaphones
- social-media and internet-based platforms
- notifications to local authorities and emergency-response agencies
- communication through traditional and community leaders and
- direct community-based communication where necessary

Multiple communication channels will be used because no single method can reliably reach all potentially affected people, particularly those in remote settlements, tourism facilities, protected areas or locations with limited electricity, telecommunications or internet connectivity.

Warning messages will be clear, concise and appropriate to the emergency level. Where evacuation is required, messages will identify the nature of the hazard, affected or potentially affected areas, required actions, evacuation directions or routes and designated safe areas or assembly points, as applicable.

3.3.11 Community Response and Emergency Action

The EWS will support communities and responsible authorities in taking appropriate action following receipt of a warning. Emergency-response arrangements will therefore be linked to the warning levels and the approved Emergency Preparedness Plan. Response arrangements will include community awareness, identification of evacuation routes and safe areas, emergency-response coordination, evacuation of vulnerable persons and mobilisation of appropriate search-and-rescue and humanitarian resources.

Particular attention will be given to children, older persons, persons with disabilities, pregnant women, persons requiring medical assistance and other people who may require additional support during evacuation. Local, district and national authorities in Zambia and Zimbabwe will coordinate with ZRA, emergency services, dam-safety personnel, local authorities and community structures to implement the required response measures. Where necessary, emergency arrangements will include transport, temporary shelter, safe drinking water, food, sanitation, healthcare and other immediate humanitarian assistance.

3.3.12 Operation, Testing and Maintenance

The EWS will operate continuously, with monitoring stations, communication systems, control centres and warning equipment maintained in operational condition. Remote and isolated installations will generally use solar photovoltaic systems with battery storage, with alternative or AC power arrangements where available and appropriate. Routine operation will include inspection, testing, calibration, servicing and repair of monitoring sensors, data loggers, telemetry equipment, sirens, solar-power systems, batteries and associated infrastructure. Access to installations will be restricted to authorised personnel, and appropriate security measures will be maintained to reduce the risk of vandalism, theft or accidental damage.

Regular siren testing and emergency simulation exercises will be undertaken to verify equipment functionality, communication links and community-response arrangements. Communities will be informed in advance of planned tests to avoid unnecessary alarm. Emergency drills should preferably be undertaken before the wet season and at least annually, subject to the approved emergency preparedness arrangements.

Operational records will be maintained for monitoring data, system alerts, warnings issued, equipment performance, maintenance activities, siren tests, communication failures and community feedback.

3.3.13 Post-Event Review and Continuous Improvement

Following a significant flood, dam-related emergency, system failure or emergency simulation, the performance of the EWS will be reviewed. The review will consider the performance of monitoring equipment, data transmission, forecasting, warning generation, communication channels, sirens, institutional coordination and community response.

Where weaknesses or gaps are identified, corrective actions will be incorporated into the relevant operating procedures, maintenance programme, warning thresholds, communication arrangements, training and community-awareness activities. Lessons from actual events and emergency exercises will therefore feed back into the monitoring, forecasting, warning and response arrangements. The EWS will also be periodically reviewed to ensure that the technology, warning thresholds, communication arrangements and emergency-response procedures remain appropriate to changing hydrological conditions, downstream development, population distribution, technology and flood-risk conditions. This will ensure that the system remains effective, reliable and fit for purpose throughout its operational life.

3.3.14 Raw Materials and Construction Materials

As the proposed project is an EWS installation project, it will not involve any industrial production processes and therefore will not require raw materials or production inputs in the conventional industrial sense. The project will, however, require limited quantities of construction and installation materials for the establishment of foundations, poles/masts, equipment supports, fencing, cabling and associated infrastructure proposed within 4m X4m construction footprints.

A. Construction and Installation Materials

At the field installation sites, the principal materials are expected to include:

- Cement and concrete for foundations and equipment bases, including foundations for poles/masts of approximately 15 m height and 2 m height fence where required
- Sand, aggregates and other concrete materials
- Reinforcement steel
- Structural steel/mild steel for poles, masts, equipment supports and mounting frames
- Galvanised steel components and brackets
- Electrical cables, conduits and cable protection systems
- Solar photovoltaic panels and mounting structures, where provided for field stations
- Batteries and battery enclosures
- Data loggers, electronic control equipment and equipment cabinets
- GSM/GPRS communication equipment, antennas and associated accessories
- Procurement and installation of automated rainfall stations equipment's, automatic water level recorders (AWLR), non-contact discharge/flow monitoring equipment, large and mini sirens, Siren control equipment, cameras and communication equipment
- Earthing and lightning-protection systems
- Fencing materials and gates, where required for site protection and
- Small quantities of paints, protective coatings, lubricants, sealants and other materials required for installation and maintenance.

The field installations will have a small physical footprint, generally limited to the equipment foundation, pole/mast, solar panel and associated protection/fencing. Existing access roads and developed locations will be used wherever practicable to minimise additional land disturbance.

B. Construction Machinery and Equipment

Construction and installation activities will be relatively small-scale and are expected to require only light to medium construction equipment. Depending on site conditions, this may include:

- 4×4 vehicles and small transport vehicles for mobilisation of personnel and equipment
- Portable drilling equipment or augers for foundation preparation
- Hand tools and small power tools
- Concrete mixer or small mobile batching/mixing equipment
- Plate compactor/rammer for backfilling and reinstatement
- Portable welding and cutting equipment

- Lifting equipment, winches or small cranes for erection of poles/masts and siren equipment, where required
- Generators for temporary electricity supply at remote sites
- Water pumps, hoses and tanks, where required for construction activities and
- Testing, commissioning and electrical/electronic installation equipment

The scale and type of machinery will vary according to site accessibility and the foundation design. Heavy construction equipment is not expected to be continuously required at the individual EWS sites. Where practicable, construction will rely on portable equipment and existing access routes to minimise ground disturbance.

C. Water Requirement

Water requirements during construction will be limited and temporary, primarily for concrete mixing and curing, dust suppression, equipment cleaning, housekeeping and workers' domestic needs. No significant process-water requirement is anticipated. Water will be obtained from approved and locally available sources, subject to availability and applicable permissions. Water abstraction from rivers, streams or other natural water bodies will not be undertaken without the necessary approval. Construction water will be used efficiently to avoid unnecessary abstraction, particularly at remote or environmentally sensitive locations. Concrete wash water, cement slurry, drilling fluids and other construction wastewater will be managed so that they do not enter rivers, streams or drainage channels. The project safeguard requirements specifically prohibit uncontrolled discharge of such materials to watercourses and require construction activities and equipment washing to be undertaken at designated locations away from watercourses.

D. Energy Requirements

Energy requirements during construction will be relatively small and will primarily relate to operation of small construction machinery and power tools, Welding and cutting equipment, Temporary lighting, where required, Testing and commissioning of electrical/electronic equipment, Temporary site offices and worker facilities, where applicable During installation, grid electricity will be used where available. At remote locations without suitable grid access, portable diesel/petrol generators may be used intermittently for small construction machinery, power tools and testing/commissioning. During operation, the remote ARG, AWLR, flow-monitoring and siren installations will have relatively low energy requirements and will generally utilise dedicated power systems, including solar photovoltaic panels and battery storage will be provided. The Command-and-Control Centres will have higher and more continuous electricity requirements for servers, IT systems, displays, communication systems and EWS decision-support software. The project provides for two Command and Control Centres with associated hardware, software and IT infrastructure. Appropriate UPS/battery backup and/or standby generation will be provided for critical systems.

E. Waste Generation

The construction phase will generate small quantities of non-hazardous and hazardous waste, mainly from foundation works, equipment installation and worker activities. Typical wastes will include:

- Excavated soil and surplus spoil
- Concrete remnants and cement bags
- Scrap steel, cables and metal off cuts
- Packaging materials, plastics and cardboard
- Used batteries and minor electronic waste
- Used oils, lubricants and oily materials
- Empty paint/coating containers and
- General domestic waste and limited construction wastewater.

Suitable excavated soil will be reused for backfilling and site reinstatement where practicable. Other wastes will be segregated, stored safely and transferred to authorised recycling or disposal facilities. No waste or spoil will be disposed of in watercourses, drainage channels, floodplains or other environmentally sensitive areas.

During operational phase, EWS will generate minimal waste during operation, mainly from routine maintenance and replacement of equipment, including spent batteries, electronic components, cables, solar/electrical components, packaging and small quantities of lubricants. Electronic waste and spent batteries will be segregated from general waste and managed through authorised recycling or disposal arrangements.

3.3.15 Hazardous Materials and Their Storage

The project will involve only limited quantities of potentially hazardous materials, primarily associated with construction and equipment maintenance. These may include:

- Diesel/petrol for construction vehicles and equipment
- Lubricants and hydraulic oils
- Paints and protective coatings
- Batteries
- Electrical/electronic components and
- Small quantities of cleaning or maintenance chemicals.

No bulk storage of hazardous chemicals is anticipated at the EWS installation sites.

Where hazardous materials are required, they will be stored in appropriate, labelled and secure containers, protected from rain and direct sunlight and located away from drainage channels and watercourses. Spill-prevention and spill-response measures will be implemented during construction and maintenance. Hazardous waste electronic waste and spent batteries will be segregated from general waste and managed through authorised recycling or disposal arrangements.

3.3.16 Products and By-products

The project will not manufacture any physical product. Therefore, the principal output of the project will be:

- Real-time monitoring information
- Flood and emergency warning information
- Audible warnings through sirens
- Communication of warnings to responsible institutions and communities; and
- Improved emergency preparedness and response.

No industrial by-product or process waste will be generated during operation.

3.3.17 Production Capacity

Not applicable. The project is not an industrial or manufacturing facility and therefore has no production capacity. The functional capacity of the project is instead defined by its monitoring and warning network, comprising 20 ARG stations, 10 AWLR stations, 7 flow-monitoring stations and 50 sirens, supported by the Command-and-Control Centres.

3.3.18 Project Schedule and Lifetime

The installation and commissioning of the EWS equipment are planned within the implementation period specified under the procurement package. The procurement requirements provide for installation/testing/commissioning of the major EWS components within 12 months of contract commencement/signing, depending on the component and contractual milestone.

Following commissioning, the project includes five years of annual maintenance services for the major EWS components. The EWS is intended to be a long-term operational public-safety system, with replacement and upgrading of individual electronic, communication and power-system components undertaken as necessary over their respective service lives.

3.4 Project Activities

The proposed EWS project will be implemented through site preparation, construction and installation, operation and maintenance, and eventual decommissioning. Unlike conventional infrastructure, industrial or mining projects involving extensive civil works, land development, excavation or processing activities, the proposed EWS is a small-scale equipment-based project with a limited physical footprint and minor construction requirements. The main activities will comprise procurement and transportation of prefabricated monitoring and warning equipment, limited site preparation and foundations, assembly and installation of ARGs, AWLRs, flow-monitoring stations and sirens, installation of communication and power systems, testing and commissioning, followed by routine operation and maintenance.

Construction-related environmental concerns are therefore expected to be localised and short-term, mainly involving minor soil disturbance, limited vegetation clearance, dust and noise, small quantities of construction waste, fuel/oil handling and potential disturbance at locations near watercourses or environmentally sensitive areas. These impacts will be minimised through use of existing or previously disturbed sites and infrastructure wherever practicable, small installation footprints, controlled working areas, appropriate waste and spill management, and site-specific environmental measures.

During the operational phase, environmental concerns are expected to be very limited, as the EWS does not involve manufacturing, processing, mining, water abstraction or continuous discharge of pollutants. The system will primarily comprise automated electronic monitoring and warning equipment, with remote stations generally requiring low energy and, where provided, solar-based power. Operational activities will mainly involve monitoring, periodic inspection, testing, maintenance and replacement of equipment, with limited waste generation. Overall, the EWS is expected to have a low environmental footprint during both construction and operation, subject to appropriate site-specific safeguards and good maintenance practices

3.4.1 Site Preparation Phase

Site preparation will be limited to the areas required for installing Automatic Rain Gauges, Automatic Water-Level Recorders, mini sirens, large sirens and associated communication and power equipment. The principal activities will include:

i. Confirming installation coordinates and site boundaries through field surveys;
ii. Obtaining permission to access and use the selected sites;
iii. Identifying underground and overhead utilities before excavation;
iv. Establishing safe access routes for workers, vehicles and equipment;
v. Clearing vegetation only within the required installation footprint;
vi. Removing obstacles that may interfere with equipment installation or performance;
vii. Levelling small areas required for equipment foundations;
viii. Marking foundation positions, trenches and equipment-safety zones;
ix. Establishing temporary storage areas for construction materials and equipment; and
x. Installing temporary safety signs and barriers around active work areas.

Site preparation will avoid unnecessary disturbance of vegetation, riverbanks, drainage channels, community infrastructure, agricultural land and culturally or environmentally sensitive areas.

3.4.2 Construction and Installation Phase

During the construction and installation phase, the contractor will undertake the following activities:

i. **Foundation Construction:** Excavate and construct concrete foundations for siren poles, monitoring stations, solar-panel supports, equipment cabinets and communication masts.

ii. **Installation of Monitoring Equipment:** Install Automatic Rain Gauges and Automatic Water-Level Recorders, including sensors, data loggers, telemetry units and protective enclosures.

iii. **Installation of Sirens:** Erect poles or supporting structures and install mini and large sirens at the approved locations. Siren orientation and mounting heights will be selected to achieve the required warning coverage.

iv. **Installation of Communication Equipment:** Install antennas, radio units, cellular modems, satellite communication devices, routers, signal boosters and associated transmission equipment.

v. **Power-System Installation:** Install solar panels, batteries, charge controllers, inverters, electrical cables, distribution boards and backup power systems. Grid connections may be provided at suitable locations.

vi. **Data Management System Installation:** Install computers, servers, software, display equipment, communication interfaces and data-storage systems at the designated control centre.

vii. **Cable and Conduit Installation:** Install electrical and communication cables in protected conduits or trenches. Excavated trenches will be backfilled and disturbed surfaces restored after installation.

viii. **Security Infrastructure:** Install fencing, locks, anti-climbing devices, warning signs and other security measures required to protect the equipment from vandalism, theft and unauthorised interference.

ix. **Environmental Controls:** Implement measures for controlling dust, noise, erosion, waste, accidental spills and disturbance of vegetation and watercourses.

x. **System Integration:** Connect the monitoring stations, DMS, communication equipment and sirens into a coordinated warning system.

xi. **Testing and Commissioning:** Test sensor accuracy, data transmission, power supply, communication links, siren activation and audible coverage before commissioning the system.

xii. **Community Awareness:** Inform surrounding communities about the purpose of the installations, siren signals, testing schedules, evacuation procedures and appropriate responses to warnings.

3.4.3 Operational Phase

The operational phase will involve continuous monitoring of environmental conditions, analysis of incoming data, dissemination of warnings and routine maintenance of the system.

i. **Hydrometeorological Monitoring:**

- Continuously monitor rainfall through the Automatic Rain Gauges;
- Monitor river and reservoir water levels through the Automatic Water-Level Recorders;
- Collect data at established intervals;
- Compare observed conditions against established warning thresholds; and
- Monitor equipment status, communication connectivity and power availability.

ii. **Data Management and Analysis:**

- Receive and store monitoring data through the DMS;
- Display real-time and historical monitoring information;
- Analyse trends in rainfall, river levels and reservoir conditions;
- Generate automated alerts when established thresholds are reached; and

- Maintain secure backups of monitoring and warning records.

iii. **Alert Verification:**

- Verify automatically generated alerts before issuing public warnings;
- Compare information from different monitoring stations and other relevant sources;
- Assess the likely magnitude, location and timing of the hazard;
- Determine the appropriate warning level; and
- Document the basis for activating or withholding a public warning.

iv. **Warning Dissemination:**

- Activate mini and large sirens in areas likely to be affected;
- Disseminate warnings through SMS, radio, television and other available communication channels;
- Notify disaster-management institutions, local authorities, emergency services and community leaders;
- Provide clear instructions on evacuation routes, safe areas and required actions; and
- Issue updated warnings as the situation develops.

v. **Confirmation and Feedback:**

- Obtain confirmation that warnings have reached responsible authorities and affected communities;
- Maintain communication with community representatives and emergency-response teams;
- Identify areas where warnings may not have been received;
- Activate alternative communication methods where necessary; and
- Record feedback on warning clarity, coverage and community response.

vi. **Equipment Inspection and Maintenance:**

- Inspect monitoring stations, sirens, communication units and power systems;
- Clean solar panels, sensors and equipment enclosures;
- Calibrate rainfall and water-level monitoring instruments;
- Repair or replace damaged components;
- Test batteries, cables, antennas and communication links; and
- Maintain vegetation around installations to ensure access and equipment performance.

vii. **Siren Testing and Emergency Exercises:**

- Conduct scheduled tests of mini and large sirens;
- Inform communities in advance of planned tests;
- Conduct emergency simulations and evacuation exercises;
- Assess siren audibility and warning-message clarity; and
- Correct any weaknesses identified during testing.

viii. **Security and Access Control:**

- Restrict access to equipment and control facilities to authorised personnel;
- Inspect fences, locks, signs and protective enclosures;
- Report vandalism, theft or unauthorised interference;
- Maintain records of personnel accessing the installations; and
- Engage local communities in protecting the equipment.

ix. **Training and Capacity Building:**

- Train control-centre operators and maintenance personnel;

- Train local authorities and emergency-response institutions in warning procedures;
- Conduct awareness programmes for affected communities;
- Provide refresher training when procedures or technologies are updated; and
- Ensure authorised personnel understand system activation and emergency communication protocols.

x. **Performance Evaluation:**

- Evaluate the accuracy and reliability of monitoring data;
- Assess the speed of alert generation and warning dissemination;
- Review siren coverage and communication-network performance;
- Evaluate community understanding and response to warnings; and
- Update warning thresholds, operational procedures and maintenance programmes where necessary.

xi. **Waste Management:**

- Separate general, recyclable, electronic and hazardous waste;
- Store used batteries and damaged electronic equipment securely;
- Transfer electronic waste and batteries to authorised recyclers or waste handlers;
- Prevent indiscriminate disposal and open burning of waste; and
- Maintain waste-transfer and disposal records.

3.4.4 Decommissioning Phase

The EWS installations may be decommissioned when they reach the end of their service life, become obsolete or are replaced by improved technology. Decommissioning will be undertaken in accordance with an approved closure and site-restoration plan. Activities will include:

a. Developing procedures for safely shutting down the monitoring, communication, warning and power systems;

b. Informing regulatory authorities, local authorities and affected communities before deactivating any monitoring or warning installation;

c. Maintaining alternative warning arrangements during the transition to replacement systems;

d. Disconnecting grid electricity, solar-power systems, batteries and communication links;

e. Removing Automatic Rain Gauges, Automatic Water-Level Recorders, sirens, antennas, telemetry units, solar panels and associated equipment;

f. Dismantling poles, masts, equipment cabinets, fences and other supporting structures that are no longer required;

g. Removing concrete foundations where they may interfere with future land use or create safety hazards;

h. Separating reusable, recyclable, electronic and hazardous materials;

i. Transferring used batteries, electronic equipment and contaminated materials to authorised recyclers or waste-management facilities;

j. Backfilling excavations and removing construction debris and surplus materials;

k. Rehabilitating disturbed areas through grading, replacement of topsoil and revegetation using appropriate local species;

l. Restoring drainage patterns and stabilising areas susceptible to erosion;

m. Inspecting the restored sites to identify any remaining safety or environmental risks;

n. Undertaking post-decommissioning monitoring where necessary; and

o. Submitting closure and environmental-restoration reports to the relevant regulatory authorities.

4 PROJECT ALTERNATIVES

4.1 Project Need

Communities downstream of Kariba Dam are exposed to riverine fluctuations and flooding arising from controlled and uncontrolled reservoir releases, extreme rainfall, rapid changes in river levels and, in a worst-case scenario, dam failure. Many exposed settlements, farms, lodges and public facilities are located in remote areas with limited access to timely and reliable warning information. This increases the risk of loss of life, displacement, damage to property and infrastructure, disruption of livelihoods and harm to wildlife and natural resources. The EWS project is therefore required to strengthen hydrometeorological monitoring, flood forecasting and the timely dissemination of clear and actionable warnings to potentially affected populations in Zambia and Zimbabwe. Through automatic monitoring stations, large and mini sirens, telecommunications and community-based communication channels, the project will enable residents, authorities and emergency-response institutions to take precautionary action before hazardous conditions reach exposed areas.

The project will also improve coordination among ZRA, disaster-management authorities, local administrations, traditional leaders, emergency services and communities. Its implementation will strengthen disaster preparedness, enhance community resilience and support safer management of the Zambezi River downstream of Kariba Dam. Temporary employment and local procurement opportunities may arise during construction, but the project's principal justification is the protection of lives, livelihoods, property and essential services.

4.2 Site Location Alternatives

The proposed EWS will comprise approximately 50 installations distributed across selected locations downstream of Kariba Dam in Zambia and Zimbabwe. The installations will include large sirens, mini sirens, Automatic Rain Gauges (ARGs), Automatic Water Level Recorders (AWLRs) and Automatic Dam Monitoring Stations (ADMSs). Site selection considered flood-warning coverage, elevation, accessibility, land ownership, security, proximity to communities, communication connectivity, exposure to flooding, wildlife movement, environmental sensitivity and ease of operation and maintenance. Wherever the original coordinates presented environmental, social, safety or land-access constraints, alternative positions within the same general coverage area were assessed.

Table 12: Site-location alternatives considered

Alternative considered	Advantages	Limitations	Decision
Original coordinates identified during preliminary EWS design	Based on the initial warning-coverage and hydrometeorological-monitoring requirements; generally positioned within or near flood-prone communities; reduces the	Some locations are close to roads, low-lying ground, wildlife movement routes, tourism facilities or privately controlled land; certain coordinates have	Selected where confirmed as environmentally, socially and technically suitable

Alternative considered	Advantages	Limitations	Decision
	need for major redesign of the EWS network	limited access, security or space	
Alternative locations within public institutional compounds, including schools, health facilities, police stations and meteorological stations	Existing security and access; known land-management authority; reduced risk of vandalism; convenient access for operation and maintenance; existing institutional presence can support warning dissemination	Schools and health facilities are sensitive receptors; construction and siren testing may disturb learners, patients, staff and visitors; formal institutional permission is required	Selected at locations such as Musokwe Health Clinic, Manyepa School, Chiawa Community Police Station and Kanyemba Meteorological Station, subject to permission and mitigation
Alternative locations within lodge or tourism premises	Secure and regularly maintained; accessible to staff; can provide warning coverage to visitors, workers and surrounding areas; existing communication and solar infrastructure may be available	Potential visual effects; disturbance to guests; wildlife interactions; access may be controlled; requires agreement with lodge management and wildlife authorities	Selected where management supports the project and an appropriate location can be agreed
Locations within protected areas or natural habitats	Improves warning coverage for remote camps, tourism facilities and people operating within protected landscapes; may support communication during flood emergencies in otherwise isolated areas	Potential interference with wildlife movement; vegetation clearance; restricted access; approval required from DNPW or ZimParks; construction and testing may disturb wildlife	Conditionally selected following ecological review and approval by the responsible protected-area authority
Open community or roadside land	Can provide broad warning coverage; visible and accessible to surrounding settlements; usually provides adequate space for the 4 m × 4 m tower footprint	Possible land-ownership disputes; exposure to vandalism; interference with traffic, pedestrians, vendors and future development; may be located on low-lying or flood-prone ground	Selected only after confirming ownership, elevation, safety, security and community acceptance
Elevated ground within the same warning-coverage area	Reduces exposure to seasonal flooding; improves siren propagation and communication coverage; can provide safer access during flood conditions	May require a minor change to the original coordinates; could require additional access arrangements or limited vegetation clearance	Preferred where the original coordinates are located on low-lying or unsafe ground
Previously disturbed or developed land	Minimises vegetation loss and habitat disturbance; existing access and utilities may be available; generally	Space may be restricted and existing utilities may constrain tower positioning	Preferred wherever warning and monitoring

Alternative considered	Advantages	Limitations	Decision
	easier to secure and maintain		requirements can still be achieved
Undisturbed greenfield location	May provide sufficient space and flexibility in tower positioning	May require vegetation clearing, access-road development and disturbance of wildlife habitat; could introduce new land requirements	Not preferred unless no technically suitable disturbed or institutional site is available

Preferred Site-location Approach

The preferred approach is to retain the original coordinates where they meet technical, environmental and social requirements. Where constraints are identified, the installation will be moved a short distance within the same warning-coverage area, preferably onto elevated, previously disturbed and secure land. The final sites will be confirmed through technical verification, stakeholder consultation and written approval from the relevant landholder or managing authority. No physical or economic displacement is anticipated. Each installation will generally require only a small footprint of approximately 4 m × 4 m, together with temporary working space during construction.

4.3 Technology Alternatives

The EWS requires an integrated combination of hazard monitoring, data transmission, warning dissemination and community-response technologies. Reliance on a single technology would create a risk of system failure and could exclude communities with limited access to electricity, mobile networks or digital communication services. A multi-technology and redundant system has therefore been selected.

Table 13: EWS technology alternatives considered

Alternative considered	Advantages	Limitations	Decision
Automatic Rain Gauges	Provide real-time rainfall measurements; support catchment monitoring and flood forecasting; can operate continuously in remote areas; reduce dependence on manual observations	Require calibration, maintenance, telemetry and protection against wildlife, vandalism and severe weather	Selected
Automatic Water Level Recorders	Provide continuous river-level data; support identification of rapid changes in river conditions; improve flood forecasting and verification of warning thresholds	Require installation near water; may be exposed to flooding, sediment, debris and restricted riverbank access	Selected

Alternative considered	Advantages	Limitations	Decision
Automatic Dam Monitoring Stations	Provide continuous monitoring of relevant dam-safety parameters; allow early identification of abnormal conditions; support informed operational decisions	Higher capital and maintenance requirements; require specialist installation, reliable data transmission and trained personnel	Selected
Large electronic sirens	Provide wide-area audible warning coverage; effective in settlements where access to mobile phones or radio is limited; can communicate urgent danger rapidly	Audible coverage is affected by terrain, wind, vegetation and building density; may disturb wildlife and sensitive receptors; warning tones must be understood by communities	Selected for larger settlements and areas requiring broader coverage
Mini electronic sirens	Appropriate for smaller villages, institutions, camps and lodges; lower energy demand; smaller installation footprint	More limited coverage than large sirens; several units may be required across dispersed settlements.	Selected
Manual sirens, bells or drums	Low cost; familiar to some communities; can operate without electricity or telecommunications	Limited range; dependent on the presence and response of designated persons; difficult to standardise and verify	Not selected
SMS and cell-broadcast alerts	Rapid dissemination to large numbers of mobile-phone users; messages can include instructions; allows targeted warning distribution	Dependent on network coverage, power availability, handset ownership and updated contact information; messages may be delayed or overlooked	Selected as one of several warning channels
Radio and television announcements	Can reach large populations and provide detailed instructions; useful for repeated updates	Dependent on broadcast coverage, electricity and audiences having devices switched on	Selected as a supplementary warning channel
Mobile applications and internet platforms	Allow rapid sharing of maps, forecasts and updates; useful for government agencies, institutions and connected users	Internet access and smartphone ownership are uneven; unsuitable as the sole method for remote communities	Selected for institutional and connected users
Community focal persons and traditional leadership structures	Trusted locally; can relay warnings in local languages; assist vulnerable households and verify receipt of warnings	Effectiveness depends on training, availability and clear communication procedures	Selected as an essential component of the people-centred warning system
Single-mode warning system	Simpler to install and manage; comparatively lower initial cost	Creates a single point of failure and may exclude people without access to the selected technology	Not selected

Alternative considered	Advantages	Limitations	Decision
Integrated multi-channel warning system	Provides redundancy; reaches different population groups; combines sirens, mobile communication, radio and community structures; improves confirmation that warnings were received	Higher initial cost; requires institutional coordination, testing, maintenance and standard operating procedures	Preferred and selected

Preferred Technology

The preferred technology is an integrated, end-to-end and people-centred EWS. Automatic monitoring instruments will collect hydrological and meteorological information, while a combination of large sirens, mini sirens, mobile alerts, radio communication and community structures will disseminate warnings. The approach supports the objective of reaching affected persons through at least three communication modes and reduces the risk that failure of one component will compromise the entire warning chain.

4.4 Energy Supply Alternatives

The EWS installations will require reliable energy for sensors, telemetry equipment, communication devices, control units and electronic sirens. Because several sites are remote or experience unreliable grid electricity, energy-source reliability was considered together with emissions, operating cost, maintenance and resilience during flood emergencies.

Table 14: Energy alternatives considered

Alternative considered	Advantages	Limitations	Decision
Grid electricity	Can provide continuous power where reliable connections exist; established maintenance arrangements; suitable for installations within developed institutional premises	Grid outages may occur during storms or flood emergencies; some remote locations are not connected; connection costs may be high	Selected where available, with backup power
Solar photovoltaic system with battery storage	Renewable and suitable for remote locations; low operating emissions; independent of the national grid; relatively low maintenance requirements; can maintain operation during emergencies	Higher initial cost; batteries require periodic replacement; solar panels may be damaged or stolen; performance can be reduced by prolonged cloud cover, dust or shading	Preferred and selected as the principal source for remote installations
Hybrid grid-solar-battery system	Provides high reliability and redundancy; reduces dependence on a single source; batteries can	Higher installation cost and more complex control and maintenance requirements	Selected for critical installations where grid

Alternative considered	Advantages	Limitations	Decision
	maintain operation during power outages		power is available
Diesel or petrol generator	Can provide high power output and emergency backup; widely understood and relatively easy to procure	Produces air emissions, noise and greenhouse gases; requires fuel storage and regular servicing; fuel may be unavailable during emergencies	Limited to temporary construction use or exceptional emergency backup
Standalone battery system	Simple and quiet; no direct operational emissions; suitable for low-power sensors	Limited operating period; requires replacement or recharging; unsuitable as the sole long-term source for sirens and communication equipment	Selected only as part of a solar or hybrid system
Wind energy	Renewable and potentially useful in consistently windy areas	Site-specific wind conditions may be insufficient; moving components require maintenance; towers could create additional visual and wildlife risks	Not selected
Fossil-fuel-based permanent power supply	Can provide dependable energy where fuel is continuously available	Produces emissions, noise and fuel-handling risks; high recurring costs; unsuitable for unattended remote installations	Not selected

Preferred Energy Source

Solar photovoltaic systems with battery storage are preferred for remote EWS locations. Grid electricity may be used at developed sites such as police stations, clinics, schools, lodges and meteorological stations, but critical equipment will be provided with battery or solar backup. The energy system will be sized to maintain warning and monitoring functions during grid failures and adverse weather conditions.

4.5 Equipment and Construction-material Alternatives

The EWS does not require conventional industrial raw materials. Its principal inputs will comprise prefabricated towers, monitoring instruments, sirens, solar panels, batteries, control equipment, communication devices, cables, concrete, reinforcement steel and security infrastructure. Alternatives were assessed according to durability, environmental effects, wildlife safety and ease of maintenance.

Table 15: Equipment and construction-material alternatives

Alternative considered	Advantages	Limitations	Decision
Galvanised-steel towers	Durable; resistant to corrosion; structurally suitable for sirens, antennas and solar equipment; comparatively easy to inspect and maintain	Requires appropriate foundations; may create visual effects; corrosion may occur if the protective coating is damaged	Selected

Alternative considered	Advantages	Limitations	Decision
Timber towers	Lower initial cost; materials may be locally available	Vulnerable to fire, termites, decay and severe weather; shorter operational life; may require harvesting of natural timber	Not selected
Reinforced-concrete tower structures	Durable and resistant to corrosion and fire	Larger footprint; greater material use; difficult to modify, transport and construct at remote sites	Not preferred
Precast or site-mixed reinforced-concrete foundations	Strong and durable; suitable for supporting towers under wind loading; limited maintenance requirements	Cement production has embodied carbon; excavation may disturb soil and nearby vegetation	Selected, with foundation design adapted to local ground conditions
Lithium-based batteries	Longer service life; high energy density; reduced frequency of replacement; suitable for solar systems	Higher initial cost; require specialised end-of-life management and protection from excessive heat	Preferred, subject to approved specifications and disposal arrangements
Lead-acid batteries	Widely available; lower purchase cost; established technology	Shorter life; contain hazardous lead and acid; require careful containment, handling and recycling	May be used where specified, subject to strict handling and licensed recycling
Standard security fencing	Protects installations from vandalism and unauthorised access	May obstruct or injure wildlife in protected areas	Selected only in developed or community locations where wildlife movement is not a concern
Wildlife-friendly protective barriers	Can protect equipment while reducing risks to wildlife; can be adapted to site conditions	Design must be agreed with wildlife authorities; some fencing types may agitate elephants or alter movement	Selected where recommended by DNPW, ZimParks or site management
Electric fencing	May deter some animals and unauthorised entry	Can injure or agitate wildlife; elephants may damage the fence and nearby infrastructure; requires maintenance and power	Not generally preferred; use only where specifically approved
Extensive vegetation clearing	Creates unrestricted construction space and visibility around equipment	Causes unnecessary habitat loss, erosion and visual disturbance	Not selected
Limited clearing confined to the	Minimises habitat disturbance; reduces	Requires careful setting-out and supervision	Selected

Alternative considered	Advantages	Limitations	Decision
installation footprint	erosion and maintains surrounding vegetation		

4.6 Waste Management Alternatives

Construction of the EWS will generate relatively small quantities of waste, including excavated material, cement bags, packaging, cable offcuts, scrap metal, food waste and general refuse. Operational waste will mainly consist of replaced batteries, damaged solar panels, electronic components, sensors, cables and maintenance materials.

Table 16: Waste-management alternatives considered

Alternative considered	Advantages	Limitations	Decision
Waste avoidance and procurement control	Reduces material use, transport requirements and disposal costs; prevents unnecessary waste generation	Requires accurate material estimates and supplier coordination	Preferred and selected
Reuse of suitable excavated material	Reduces the volume requiring disposal; useful for backfilling and reinstatement	Unsuitable material cannot be reused; contaminated material would require separate management	Selected
Segregation of waste at source	Enables recycling and safe handling; prevents mixing of hazardous and non-hazardous waste	Requires labelled containers, supervision and transport arrangements	Selected
Recycling of scrap metal, cables, packaging and suitable plastics	Conserves resources and reduces disposal volumes	Recycling services may be limited in remote areas; temporary storage may be required	Selected where licensed facilities are available
Supplier take-back for batteries, solar panels and electronic equipment	Promotes safe recovery of hazardous and electronic components; reduces the risk of informal disposal	Depends on supplier agreements and availability of approved recycling facilities	Preferred and selected
Disposal through licensed waste facilities	Provides controlled disposal and regulatory accountability	Long transport distances may be required from remote sites	Selected for waste that cannot be reused or recycled
Burial or burning of waste at installation sites	Low immediate transport cost	May contaminate soil, surface water and groundwater; creates smoke, fire and wildlife risks; inconsistent with good environmental practice	Prohibited
Abandonment of obsolete equipment at sites	Avoids immediate removal costs	Creates safety, visual and pollution risks; may release hazardous substances	Prohibited

Preferred Waste-management Approach

The project will apply the waste-management hierarchy of avoidance, reduction, reuse, recycling and controlled disposal. Waste will not be burned, buried or abandoned at installation sites. Batteries, damaged solar panels and electronic equipment will be stored securely and transferred to suppliers or appropriately licensed waste-management facilities.

4.7 Pollution-Abatement Alternatives

The EWS will not involve continuous industrial processing and is therefore not expected to generate significant operational emissions or effluent. Potential pollution will mainly arise from construction dust, vehicle exhaust emissions, noise, accidental fuel or oil spills, concrete works, vegetation clearance and periodic siren testing.

Table 17: Pollution-abatement alternatives considered

Alternative considered	Advantages	Limitations	Decision
Use of existing roads and access tracks	Minimises vegetation loss, soil disturbance, dust and erosion; reduces construction costs	Some existing roads are seasonally inaccessible or in poor condition	Preferred and selected
Construction of new permanent access roads	Provides direct and reliable access	Causes additional vegetation clearance, erosion, habitat fragmentation and land disturbance	Not selected unless essential for safe access
Watering or damping of active dusty surfaces	Reduces dust affecting communities, workers and vegetation	Water availability may be limited; excessive watering may cause erosion or muddy conditions	Selected where dust becomes significant
Covering and securing transported materials	Prevents dust and material loss during transport	Requires contractor supervision	Selected
Use of well-maintained vehicles and equipment	Reduces exhaust emissions, noise, leaks and breakdowns	Requires regular inspection and maintenance	Selected
Restriction of noisy construction activities to daytime hours	Reduces disturbance to communities, schools, clinics, lodges and wildlife	May extend the construction programme	Selected
Uncontrolled full-volume siren testing	Confirms maximum audible range	May alarm communities, disturb patients and learners, affect lodge guests and cause wildlife disturbance	Not selected
Controlled siren testing following notification	Allows confirmation of system performance while reducing alarm and disturbance; enables coordination with communities and institutions	Requires advance planning and stakeholder communication	Selected

Alternative considered	Advantages	Limitations	Decision
Remote diagnostics and silent equipment testing	Reduces the need for frequent audible tests and site visits; minimises disturbance	Cannot completely replace periodic audible testing of sirens	Selected as the principal routine-testing method
Spill-prevention and response measures	Protects soil, surface water and groundwater; reduces clean-up requirements	Requires training, suitable storage and availability of spill kits	Selected
Uncontained refuelling and maintenance near rivers	Operationally convenient	Creates a high risk of water and soil contamination	Prohibited
Reinstatement of temporarily disturbed areas	Reduces erosion, visual effects and habitat degradation	Requires post-construction monitoring	Selected

Preferred Pollution-control Approach

Pollution prevention will be achieved primarily through careful site selection, a limited construction footprint, use of existing access routes, properly maintained equipment, controlled material handling, spill-prevention measures and prompt reinstatement of disturbed ground. Construction near rivers will be carefully controlled, and fuels, oils, cement and hazardous materials will not be stored or handled close to the riverbank. Siren tests and mock drills will be planned in consultation with affected communities and sensitive institutions. At schools and healthcare facilities, audible testing will be undertaken only after advance notification and at times agreed with the responsible management. Within protected areas and lodge environments, testing will be coordinated with DNPW, ZimParks and facility management to minimise disturbance to wildlife, visitors and staff.

5 DESCRIPTION OF THE BASELINE ENVIRONMENT

5.1 Climate

The project area experiences a distinct seasonal climate characterised by a wet season and a prolonged dry season. Rainfall is mainly concentrated between November and April, with the highest precipitation generally occurring from December to February. Rainfall declines considerably from May and remains very low between June and September. Temperatures are lowest during the cool, dry months of June and July and increase progressively toward the hot season, with the highest temperatures generally recorded between September and November. Historical rainfall records for Zambia from 1901 to 2022 indicate considerable year-to-year variability, with annual precipitation generally fluctuating around 1,000 mm. Some years recorded rainfall exceeding 1,200 mm, while drier years received less than 850 mm. The long-term rainfall distribution also indicates changes in the amount and variability of precipitation between 1951 and 2020. Such variability may result in alternating periods of drought, intense rainfall and unusually high river flows.

These climatic conditions are particularly relevant to the proposed Early Warning System because heavy rainfall within the wider Zambezi River Catchment can rapidly increase tributary flows, reservoir inflows and downstream river levels. The concentration of rainfall within a relatively short season may also increase the likelihood of flash floods and riverine flooding, particularly when soils are already saturated or when heavy rainfall coincides with controlled or uncontrolled reservoir releases. The proposed installation of Automatic Rain Gauges, Automatic Water-Level Recorders and the Data Management System will strengthen the continuous monitoring of these climatic and hydrological conditions. The information collected will support flood forecasting, identification of abnormal rainfall and river-level conditions, and timely dissemination of warnings to potentially affected communities.

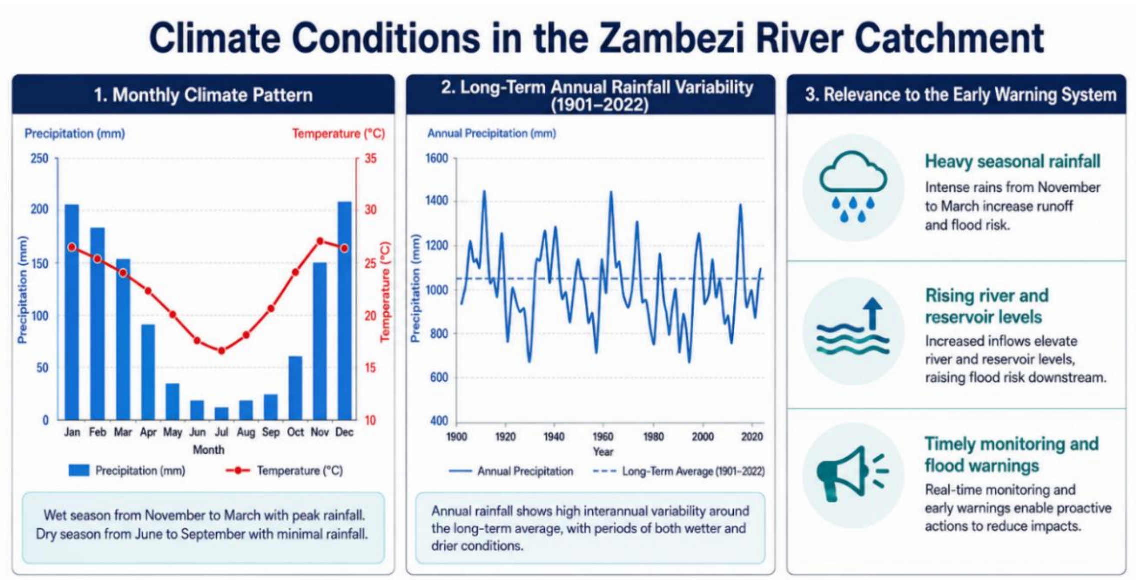

Figure 11: Seasonal climate patterns and their relevance to flood early warning

5.2 Rainfall

The project area experiences a strongly seasonal rainfall regime influenced principally by the movement of the Inter-Tropical Convergence Zone (ITCZ). The rainy season generally extends from October or November to March or April, while the period from May to August is predominantly dry. Rainfall increases as the tropical rain belt moves southwards over the Zambezi Basin and decreases as it retreats northwards. The concentration of rainfall within a relatively short period creates significant seasonal variations in river discharge, reservoir inflows, groundwater recharge and floodplain inundation.

On the Zambian side, annual rainfall generally varies from approximately 700 mm in the southern parts of the country to about 1,400 mm in the north. The southern project districts, including Siavonga, Chirundu, Kafue, Chikankata and Luangwa, are comparatively dry and experience lower and more variable rainfall than northern Zambia. During the wettest months, rainfall may range from approximately 150 mm to 300 mm per month. From May to August, however, rainfall is extremely low or virtually absent. The baseline report specifically characterises communities around Siavonga and Lake Kariba as occurring within a dry climatic environment where limited rainfall contributes to soil erosion, low soil fertility and difficult agricultural conditions.

Zimbabwe similarly experiences a distinct wet season from approximately October to March. Based on the 1991-2020 climatological period presented in the report, mean monthly precipitation ranges from about 2 mm during the driest months to approximately 160 mm during the wettest months, producing an annual average of roughly 670 mm. This demonstrates that the Zimbabwean portion of the project area is generally semi-arid and susceptible to prolonged dry periods, although intense rainfall events may still cause rapid runoff, river-level increases and localised flooding.

Rainfall in both Zambia and Zimbabwe is subject to considerable interannual variability. El Niño conditions generally produce below-average rainfall over southern Zambia and Zimbabwe, increasing the likelihood of drought and reduced reservoir inflows. La Niña conditions tend to produce wetter-than-average conditions and may increase the potential for flooding. Rainfall in Zimbabwe is also influenced by the Indian Ocean Dipole, with a positive Indian Ocean Dipole often associated with rainfall deficits. Consequently, total annual rainfall alone is not an adequate indicator of flood risk; rainfall intensity, duration, spatial distribution, antecedent soil moisture and catchment conditions must also be considered.

This rainfall pattern is particularly important to the EWS because heavy precipitation within the Kariba and downstream sub-catchments can rapidly increase surface runoff, tributary discharge, reservoir inflows and Zambezi River levels. When catchment rainfall coincides with high reservoir levels or controlled releases from Kariba Dam, downstream flood risk may increase considerably. The baseline report therefore recommends real-time monitoring of rainfall within the relevant sub-catchments and integration of rainfall data into hydrological rainfall-runoff models and hydraulic flood-simulation models.

5.3 Relative Humidity

Relative humidity in the project area is closely associated with the seasonal rainfall cycle. Humidity is generally highest during the rainy season, when moist air associated with the ITCZ dominates the region, cloud cover increases and rainfall becomes frequent. During this period, atmospheric moisture remains comparatively high, particularly during the night and early morning. Humidity may decline during the warmer afternoon hours as air temperatures rise, even where the absolute amount of atmospheric moisture remains high.

Relative humidity progressively decreases after the rainy season as rainfall declines and the dry season becomes established. During the cool, dry period from approximately May to August, morning humidity may remain moderate because of lower temperatures, dew formation and the influence of large water bodies such as Lake Kariba and the Zambezi River. Afternoon humidity, however, is generally lower as the air warms and the land surface dries.

The lowest relative humidity conditions are likely during the late dry and hot season, particularly from August to October or November. During this period, high temperatures, dry soils, limited cloud cover and the absence of rainfall increase atmospheric dryness. These conditions promote rapid moisture loss from soils and vegetation, increase evaporation and elevate the risk of dust generation and vegetation fires. The contrast between relatively humid riverine and lakeshore environments and drier upland areas may also create local variations across the project area.

Humidity is relevant to the EWS infrastructure because prolonged high moisture levels can encourage corrosion, condensation and deterioration of electrical connections, sensors and communication equipment. Conversely, very dry conditions may increase dust accumulation on sensors, solar panels and equipment enclosures. Monitoring and warning equipment should therefore be weatherproof, corrosion-resistant and adequately sealed, while routine maintenance should include inspection for moisture ingress, corrosion and dust accumulation.

5.4 Wind Conditions

Wind conditions within the project area vary according to season, topography and proximity to Lake Kariba, the Zambezi River and surrounding escarpments. Surface winds are generally lighter during the wet season but may become strong and highly variable during thunderstorms. Convective storms can produce sudden wind gusts, turbulence and rapid changes in wind direction. Such conditions may occur immediately before or during intense rainfall and can damage weak structures, interrupt communications or affect solar-powered installations.

During the dry season, winds may become more persistent, especially from the cool season into the hot period. Dry-season winds passing over exposed ground can lift loose soil and generate dust, particularly along unpaved access roads, cleared sites and sparsely vegetated areas. The baseline report consequently recommends the use of water spraying or other dust-suppression measures during construction, particularly under dry and windy conditions.

Local wind patterns may be modified by the Zambezi Valley's topography. Valleys and escarpments can channel winds along particular directions, while daytime heating and nighttime cooling may produce local upslope, downslope, lake-breeze and land-breeze circulations. Areas close to Lake Kariba may therefore experience wind conditions that differ from those of inland or elevated locations. Because the EWS installations are distributed across several districts, prevailing wind direction and site-specific exposure should be confirmed during detailed site surveys.

5.5 Sunshine and Solar radiation

Sunshine duration is strongly influenced by seasonal changes in cloud cover. The dry season generally experiences long periods of clear skies and abundant sunshine, particularly from May to October. The late dry season is normally characterised by intense solar radiation, high daytime temperatures and limited cloud cover. These conditions contribute to rapid drying of soils and vegetation and increase evaporation from Lake Kariba, rivers and exposed water surfaces.

Sunshine hours decrease during the rainy season because of increased cloud cover, atmospheric moisture and frequent storm development. Nevertheless, the rainy season does not consist entirely of overcast conditions; periods of strong sunshine may occur between rainfall events. High humidity combined with solar heating can contribute to the development of convective storms, which may produce intense, short-duration rainfall and sudden increases in runoff.

The high level of sunshine across the project area provides favourable conditions for powering remote EWS installations using solar photovoltaic systems. Solar panels can support Automatic Rain Gauges, Automatic Water-Level Recorders, telemetry equipment and sirens in locations where grid electricity is unavailable or unreliable. Battery storage will, however, be required to maintain continuous operation at night and during extended periods of cloud cover in the rainy season.

Solar-system sizing should account for seasonal reductions in solar radiation, equipment energy demand, battery autonomy, temperature effects and potential shading from trees, buildings or terrain. Panels should be oriented to maximise solar exposure and installed where they will not be shaded during critical daylight hours. Routine cleaning will also be necessary because dust accumulation during the dry season can reduce solar-panel efficiency.

5.6 Ecological Resources

5.6.1 Ecological Resources within the Project Area

The proposed Early Warning System covers an ecologically important section of the Zambezi River extending from downstream of Kariba Dam to the confluence with the Luangwa River. The area includes portions of Zambia and Zimbabwe and contains an interconnected landscape of woodlands, riverine forests, grasslands, floodplains, wetlands, rivers, pools and protected wildlife areas. These habitats support diverse plant and animal communities and provide essential ecosystem services, including riverbank stabilisation, groundwater recharge, flood regulation, nutrient cycling, carbon storage and maintenance of wildlife migration routes.

Vegetation and Habitat Types

Vegetation across the project area is principally composed of miombo woodland, mopane woodland, munga or savanna woodland, dry deciduous forest, riverine forest, floodplain grassland, wetland vegetation and scattered thickets. The distribution of these vegetation types is influenced by rainfall, soil conditions, elevation, distance from the Zambezi River and the seasonal flooding regime.

Miombo woodland

Miombo woodland is one of the most extensive vegetation types on the Zambian side. It is characterised by trees belonging mainly to the genera BRACHYSTEGIA, JULBERNARDIA and ISOBERLINIA. Important species include miombo or msasa (BRACHYSTEGIA SPICIFORMIS), mupfuti (BRACHYSTEGIA BOEHMII), Brachystegia FLORIBUNDA and JULBERNARDIA GLOBIFLORA.

Most miombo trees shed their leaves during the dry season, allowing sunlight to reach the woodland floor and encouraging the growth of grasses, herbs and shrubs. This understorey provides grazing and browsing resources for elephants, antelopes, zebras and other herbivores. Miombo woodland also provides nesting, feeding and shelter habitats for numerous bird, reptile, insect and small-mammal species.

Mopane woodland

Mopane woodland, dominated by COLOPHOSPERMUM MOPANE, is widespread in the hotter and drier sections of the Zambezi Valley, particularly around Chirundu and Siavonga in Zambia and Mana Pools and adjoining safari areas in Zimbabwe. Mopane is drought-resistant and adapted to high temperatures, seasonal water shortages and relatively nutrient-rich soils.

Mopane leaves provide an important dry-season food resource for elephants, giraffes and several antelope species. Mopane trees also support mopane worms, which have ecological importance and provide a source of food and income for some communities. Areas farther from the Zambezi River in Mana Pools are characterised by mopane woodland, dense jesse bush and scattered baobab trees.

Munga and savanna woodland

Munga woodland is an open, park-like savanna vegetation type characterised by scattered or grouped deciduous trees, generally dominated by ACACIA—now principally classified under Vachellia and SENEGALIA—together with COMBRETUM and TERMINALIA species. Trees may reach approximately 18 metres and can occur over a grass-dominated understorey.

In the lower Zambezi and Luangwa valleys, better-drained and elevated areas tend to support COMBRETUM-TERMINALIA woodland, while lower and less freely drained areas are more commonly associated with thorn-dominated vegetation. These open woodlands provide important feeding habitats for antelopes, buffaloes, elephants and other herbivores and hunting grounds for lions, leopards, cheetahs and African wild dogs.

Dry deciduous forest and thickets

Dry deciduous forest occurs as woodland or forest with a predominantly deciduous canopy and a shrub or thicket layer beneath it. The baseline assessment identifies Baikiaea forest and Itigi thicket as important dry-forest formations. Baikiaea forest has a canopy approximately 9-18 metres high, typically composed of BAIKIAEA PLURIJUGA and PTEROCARPUS ANTUNESII. Other plants include COMBRETUM COLLINUM, locally emergent Entandrophragma CAUDATUM and a deciduous thicket layer comprising shrubs and climbing plants. Itigi thicket consists of deciduous and semi-deciduous woodland species, including BAPHIA MASSAIENSIS, BOSCIA ANGUSTIFOLIA, BURRTIA PRUNOIDES, BUSSEA MASSAIENSIS, DIOSPYROS MWEROENSIS and the cactus-like succulent EUPHORBIA CANDELABRUM. The dense understorey provides cover and refuge for small mammals, reptiles, birds and invertebrates.

Riverine forest

Riverine forests occur along the Zambezi River, its tributaries and associated floodplain channels. These forests are particularly important in the Kafue, Chirundu, Lower Zambezi and Luangwa areas. They contain mixtures of evergreen and deciduous trees adapted to moist alluvial soils, including sycamore fig (FICUS SYCOMORUS), Natal mahogany (TRICHILIA EMETICA), winter thorn (FAIDHERBIA ALBIDA), jackalberry (DIOSPYROS MESPILIFORMIS) and river bushwillow (COMBRETUM ERYTHROPHYLLUM).

Riverine forests provide shade, bank stability and cooler microclimates. They serve as feeding, breeding and refuge habitats for birds, primates, antelopes and other terrestrial fauna. They also provide important habitat at the interface between land and water for hippopotamuses, crocodiles and numerous aquatic and semi-aquatic species.

Floodplains, grasslands and wetlands

Seasonal flooding creates extensive floodplain habitats along sections of the Zambezi River. Floodwaters deposit nutrient-rich alluvial sediments that sustain productive grasslands and riverine woodland, particularly in Mana Pools and Lower Zambezi National Park. The floodplains provide grazing areas for buffaloes, zebras, impalas, waterbucks, elands and other herbivores. Wetlands, river channels, pools and backwaters support common reeds (PHRAGMITES AUSTRALIS), papyrus (CYPERUS PAPYRUS), Nile cabbage (PISTIA STRATIOTES), grasses and other water-associated plants. These habitats provide breeding and feeding grounds for fish, crocodiles, hippopotamuses, waterbirds and amphibians. They also moderate floods, retain sediment, recycle nutrients and recharge groundwater.

Flora on the Zambian Side

The Zambian project districts including Siavonga, Chirundu, Kafue, Chikankata and Luangwa support diverse native plant communities adapted to semi-arid and subtropical conditions. Vegetation is generally denser along the Zambezi River and its tributaries because alluvial soils and moisture availability support larger trees and more diverse understorey vegetation.

Important species identified in the baseline assessment include:

- Miombo or msasa (BRACHYSTEGIA SPICIFORMIS);
- Mupfuti (BRACHYSTEGIA BOEHMII);
- Msasa (BRACHYSTEGIA FLORIBUNDA);
- JULBERNARDIA GLOBIFLORA;
- Mopane (COLOPHOSPERMUM MOPANE);
- Leadwood (COMBRETUM IMBERBE);
- Winter thorn (FAIDHERBIA ALBIDA);
- African teak (PTEROCARPUS ANGOLENSIS);
- Fever tree (VACHELLIA XANTHOPHLOEA);
- Jackalberry (DIOSPYROS MESPILIFORMIS);
- Sycamore fig (FICUS SYCOMORUS);
- Baobab (ADANSONIA DIGITATA);
- Raisin bush (GREWIA BICOLOR);
- Magic guarri (EUCLEA DIVINORUM);
- Umbrella thorn (VACHELLIA TORTILIS);
- Sweet thorn (VACHELLIA KARROO);
- Camel thorn (VACHELLIA ERIOLOBA);
- Red thorn (VACHELLIA SEYAL);
- Guinea grass (PANICUM MAXIMUM);
- Common reed (PHRAGMITES AUSTRALIS);
- Papyrus (CYPERUS PAPYRUS); and
- Nile cabbage (PISTIA STRATIOTES).

Most of the recorded plants are classified as Least Concern. However, the report identifies leadwood as Near Threatened on the Zambian flora list. This increases the importance of avoiding unnecessary removal of mature trees during the construction of siren foundations, monitoring stations, access paths and associated infrastructure.

5.6.2 Flora on the Zimbabwean Side

The Zimbabwean side, particularly Mana Pools National Park and the Charara, Hurungwe, Sapi, Chewore and Dande safari areas, contains open woodland, mature riverine forest, mopane woodland, floodplain grassland, jesse bush and baobab-dominated landscapes.

Important plants identified include:

- Baobab (Adansonia digitata);
- Apple leaf (Philenoptera violacea);
- Wild mango (Cordyla africana);
- Leadwood (Combretum imberbe);
- Jackalberry or ebony (Diospyros mespiliformis);
- Mopane (Colophospermum MOPANE);
- Large-leaved false thorn (Albizia harveyi);
- Rain tree (Lonchocarpus capassa);

- Nyala tree (Xanthocercis zambesiaca);
- Sycamore fig (Ficus sycomorus);
- African mahogany (Khaya anthotheca);
- Winter thorn (Faidherbia albida);
- Natal mahogany (Trichilia emetica);
- Burkea (Burkea africana);
- Knob thorn (Senegalia nigrescens);
- Silver cluster-leaf (Terminalia sericea);
- Marula (Sclerocarya birrea);
- River bushwillow (Combretum erythrophyllum);
- Camel thorn (Vachellia erioloba);
- Umbrella thorn (Vachellia tortilis);
- Fever tree (Vachellia xanthophloea);
- Red thorn (Vachellia seyal); and
- Magic guarri (Euclea divinorum).

The mature riverine woodlands of Mana Pools are strongly influenced by alluvial soils and seasonal flooding. These woodlands remain productive into the dry season and provide essential browse, shade and shelter for elephants, antelopes and birds. African mahogany is identified as Vulnerable in the baseline report and should receive particular consideration during site selection.

5.6.3 Terrestrial Fauna on the Zambian Side

Lower Zambezi National Park, the Chiawa Game Management Area and surrounding landscapes support high mammalian diversity. Common large mammals include African elephants, African buffaloes, hippopotamuses, zebras, impalas, greater kudus, elands, waterbucks, warthogs and several duiker species.

The area also supports important predators and scavengers, including:

- Lion (Panthera leo);
- Leopard (Panthera pardus);
- Cheetah (Acinonyx jubatus);
- African wild dog (Lycaon pictus);
- Spotted hyena (Crocuta crocuta);
- Side-striped jackal (Canis adustus); and
- Nile crocodile (Crocodylus niloticus).

Primates include vervet monkeys, blue or samango monkeys, Moloney's monkeys and baboons. Antelope recorded in the wider landscape include yellow-backed duiker, blue duiker, common duiker, red forest duiker, steenbok, Sharpe's grysbok, oribi, klipspringer, reedbuck, puku, impala, roan antelope, sable antelope, tsessebe, Lichtenstein's hartebeest, bushbuck, sitatunga, greater kudu and eland.

Several species have elevated conservation importance. The baseline identifies the African elephant as Endangered, African wild dog as Endangered, black rhinoceros as Critically

Endangered, and lion, leopard, cheetah and hippopotamus as Vulnerable. Roan antelope, zebra, yellow-backed duiker and African buffalo are also identified as having conservation significance in the report's species accounts or tables.

5.6.4 Terrestrial Fauna on the Zimbabwean Side

Mana Pools National Park and the neighbouring safari areas support comparable large-mammal communities because the Zambezi River forms an ecological system shared by both countries. Mana Pools is particularly noted for large populations of elephants and hippopotamuses and significant populations of lions, leopards, African wild dogs and buffaloes.

Herbivores include impalas, waterbucks, zebras, elands, kudus and other antelopes. The wider Charara, Hurungwe, Sapi, Chewore and Dande landscapes also support elephants, buffaloes, lions, leopards, giraffes, zebras and numerous antelope species. African wild dogs and striped hyenas are among the rarer carnivores reported from the Zimbabwean side.

Seasonal flooding determines the availability of water, grazing and browse. During the dry season, wildlife becomes increasingly concentrated around permanent channels, pools and riverine forests. This concentration makes the Zambezi River and associated floodplains essential dry-season refuges.

5.6.5 Avifauna

The combination of rivers, pools, wetlands, floodplains, grasslands and woodlands supports diverse resident and migratory bird communities. The Lower Zambezi area supports African fish eagles, white-backed vultures, carmine bee-eaters and numerous other water-associated and woodland birds. Mana Pools and surrounding areas support approximately 380 bird species. Species identified in the baseline include the African skimmer, Goliath heron, yellow-billed stork and white-headed vulture. Seasonal floods expose and inundate feeding areas at different times, producing habitats suitable for fish-eating birds, waders, herons, storks and migratory species.

Threatened or conservation-important birds recorded more broadly in Zambia include the Madagascar squacco heron, slaty egret, Cape vulture, lappet-faced vulture, greater spotted eagle, lesser kestrel, corn crake, wattled crane, black-cheeked lovebird, blue swallow and papyrus yellow warbler. Near-threatened species include the shoebill, lesser flamingo, pallid harrier, Taita falcon, Denham's bustard, great snipe, African skimmer, Chaplin's barbet and olive-headed weaver. Not all these species necessarily occur at individual EWS installation sites, and site-level ecological surveys will be required to confirm their presence.

5.6.6 Aquatic Ecology

The Zambezi River, its tributaries, wetlands and permanent pools support important aquatic ecosystems on both sides of the international boundary. Fish identified in the Zambian section include tilapia (OREOCHROMIS species) and catfish (CLARIAS species). The Zimbabwean section supports African tigerfish (HYDROCYNUS VITTATUS), Zambezi yellowfish (LABEO ALTIVELIS) and other riverine fish.

These fish populations support crocodiles, fish-eating birds and local fishing livelihoods. Aquatic productivity is influenced by river flow, water depth, water quality, sediment transport, nutrient cycling and the seasonal connection between the main river channel and its floodplains. Changes to Kariba Dam releases can modify these processes by altering the timing, duration and extent of downstream flooding. Hippopotamuses and Nile crocodiles are dominant components of the aquatic and riparian fauna. Hippopotamuses transfer nutrients between terrestrial grazing areas and aquatic environments, while crocodiles function as apex predators that help regulate fish and other animal populations.

5.6.7 Protected Areas and Key Biodiversity Areas

The principal protected and ecologically sensitive areas within or near the project's area of influence include:

- Lower Zambezi National Park in Zambia;
- Chiawa Game Management Area in Zambia;
- Mana Pools National Park in Zimbabwe;
- Chewore Safari Area;
- Charara Safari Area;
- Doma Safari Area;
- Hurungwe Safari Area;
- Sapi Safari Area;
- Dande Safari Area; and
- The wider Luangwa Valley ecosystem.

Lower Zambezi National Park contains riverine forest, open grassland, woodland and floodplain habitats and supports elephants, lions, leopards, buffaloes and rich birdlife. The Chiawa Game Management Area acts as an important buffer and wildlife-movement area adjoining the park. Mana Pools National Park is a UNESCO World Heritage Site recognised for its landscapes, seasonal pools, floodplains, riverine forests and abundant wildlife. Together with neighbouring safari areas and the Lower Zambezi landscape, it forms a transboundary ecological complex of international conservation importance.

5.6.8 Ecological Connectivity and Wildlife Corridors

Although the wildlife authorities of Zambia and Zimbabwe indicated that no official cross-border wildlife corridors have been mapped, regular wildlife movement across and along the Zambezi River occurs, especially when river levels are low. Elephants, buffaloes, lions, antelopes and other animals move between habitats in search of water, food and breeding areas.

The baseline identifies three possible ecological linkages:

i. The Zambezi-Mana Pools Corridor, which supports seasonal movement of elephants, buffaloes and lions;
ii. The Lower Zambezi Corridor, connecting Lower Zambezi National Park with Mana Pools and supporting elephants, antelopes and other wildlife; and

iii. The Kafue-Luangwa Corridor, which facilitates the movement of elephants, lions and other large mammals between major wildlife landscapes in Zambia.

These linkages maintain genetic exchange, allow animals to respond to seasonal changes and strengthen the resilience of wildlife populations. EWS installations must therefore be positioned so that towers, fences, access paths and maintenance activities do not obstruct established animal-movement routes.

5.6.9 Human Pressure and Ecological Threats

The ecological resources of the project area are under pressure from agricultural expansion, tree cutting, charcoal production, settlement growth, infrastructure development, tourism activities, poaching and habitat fragmentation. Communities around Namomba and Chalokwa reported sparse tree cover and continuing vegetation loss associated with fuelwood collection and small-scale agriculture.

Human-wildlife conflict is also significant. Communities reported elephants entering settlements and farmland, hippopotamuses destroying crops along riverbanks, crocodiles attacking livestock and occasionally people, and lions moving into settlements from adjoining protected areas. These interactions become more frequent where agricultural land and settlements expand into wildlife habitats or movement routes.

5.7 Hydrological and Hydrogeological Assessment

The project area extends along the Zambezi River from Kariba Dam to the Luangwa River confluence and includes hydrologically interconnected areas in Zambia and Zimbabwe. Its hydrological regime is controlled by the Zambezi River, Lake Kariba, the Kafue and Luangwa rivers, numerous tributaries and seasonal streams, wetlands, floodplains, rainfall-runoff processes and controlled releases from Kariba Dam. Surface water and groundwater resources support domestic water supply, agriculture, livestock, fisheries, tourism, wildlife and ecosystem functioning on both sides of the river.

5.7.1 Regional Hydrological Setting

The Zambezi River is the principal surface-water feature within the project area. Its downstream flow is influenced by rainfall over the wider catchment, inflows from tributaries, water storage within Lake Kariba and the operation of Kariba Dam. The dam moderates the natural flow regime by retaining wet-season inflows and releasing water according to reservoir operating requirements. Although regulation reduces some of the natural variability in downstream flows, controlled releases, emergency releases, uncontrolled discharges or a dam-related incident could produce rapid increases in downstream river levels. Flood risk may become particularly severe where dam releases coincide with heavy rainfall and high flows from downstream tributaries.

The Kafue and Luangwa rivers are the principal tributaries joining the Zambezi downstream of Kariba Dam. They contribute substantial quantities of water, sediment and nutrients to the main river system. Their flows influence downstream water levels, floodplain inundation, aquatic habitats and the timing and magnitude of flooding near their confluences with the Zambezi.

5.7.2 Seasonal Flow Regime

The hydrological regime is highly seasonal. River discharge, streamflow, groundwater recharge and floodplain inundation generally increase during the rainy season from approximately November to April. Intense or prolonged rainfall generates runoff from plateaus, escarpments, valleys and smaller sub-catchments, causing tributaries and seasonal streams to swell. During the dry season, flows in the main rivers decline and many smaller rivers and streams contract significantly or dry up. Communities located away from permanent rivers consequently become increasingly dependent on boreholes, wells, wetlands and residual pools. Seasonal fluctuations affect water availability for domestic use, livestock, irrigation, fisheries and wildlife.

Seasonal flooding deposits nutrient-rich alluvial sediments across low-lying land, replenishes wetlands, supports floodplain agriculture and contributes to groundwater recharge. However, unusually high flows can inundate settlements, damage crops and infrastructure, interrupt transport and expose communities to water-related health and safety risks.

5.8 Hydrology on Zambian Side

5.8.1 Siavonga District

The hydrology of Siavonga District is dominated by Lake Kariba and the Zambezi River. Kariba Ward, situated along the northern shoreline of Lake Kariba, is directly influenced by changes in lake level. The lake provides water for domestic use, fisheries, tourism and ecological processes and contributes to a relatively humid microclimate near the shoreline.

Streams and seasonal rivers drain from the surrounding escarpment into Lake Kariba. Their flows increase during the rainy season, transporting runoff and sediment and contributing to groundwater recharge. Seasonal changes in lake level may also influence groundwater conditions in low-lying lakeshore areas by changing the hydraulic relationship between the lake and adjacent groundwater.

Nanyanga Ward, located farther inland, depends more heavily on small seasonal streams draining the Zambezi Escarpment. These streams expand during the rainy season but may dry up during prolonged dry periods. Wells, boreholes and groundwater stored within local aquifers therefore become important sources of water during the dry season. The rugged escarpment terrain may produce rapid runoff during intense storms. Water can move quickly down steep slopes into drainage channels, increasing erosion, sediment transport and the possibility of localised flash flooding. Rainfall and water-level monitoring within both upland drainage areas and lakeshore zones will therefore be important.

5.8.2 Chirundu District

The hydrology of Chirundu District is strongly controlled by the Zambezi River. Low-lying areas such as Chirundu and Chirundu West are exposed to seasonal river flooding. Floodwaters spread across adjacent plains, deposit nutrient-rich sediments and replenish soil moisture, supporting agriculture in wards such as Kapululira and Kanyanga. Inland wards, including Lusitu, Musaya, Mushungu and Njame, rely on smaller tributaries and seasonal streams. These watercourses generally have higher flows during the rainy season but may become greatly reduced or dry during the dry season. This seasonal limitation increases dependence on wells and boreholes.

Wetlands around Ng'ombe Ilede and Nkandabwe perform important hydrological functions by temporarily storing floodwater, reducing the speed of runoff, recharging groundwater and supporting biodiversity. Disturbance of these wetlands or blockage of natural drainage could increase local flood risk and reduce dry-season water availability.

The district's hydrological system connects escarpment runoff, seasonal tributaries, wetlands, groundwater and the Zambezi River. Flooding may originate from local rainfall, increased upstream Zambezi flow or releases from Kariba Dam. Monitoring arrangements must consequently account for both local catchment conditions and upstream reservoir operations.

5.8.3 Chikankata District

Chikankata District contains a combination of permanent and seasonal surface-water sources, smaller tributaries and groundwater resources. Streams follow natural drainage routes created by the district's rolling hills and valleys and generally flow towards the Zambezi River or associated water bodies. Streamflow increases during the rainy season, providing water for agriculture, rural communities and natural ecosystems. Many smaller streams decrease substantially or dry up during the dry season, resulting in seasonal water shortages in areas without reliable piped-water systems.

Groundwater is especially important in rural parts of Chikankata. Communities commonly obtain water from boreholes and wells accessing relatively shallow aquifers. These aquifers are recharged mainly by rainfall infiltration and, in low-lying areas, by interaction with seasonal streams and the Zambezi floodplain system. Groundwater levels may fluctuate considerably between wet and dry seasons. Recharge is generally greatest during periods of sustained rainfall when soils become sufficiently wet to allow water to infiltrate below the root zone. During extended dry periods, abstraction and natural discharge may lower groundwater levels and reduce the yields of shallow wells.

5.8.4 Kafue District

The hydrology of the project wards in Kafue District is closely associated with the Kafue River, seasonal flooding, wetlands and groundwater. The Kafue River is a major tributary of the Zambezi and contributes significantly to the regional flow regime. Chisakila benefits from seasonal flooding that deposits fertile sediments and contributes to groundwater recharge. Chitende, situated within the broader Kafue Flats system, contains extensive wetlands that retain water during both wet and dry periods. These wetlands support agriculture, fishing, livestock grazing, wildlife and natural flood attenuation. Chiyaba experiences periodic flooding that enriches soils and creates seasonal water bodies used by crops and livestock.

Kambale occupies relatively elevated terrain and is less frequently flooded. It depends more heavily on seasonal streams and groundwater for domestic use and irrigation.

The Kafue Flats and associated wetlands temporarily store large volumes of water and release them gradually. They therefore influence downstream flood peaks, groundwater recharge, sediment deposition and ecosystem productivity. Changes in Kafue River flow may combine with high Zambezi water levels and affect flood conditions near the confluence.

5.8.5 Rufunsa District

The Zambezi River is the primary hydrological influence on Nyamanongo Ward and other river-associated areas of Rufunsa District. Seasonal flooding deposits fertile alluvial material along riverbanks and floodplains, creating productive land for maize, millet, vegetable cultivation and other smallholder agricultural activities.

During the rainy season, tributaries and streams descending from surrounding highlands increase in flow and discharge into the Zambezi. These watercourses show marked seasonal variability and may carry little or no water during the dry season. The Chongwe and Luangwa rivers also influence the wider hydrological setting. They provide water for agriculture, natural habitats and local consumption. During high rainfall periods, they may overflow onto adjacent plains, while wells and boreholes become increasingly important when river levels decline.

Low-lying farms and settlements remain exposed to peak rainy-season floods. Warning requirements must therefore consider both riverine flooding from the Zambezi and rapid runoff from local tributary catchments.

5.8.6 Luangwa District

Luangwa District is located at the confluence of the Luangwa and Zambezi rivers and has one of the most hydrologically dynamic settings within the project area. The Luangwa River flows generally from north to south and forms the principal drainage feature of the district. Its western tributaries include the Ilinda, Chinga Miseshi, Kava and Lunsemfwa rivers. Other watercourses include the Chilukusha, Kakala, Kaunga, Kaulungu, Mulambwa and Janeiro streams. The Rufunsa River flows from the north-west, crosses portions of the district and joins the Luangwa River.

Rainfall between November and April increases river discharge and causes the Luangwa to overflow into adjoining floodplains. These floods deposit silt, replenish wetlands and support subsistence cultivation of maize, sorghum and millet. Rivers, streams and wetlands also sustain fish populations, livestock grazing and wildlife habitats. During the dry season, the flow of smaller streams declines and some watercourses dry up. Communities may face reduced water availability and become dependent on permanent river reaches, pools, wetlands, wells and boreholes.

Flooding near the Luangwa-Zambezi confluence is especially complex. High Zambezi River levels caused by downstream catchment runoff or releases from Kariba Dam can impede the discharge of the Luangwa River. This produces a backwater or backflow effect, causing water levels in the lower Luangwa and its tributaries to rise. Where high Luangwa flows occur at the same time, floodplains and wetlands may be inundated rapidly and over a wider area.

5.9 Hydrology on the Zimbabwean Side

5.9.1 Kariba District

Hydrological conditions in Kariba District are dominated by Lake Kariba and the Zambezi River. The district lies along the southern shore of the lake and includes steep escarpments, hills, plateaus and low-lying areas adjoining the water. Lake Kariba supports fisheries, tourism, water supply and irrigation and acts as the main storage component regulating downstream Zambezi flows. Variations in reservoir inflow, evaporation, hydropower operations and spillway releases determine changes in lake level and downstream discharge.

Runoff from steep terrain may enter the lake or river through short, seasonal drainage channels. During intense rainfall, these channels can respond rapidly, causing erosion, sediment movement and localised flooding. Low-lying areas below the dam remain sensitive to sudden increases in river discharge arising from regulated or emergency water releases.

5.9.2 Hurungwe District

Hurungwe District contains undulating terrain, river valleys, flat savannas and smaller catchments draining towards the Zambezi River. Numerous seasonal rivers and streams carry runoff during the rainy season and contribute to the wider Zambezi drainage network. Surface-water availability is therefore strongly seasonal. Streamflow increases during heavy rainfall but declines substantially during the dry season. The seasonal watercourses provide water for wildlife, communities and ecosystems while also contributing to local flood risk where they cross low-lying floodplains.

Flooding may arise from a combination of local catchment rainfall, high Zambezi River levels and backwater effects. Where the main river is already high, drainage from tributaries may be impeded, causing water to spread over adjoining floodplains.

5.9.3 Mana Pools and Downstream Floodplains

The Zambezi River and its seasonal flood cycle are fundamental to the hydrology of Mana Pools and adjoining safari areas. Floodwaters fill channels, pools, backwaters and low-lying depressions, creating a mosaic of aquatic and floodplain habitats. As water levels recede, some pools remain and become important dry-season water sources for fish and wildlife.

The productivity of the floodplain depends on the timing, depth, duration and frequency of inundation. Floodwaters deposit fine alluvial sediments, redistribute nutrients, recharge shallow groundwater and sustain riverine vegetation. Significant alteration of the natural flooding pattern may affect pool persistence, vegetation productivity, fish habitats and wildlife access to water.

5.10 Hydrogeological Conditions

Groundwater and surface water are closely connected throughout much of the project area. Rainfall infiltrates through soils and weathered geological materials to recharge aquifers, while rivers, lakes, wetlands and floodplains may either recharge groundwater or receive groundwater discharge, depending on seasonal water levels. Groundwater is particularly important during the dry season when seasonal rivers and streams cease flowing. Rural communities commonly depend on boreholes and shallow wells for domestic use, livestock watering and limited irrigation. The reliability of these sources depends on aquifer characteristics, recharge, abstraction rates, borehole construction and seasonal climatic conditions.

5.10.1 Groundwater Recharge

The principal source of groundwater recharge is seasonal rainfall. Recharge occurs most effectively when rainfall is sufficiently prolonged or intense to infiltrate below the soil zone. Additional recharge may occur through riverbeds, wetlands, floodplains, seasonal streams and the margins of Lake Kariba.

Low-lying alluvial areas may experience relatively strong interaction between groundwater and surface water. During floods or high lake and river levels, water may infiltrate into adjoining sediments and raise the local water table. As surface-water levels fall, stored groundwater may gradually discharge back into rivers, wetlands or pools.

Recharge is likely to be lower on steep, rocky escarpments where rainfall runs off quickly and soils are thin. Fractures, joints and weathered zones within bedrock may nevertheless provide local pathways for infiltration and groundwater storage.

5.10.2 Aquifer Characteristics

The baseline report specifically identifies shallow aquifers in Chikankata and refers to groundwater accessed through boreholes and wells in Siavonga, Chirundu, Rufunsa and other inland areas. However, it does not provide detailed aquifer classifications, borehole yields, groundwater contours, transmissivity values, storage coefficients or depth-to-water measurements.

The geology of the wider project area includes granitic and gneissic basement rocks, metamorphic formations, Karoo sedimentary units and alluvial deposits. In general, groundwater within basement terrain is expected to occur mainly in weathered or fractured zones, while alluvial deposits along rivers and floodplains may contain shallower groundwater. This relationship must be confirmed through location-specific hydrogeological investigations before foundations or boreholes are constructed.

5.10.3 Groundwater-Level Variability

Groundwater levels are expected to rise during and shortly after the rainy season and decline throughout the dry season. The scale of this fluctuation will vary according to rainfall, proximity to rivers or Lake Kariba, aquifer storage and groundwater abstraction.

Near Lake Kariba and major rivers, high surface-water levels may cause the groundwater table to rise in adjoining low-lying areas. This could affect foundation stability, excavation conditions and the risk of water entering equipment bases or cable trenches. During droughts, declining river and reservoir levels may be accompanied by reduced groundwater recharge and lower yields from shallow wells.

5.10.4 Groundwater Vulnerability

Shallow groundwater near settlements, agricultural land and floodplains may be vulnerable to contamination from pit latrines, waste disposal, livestock, fuel spills, agricultural runoff and floodwater. Flooding can mobilise contaminants and introduce them into wells or boreholes, particularly where wellheads are not properly sealed or elevated. EWS construction activities are not expected to require significant groundwater abstraction or generate substantial effluent. Nevertheless, fuels, oils, batteries, cement and waste materials must be handled carefully to prevent contamination. Monitoring stations and siren foundations should not be located where they could obstruct drainage, damage wetlands or affect community water points.

5.11 Surface Water-Groundwater Interaction

The baseline demonstrates a strong relationship between surface water and groundwater. Seasonal streams and rivers recharge aquifers during the rainy season, while groundwater supports wells, wetlands and potentially river baseflow during dry periods. Lake Kariba and the Zambezi River influence groundwater levels in adjacent lowlands, and wetlands temporarily store both surface water and shallow groundwater. This interaction is important for flood forecasting because groundwater and soil-moisture conditions affect catchment response. Where soils and shallow aquifers are already saturated, a greater proportion of rainfall becomes direct runoff, producing more rapid increases in river levels. Conversely, dry soils and depleted aquifers may initially absorb a larger proportion of rainfall, although intense storms can still generate flash floods on steep or compacted surfaces.

5.12 Water Quality Considerations

The baseline indicates that the Zambezi and Kafue rivers generally contain low concentrations of dissolved substances and are comparatively clean. However, river regulation below dams may produce thermal changes, reduced suspended sediment and periods of low dissolved oxygen. Smaller tributaries draining areas with greater agricultural, settlement or other human influence may contain higher concentrations of nutrients and dissolved ions. Flood events can temporarily reduce water quality by transporting sediment, organic matter, waste and other contaminants into rivers, wetlands, wells and boreholes. Although detailed site-specific water-quality data were not available, water quality remains important because communities, livestock, wildlife and aquatic ecosystems depend on these resources. Post-flood inspection and testing of community water sources may be necessary where inundation affects wells or boreholes

5.13 Flooding Processes and Risk

The principal flood-generating mechanisms within the project area include:

i. Prolonged or intense rainfall over the Zambezi, Kafue and Luangwa catchments;
ii. Rapid runoff from steep escarpments and small tributary catchments;
iii. Seasonal overflow of the Zambezi, Kafue and Luangwa rivers;
iv. High inflows into Lake Kariba;
v. Controlled, uncontrolled or emergency releases from Kariba Dam;
vi. Backwater effects where high Zambezi levels impede tributary discharge;
vii. Coincidence of dam releases with high downstream tributary flows;
viii. Saturated soils and elevated groundwater levels that reduce infiltration capacity; and
ix. A potential dam-break event resulting in rapid and extensive downstream inundation.

Flood behaviour will differ across the project area. Narrow valleys and steep tributary catchments may experience rapid-onset flooding, while broad floodplains and wetlands may experience slower but more extensive inundation. Areas near the Luangwa confluence are especially sensitive to the interaction between the two rivers.

5.14 Relevance to the Early Warning System

The hydrological and hydrogeological setting confirms the need for an integrated EWS that monitors conditions across the whole catchment rather than relying on a single river-level station. The system should combine:

- Rainfall measurements within important sub-catchments;
- Lake Kariba water levels and reservoir inflows;
- Dam-release and spillway-operation information;
- Zambezi River levels downstream of the dam;
- Water levels on the Kafue and Luangwa rivers;
- Tributary and floodplain water levels at vulnerable locations;
- Soil-moisture and groundwater information where relevant;
- Weather forecasts and satellite rainfall estimates; and
- Hydrological and hydraulic modelling.

Automatic Rain Gauges should be located where they can represent rainfall over important tributary catchments. Automatic Water-Level Recorders should be positioned at hydraulically significant river sections and near vulnerable communities. Stations near river confluences should be capable of identifying backwater effects and rapid water-level changes. All equipment should be installed above expected flood levels or protected against inundation, erosion, floating debris and bank collapse. Foundations should be informed by local groundwater conditions and soil stability. Installation must avoid obstructing natural drainage channels, wetlands or floodplain flow paths.

5.15 Data Gaps and Further Assessment Requirements

The baseline assessment identifies major gaps in the information required for detailed hydrological and hydraulic modelling. Historical rainfall and pan-evaporation records had been requested from the Zambia Meteorological Department and the Meteorological Services Department of Zimbabwe but had not been received. Historical river-flow and water-level data for the Zambezi and its tributaries had also been requested from the Water Resources Management Authority. River cross-section data, Kariba reservoir elevation-area-volume curves and operational information for relevant dams were also required for hydraulic modelling. From a hydrogeological perspective, the report does not provide detailed aquifer maps, seasonal groundwater levels, borehole yields or groundwater-quality results.

The detailed design should therefore obtain and evaluate:

- Long-term rainfall, evaporation, river-flow and reservoir-level records;
- Dam operating rules and release records;
- River and floodplain cross-sections;
- Ground elevations at proposed installations;
- Seasonal groundwater levels;
- Borehole and aquifer information;
- Soil permeability and infiltration conditions;
- Surface-water and groundwater quality;
- Historical flood extents and community flood observations; and
- Projected climate-change effects on rainfall and flood frequency.

These data will support accurate rainfall-runoff modelling, flood-routing analysis, inundation mapping, warning-threshold determination and resilient siting of the EWS infrastructure.

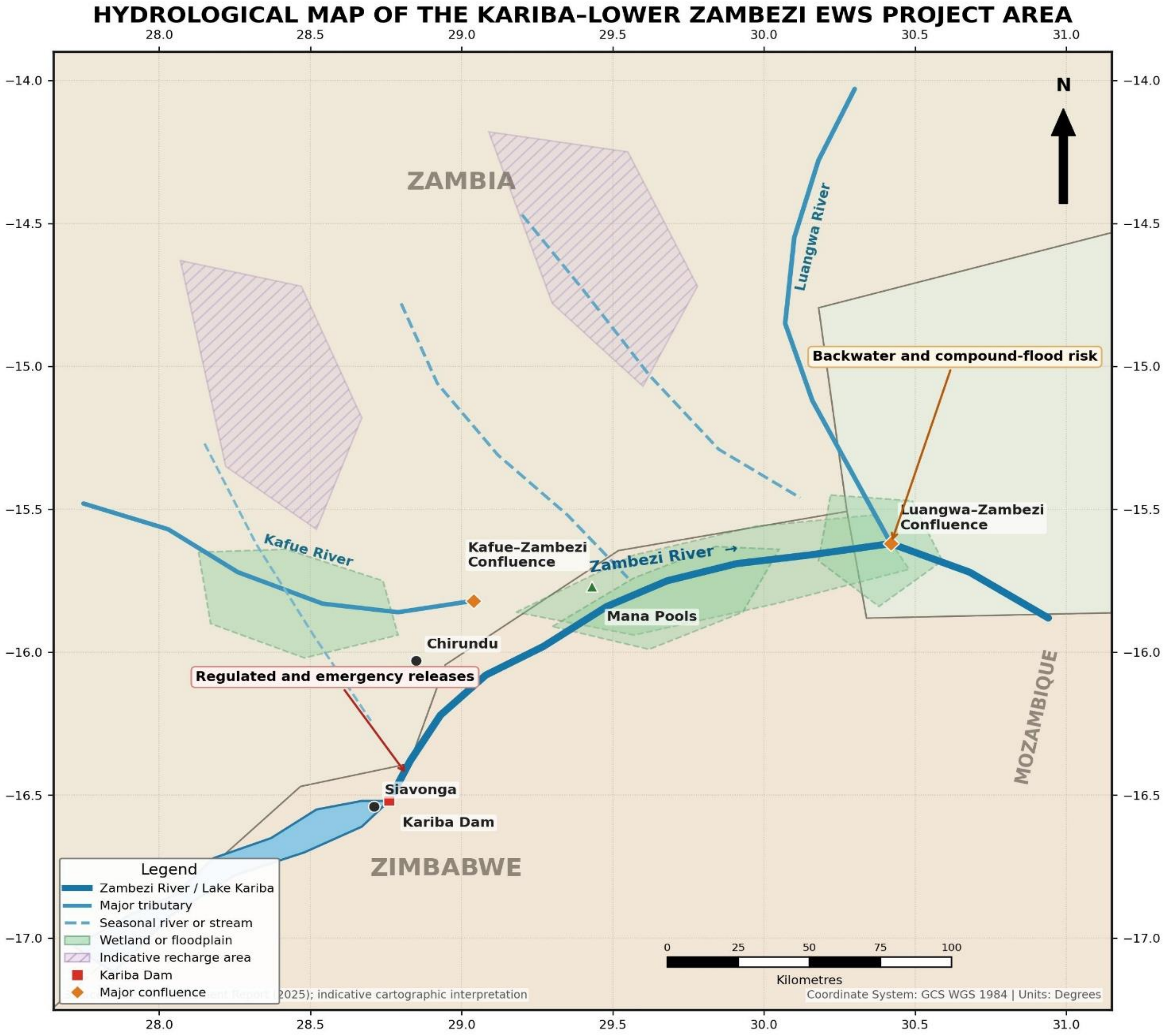

Figure 12: Hydrogeological Map of Kariba Lower Zambezi EWS Project Area

5.16 Hydrogeology

The hydrogeological conditions within the Early Warning System project area are influenced by the geological formations, seasonal rainfall, Lake Kariba, the Zambezi River and its major tributaries. The project area extends from Kariba Dam to the Luangwa River confluence and includes parts of Siavonga, Chirundu, Chikankata, Kafue, Rufunsa and Luangwa districts in Zambia, together with Kariba and Hurungwe districts in Zimbabwe. Groundwater is an important supplementary water resource, particularly in rural communities where seasonal streams dry up and access to piped water is limited.

5.16.1 Regional Geological Influence on Groundwater

Groundwater occurrence within the project area is controlled by a combination of Precambrian basement rocks, metamorphic formations, Karoo sedimentary rocks, weathered rock zones and unconsolidated alluvial deposits. These formations have different groundwater-storage and transmission characteristics.

In areas underlain by granitic, gneissic and metamorphic basement rocks, groundwater is principally stored and transmitted through fractures, joints, faults and weathered zones. Fresh, unfractured basement rock generally has low primary porosity and limited groundwater-storage capacity. Productive boreholes are therefore more likely to be associated with deeply weathered areas, fractured zones, geological contacts and fault systems.

Karoo sedimentary formations occurring around Lake Kariba and parts of the wider Zambezi Valley may provide groundwater where sandstone, fractured mudstone and other permeable units are present. Groundwater yields within these formations are expected to vary according to lithology, degree of weathering, fracturing and the continuity of permeable layers.

Alluvial deposits occur along the Zambezi, Kafue and Luangwa rivers, their tributaries and adjoining floodplains. These deposits generally consist of varying proportions of sand, silt, clay and gravel. Sandy and gravelly alluvial layers may form relatively shallow aquifers with stronger hydraulic connections to rivers and wetlands. Clay-rich layers may restrict vertical groundwater movement and produce perched or locally confined groundwater conditions.

5.16.2 Groundwater Occurrence

Groundwater within the project area occurs mainly in three general aquifer settings:

1. **Weathered basement aquifers**, where groundwater is stored within decomposed or chemically weathered rock above the solid bedrock;
2. **Fractured-rock aquifers**, where water flows through joints, faults, fractures and other secondary openings within otherwise impermeable rock; and
3. **Alluvial aquifers**, where groundwater is stored within unconsolidated river, floodplain and valley deposits.

Shallow groundwater is expected in low-lying areas near Lake Kariba, the Zambezi River, the Kafue Flats, the Luangwa floodplains and permanent wetlands. The depth to groundwater is likely to increase in elevated escarpment areas, where slopes are steep, soils are thinner and surface runoff is rapid.

The baseline assessment specifically identifies reliance on shallow aquifers in Chikankata District. Boreholes and wells are common water sources and provide water for domestic consumption, livestock and agricultural activities, particularly during the dry season. Communities in inland parts of Siavonga, Chirundu, Rufunsa and Luangwa also depend on wells and boreholes when seasonal surface-water sources diminish.

5.16.3 Groundwater Recharge

Rainfall is the principal source of groundwater recharge. Most recharge occurs during the rainy season, generally from November to April, when sustained rainfall infiltrates the soil and percolates into underlying weathered formations, fractures and alluvial deposits.

The rate of recharge varies according to rainfall intensity and duration, soil permeability, vegetation cover, slope, geology, antecedent soil moisture and land use. Sandy and loamy soils generally permit greater infiltration than clay-rich or compacted soils. Recharge may be limited on steep escarpments because rainfall runs off rapidly before it can infiltrate.

Additional recharge occurs through:

- Infiltration from seasonal rivers and streams;
- Seepage from the Zambezi, Kafue and Luangwa rivers;
- Floodwater spreading across alluvial plains;
- Temporary storage in wetlands and depressions;
- Infiltration along riverbeds and drainage channels; and
- Seepage from Lake Kariba into hydraulically connected formations.

During seasonal flooding, water may infiltrate through permeable floodplain deposits and raise the local groundwater table. Wetlands also slow surface runoff and increase the time available for infiltration. These processes sustain groundwater beyond the rainy season and contribute to the continued functioning of springs, wells, pools and riverine vegetation.

5.16.4 Groundwater-Surface Water Interaction

Groundwater and surface water are closely connected within the Zambezi Valley. Rivers, wetlands and Lake Kariba may recharge groundwater when their water levels are high. During the dry season, groundwater may discharge into river channels, wetlands and permanent pools, helping to maintain baseflow and aquatic habitats.

Groundwater levels near Lake Kariba are likely to respond to seasonal and operational changes in reservoir level. Rising lake levels can increase hydraulic pressure and raise groundwater levels in adjoining low-lying areas. Declining reservoir levels may cause groundwater to drain towards the lake, lowering the local water table.

A similar relationship occurs along the Zambezi, Kafue and Luangwa floodplains. During floods, river water infiltrates adjacent alluvial deposits and temporarily increases groundwater storage. As river levels fall, groundwater stored in the floodplain may gradually return to the river or remain available to shallow wells, vegetation and wetlands.

This interaction is important for flood-risk assessment. When soils and shallow aquifers are already saturated, their capacity to absorb additional rainfall is reduced. A greater proportion of subsequent rainfall becomes surface runoff, increasing the likelihood of rapid river-level rises and floodplain inundation.

5.16.5 Hydrogeology of the Zambian Project Area

Siavonga District

Groundwater conditions in Siavonga are influenced by Lake Kariba, seasonal streams and the fractured rocks of the Zambezi Escarpment. Low-lying lakeshore areas may contain shallow groundwater associated with alluvial and weathered deposits, while upland communities depend on groundwater stored within weathered and fractured bedrock.

In Kariba Ward, seasonal fluctuations in Lake Kariba may influence groundwater levels near the shoreline. Streams draining the escarpment also contribute to recharge during the rainy season. Nanyanga Ward relies more heavily on seasonal streams, wells, boreholes and underground aquifers because many surface-water sources diminish during the dry season.

The rugged terrain and thin soils in elevated areas may limit infiltration and produce rapid surface runoff. Groundwater availability is therefore likely to be localised around fractured rock, weathered zones and valley-bottom deposits.

Chirundu District

Groundwater in Chirundu is associated with alluvial deposits along the Zambezi River, wetlands, seasonal tributaries and weathered or fractured rock farther inland. Seasonal flooding contributes to groundwater recharge in low-lying areas, while wetlands around Ng’ombe Ilede and Nkandabwe retain water and promote infiltration. Inland wards such as Lusitu, Musaya, Mushungu and Njame depend more heavily on groundwater during the dry season, when smaller tributaries and streams cease flowing. Groundwater levels are likely to be shallower near rivers and wetlands and deeper in elevated areas away from permanent surface water.

Chikankata District

Chikankata relies significantly on shallow groundwater resources. Boreholes and wells provide water to rural communities and support agriculture during dry periods. Recharge occurs through rainfall infiltration, seasonal streams and floodplain processes associated with the wider Zambezi system. Groundwater levels may fluctuate considerably between seasons. Water levels rise during and shortly after the rainy season and decline as the dry season progresses. Shallow wells may therefore become less reliable during prolonged droughts or where groundwater abstraction is concentrated.

Kafue District

The Kafue River, Kafue Flats and associated wetlands strongly influence local hydrogeological conditions. Seasonal floods spread water across broad low-lying areas, recharge shallow alluvial aquifers and maintain high soil-moisture conditions. Groundwater is expected to be relatively shallow in parts of Chisakila, Chitende and Chiyaba that are close to the river and wetlands. Kambale, located on higher ground, depends more heavily on groundwater and seasonal streams and may have a greater depth to the water table. High groundwater levels may occur in wetland and floodplain areas during the rainy season. Such conditions could affect excavation, foundation stability and the installation of underground cables or equipment cabinets.

Rufunsa District

Groundwater in Rufunsa is replenished by rainfall, seasonal tributaries and periodic flooding along the Zambezi and associated rivers. Boreholes and wells become especially important during the dry season when smaller streams decline or disappear. Alluvial deposits along river valleys may provide shallow groundwater, while upland areas are more likely to depend on fractured and weathered bedrock aquifers. Groundwater availability is expected to vary considerably according to local geology and topography.

Luangwa District

Groundwater conditions in Luangwa District are influenced by the Luangwa and Zambezi rivers, their tributaries, wetlands and extensive floodplain deposits. Seasonal floods recharge shallow groundwater and sustain wetlands, grazing areas and riverine vegetation. At the Luangwa-Zambezi confluence, high water levels and backwater effects may cause groundwater levels to rise across adjacent floodplains. Low-lying areas may consequently experience waterlogged soils and shallow groundwater during periods of high river flow. During the dry season, groundwater stored in alluvial deposits becomes important for communities, livestock and ecological systems. However, shallow water sources near settlements and floodplains may be susceptible to contamination.

5.16.6 Hydrogeology of the Zimbabwean Project Area

Kariba District

Kariba District is underlain by granitic and gneissic basement rocks together with patches of Karoo sedimentary formations and local alluvial deposits. Groundwater in basement areas is expected to occur primarily in weathered and fractured zones. Karoo sedimentary units may provide groundwater where permeable or fractured layers are present. Near Lake Kariba, groundwater levels may be influenced by reservoir fluctuations and seepage between the lake and surrounding geological formations. Low-lying shoreline areas may have comparatively shallow groundwater, while escarpment and plateau areas may require deeper boreholes targeting weathered zones or geological structures.

Hurungwe District

Hurungwe District contains metamorphic rocks, weathered formations and alluvial deposits associated with river valleys and the Zambezi floodplain. Groundwater occurs within weathered and fractured rock and within unconsolidated valley deposits. Seasonal streams contribute to recharge during the rainy season. In floodplain areas, high Zambezi River levels may temporarily raise the water table and recharge shallow aquifers. Groundwater availability is likely to decline during the dry season as recharge ceases and water is lost through abstraction, evapotranspiration and discharge to surface-water bodies.

Mana Pools and adjoining areas contain seasonal pools and floodplain depressions that are closely linked to river levels and shallow groundwater. Floodwater recharges these features, while groundwater may help maintain some residual pools after the main floodwaters recede.

5.16.7 Groundwater Quality and Vulnerability

The attached baseline report does not provide detailed groundwater-quality results. Nevertheless, groundwater quality is likely to vary according to aquifer geology, depth, residence time, land use and proximity to settlements, agriculture and surface-water bodies.

Shallow alluvial aquifers and hand-dug wells are particularly vulnerable to contamination because they have limited natural protection from activities at the ground surface. Potential contamination sources include:

- Pit latrines and poorly managed sanitation facilities;
- Domestic waste disposal;
- Livestock enclosures and watering points;
- Agricultural fertilisers and pesticides;
- Fuel and oil spills;
- Floodwater carrying sediment, sewage and waste;
- Poorly sealed boreholes and wells; and
- Construction materials and chemicals.

Flooding can submerge wellheads, mobilise contaminants and transport polluted water into shallow groundwater systems. Community boreholes and wells within inundated areas should therefore be inspected and, where necessary, tested and disinfected before being returned to use after a flood.

5.16.8 Implications for EWS Infrastructure

Hydrogeological conditions must be considered when selecting and designing sites for sirens, monitoring stations, communication equipment and solar-power systems. Installations in areas with shallow groundwater, waterlogged soil or seasonal flooding may experience foundation instability, corrosion, cable damage or water ingress.

Site-specific investigations should establish:

- Seasonal depth to groundwater;
- Soil and rock conditions;
- Foundation-bearing capacity;
- Flood and waterlogging history;
- Proximity to wells, boreholes and springs;
- Surface-water drainage;
- Potential for riverbank erosion; and

- Groundwater contamination risks.

Foundations should be positioned above expected flood levels and designed to withstand saturated ground conditions. Underground equipment should be avoided where groundwater is shallow. Cable trenches should be sealed and drained to prevent water accumulation, while electrical cabinets and batteries should be elevated and housed in weather-resistant enclosures. Construction activities must not obstruct groundwater recharge pathways, wetlands or natural drainage channels. Refuelling, equipment servicing and chemical storage should be undertaken away from boreholes, wells, rivers and wetlands. Spill kits and containment measures should be provided at active work sites.

5.16.9 Hydrogeological Baseline

Groundwater forms an important component of the physical environment within the proposed Early Warning System project area, particularly in rural communities where piped water supplies are limited and seasonal streams dry up during the prolonged dry season. The hydrogeological baseline covers the section of the Zambezi River extending from Kariba Dam to the Luangwa River confluence, including the affected districts of Zambia and Zimbabwe.

Groundwater occurrence across the project area is influenced by the underlying geology, seasonal rainfall, topography, soil conditions and proximity to Lake Kariba, the Zambezi River and its tributaries. The principal geological formations include Precambrian granitic and gneissic basement rocks, metamorphic formations, Karoo sedimentary units, weathered rock zones and unconsolidated alluvial deposits associated with river valleys and floodplains.

Within the basement-rock areas, groundwater occurs principally in weathered formations and fractures, joints and faults within the underlying bedrock. Fresh and unfractured basement rock generally has limited groundwater-storage capacity. Groundwater availability is therefore expected to vary considerably between locations depending on the depth of weathering, intensity of fracturing and presence of geological structures.

Karoo sedimentary formations occur in parts of the Lake Kariba and wider Zambezi Valley area. These formations may store and transmit groundwater where permeable sandstone units, weathered layers or fractured sedimentary rocks are present. Groundwater yields within these formations are likely to depend on their lithology, thickness, continuity and degree of fracturing.

Alluvial aquifers occur along the Zambezi, Kafue and Luangwa rivers and within associated tributary valleys, wetlands and floodplains. These deposits consist of varying proportions of sand, gravel, silt and clay. Sandy and gravelly deposits may contain relatively shallow groundwater and have strong hydraulic connections with nearby rivers and wetlands. Fine-grained and clay-rich deposits have lower permeability and may restrict groundwater movement.

Groundwater Recharge and Seasonal Variation

Rainfall is the principal source of groundwater recharge within the project area. Recharge occurs mainly during the rainy season, generally between November and April, when sustained rainfall infiltrates the soil and percolates into weathered rock, fractures and alluvial deposits. Additional recharge occurs through seasonal streams, riverbeds, wetlands, floodplains and seepage from Lake Kariba and the major rivers. Groundwater levels are expected to display marked seasonal variation. Water levels generally rise during and immediately after the rainy season and gradually decline during the dry season as recharge decreases and water is lost through abstraction, evapotranspiration and natural discharge into surface-water systems. Shallow wells may become less reliable during prolonged dry periods, particularly in areas located away from permanent rivers and wetlands.

Recharge conditions vary according to topography and soil type. Relatively flat areas containing sandy or loamy soils generally permit greater infiltration, while steep escarpment slopes with shallow or rocky soils generate more surface runoff. Floodplains and wetlands provide important recharge areas because they retain water and increase the amount of time available for infiltration.

Surface Water and Groundwater Interaction

Surface water and groundwater are closely connected throughout the project area. Lake Kariba, the Zambezi River and the Kafue and Luangwa rivers may recharge adjacent groundwater systems when their water levels are high. During the dry season, groundwater stored in alluvial deposits may gradually discharge into river channels, wetlands and permanent pools, helping to maintain baseflow and ecological conditions. Seasonal flooding raises groundwater levels in low-lying areas and replenishes shallow alluvial aquifers. When floodwaters spread across the floodplains, water infiltrates through permeable sediments and increases local groundwater storage. As river levels decline, part of the stored groundwater may return to the river or remain available to wells, vegetation and wetlands.

The relationship between Lake Kariba and adjoining groundwater is likely to be particularly important within lakeshore areas. Rising reservoir levels may raise groundwater levels in adjacent low-lying land, while declining lake levels may result in groundwater drainage towards the reservoir. These changes may influence water availability, soil saturation and the stability of structures constructed close to the shoreline.

Hydrogeological Conditions on the Zambian Side

In Siavonga District, groundwater conditions are influenced by Lake Kariba, the Zambezi River, seasonal streams and the fractured rocks of the Zambezi Escarpment. Low-lying lakeshore areas are likely to contain relatively shallow groundwater associated with alluvial and weathered deposits. In elevated inland areas, groundwater is expected to occur mainly within weathered and fractured bedrock. Kariba Ward experiences the direct influence of seasonal Lake Kariba water-level fluctuations. Streams and seasonal drainage channels flowing from the escarpment contribute to groundwater recharge during the rainy season. Nanyanga Ward is more dependent on small seasonal streams, wells and boreholes because many surface-water sources reduce substantially or dry up during the dry season.

In Chirundu District, groundwater occurs within alluvial deposits along the Zambezi River, wetlands, seasonal tributary valleys and weathered or fractured rocks farther inland. Seasonal flooding replenishes shallow groundwater in low-lying areas. Wetlands around

Ng'ombe Ilede and Nkandabwe retain floodwater, regulate local drainage and contribute to groundwater recharge.

The inland areas of Chirundu District, including Lusitu, Musaya, Mushungu and Njame, rely increasingly on groundwater during the dry season. Wells and boreholes provide supplementary water where seasonal streams no longer flow. Groundwater levels are generally expected to be shallower close to the Zambezi River and wetlands and deeper in elevated areas.

In Chikankata District, groundwater is an important source of water for rural communities and agricultural activities. The district relies on shallow aquifers recharged by rainfall, seasonal streams and the wider influence of the Zambezi floodplain system. Boreholes and wells provide water during the dry season, although their yields and water levels may fluctuate considerably throughout the year.

The hydrogeological conditions in Kafue District are closely associated with the Kafue River, the Kafue Flats and extensive wetland areas. Seasonal flooding contributes to the recharge of shallow aquifers and maintains relatively high soil-moisture and groundwater conditions within low-lying areas. Chisakila, Chitende and Chiyaba are influenced by seasonal floods and wetland storage, while Kambale, situated on comparatively higher ground, depends more heavily on seasonal streams and groundwater.

In Rufunsa District, groundwater is recharged by rainfall, seasonal tributaries and periodic flooding along the Zambezi and associated river systems. Boreholes and wells become particularly important during the dry season when smaller watercourses decline or disappear. Shallow groundwater may occur within river-valley alluvium, while upland areas are expected to depend on weathered and fractured bedrock aquifers. Luangwa District contains extensive alluvial deposits associated with the Luangwa and Zambezi rivers, their tributaries and floodplains. Seasonal flooding replenishes shallow groundwater and supports wetlands, grazing areas, agriculture and riverine vegetation. Groundwater levels may rise significantly near the Luangwa-Zambezi confluence when high Zambezi water levels create backwater conditions and cause the surrounding floodplains to become inundated.

<u>Hydrogeological Conditions on the Zimbabwean Side</u>

The hydrogeological conditions of Kariba District are influenced by Lake Kariba, the Zambezi River and the underlying granitic, gneissic and Karoo sedimentary formations. Groundwater in basement areas occurs primarily in weathered and fractured rock. Sedimentary formations may contain groundwater where permeable or fractured layers are present.

Low-lying areas near Lake Kariba may have relatively shallow groundwater that responds to reservoir-level fluctuations. In escarpment and plateau areas, groundwater is likely to occur at greater depths and may be concentrated along fractures, faults and deeply weathered zones. Hurungwe District is underlain by metamorphic formations and local alluvial deposits associated with river valleys and the Zambezi floodplain. Groundwater occurs within weathered and fractured rock formations and unconsolidated valley deposits. Seasonal streams contribute to recharge during the rainy season, while high Zambezi River levels may temporarily raise the water table in adjoining floodplains.

Within Mana Pools and the surrounding safari areas, seasonal pools and floodplain depressions are closely connected to the Zambezi River and shallow groundwater. Floodwater replenishes these pools and recharges the surrounding alluvial deposits. Some pools may continue to hold water after the main floods recede, providing important dry-season water sources for wildlife and supporting riverine vegetation.

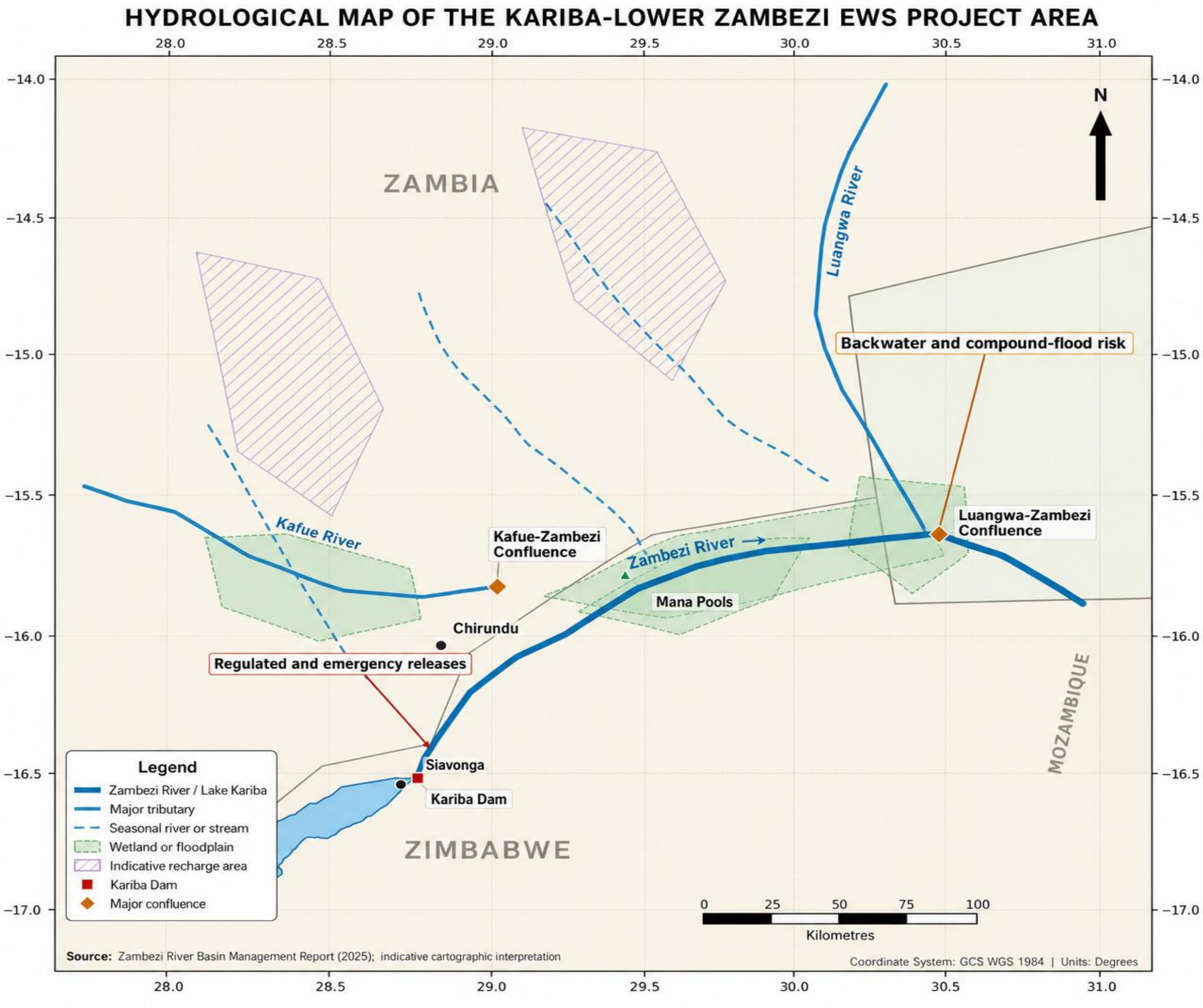

Figure 13: Hydrogeological Map with Potential Yields

5.16.10 Aquifer Vulnerability

The groundwater systems within the proposed Early Warning System project area occur mainly within fractured and weathered basement rocks, permeable units of the Karoo sedimentary formations and unconsolidated alluvial deposits associated with the Zambezi, Kafue and Luangwa rivers. In areas underlain by crystalline basement rocks, groundwater storage and movement depend predominantly on secondary porosity provided by fractures, joints, faults and weathered zones because the intact rocks generally have low primary porosity and permeability.

Groundwater vulnerability varies across the project area. It is expected to be comparatively high within shallow alluvial aquifers, floodplains, wetlands, river valleys, highly fractured formations and areas where the water table is close to the surface. These settings provide relatively direct pathways through which pollutants may enter the groundwater. Vulnerability may be lower where aquifers are deeper or covered by thick, relatively impermeable materials; however, fractures, poorly constructed boreholes and geological discontinuities can bypass this natural protection.

Contamination Risks

Although the EWS will not involve industrial production or substantial wastewater generation, groundwater contamination could arise from poorly managed construction, maintenance and sanitation activities. Potential pollutants include fuels, oils, lubricants, cement wash water, cleaning chemicals, used batteries, electronic waste, domestic waste and sanitary effluent generated by workers.

Agricultural runoff containing fertilisers, pesticides, animal waste and suspended sediment may also affect groundwater quality, especially where proposed installations are situated near cultivated floodplains and rural settlements. During heavy rainfall and flooding, these materials may be mobilised and transported into seasonal streams, wetlands, shallow wells and permeable alluvial deposits.

The risk of contamination is greatest near the Lake Kariba shoreline, riverbanks, wetlands, floodplains, seasonal drainage channels and shallow community water sources. Construction materials, fuels and waste should therefore not be stored or handled within these sensitive areas.

Point-Source Pollution and Groundwater-Flow Direction

Potential point sources of groundwater pollution associated with the project include temporary sanitation facilities, fuel-storage containers, equipment-maintenance areas, waste-storage points and accidental spill locations. Where such facilities are poorly contained, pollutants may infiltrate the ground and migrate through permeable soils, weathered zones and bedrock fractures.

Groundwater flow within shallow alluvial aquifers is generally expected to follow the local hydraulic gradient towards rivers, wetlands, floodplain depressions and other low-lying areas. In fractured-rock aquifers, however, groundwater movement may be controlled by joints, faults and fractures and may not always correspond directly with the surface slope.

The precise groundwater-flow direction should therefore be confirmed during site verification where installations are proposed near boreholes, wells, springs, wetlands or other sensitive receptors. Temporary toilets, fuel storage, waste-storage areas and equipment-servicing locations should be positioned hydraulically downgradient from community water points wherever practicable.

All fuels, lubricants, batteries and chemicals should be stored in covered and bunded areas on impermeable surfaces. Maintenance activities should use drip trays, and spill kits should be available at active installation sites. Waste should be removed regularly by authorised service providers and should not be buried, burned or disposed of within drainage channels or floodplains.

Groundwater-Quality Risks

Weathering of basement and sedimentary rocks may naturally release dissolved minerals into groundwater. Groundwater within parts of the project area may therefore contain elevated concentrations of iron, manganese, magnesium, sodium or other dissolved constituents, depending on local geological conditions and the length of time the water has remained in contact with the aquifer material. High concentrations of iron and manganese can affect the colour and taste of water and may cause staining or mineral deposits within borehole equipment. Turbidity may result from poor borehole construction, inadequate borehole development, fine sediment within shallow aquifers or sediment intrusion during floods. Site-specific water-quality testing would be required to confirm the presence and concentration of these constituents.

The available baseline information does not include project-wide groundwater-quality sampling results. Accordingly, no general conclusion should be made that groundwater throughout the entire EWS area complies with drinking-water standards. Existing borehole data should be obtained from the relevant water authorities, and groundwater should be tested before being used for drinking or other domestic purposes by construction and maintenance personnel.

Pathogen Intrusion

Shallow groundwater sources may be vulnerable to pathogens from pit latrines, livestock enclosures, open defecation, poorly managed waste and contaminated surface runoff. Fractures, permeable alluvial deposits, poorly sealed boreholes and unprotected wells may provide preferential pathways through which pathogens reach groundwater. The risk may increase during intense rainfall and flooding because contaminated surface water can enter wells or infiltrate shallow aquifers. Boreholes and wells within inundated areas should be inspected and, where necessary, disinfected and tested before being returned to use.

Temporary sanitation facilities for project personnel should be located at safe distances from boreholes, wells, rivers, wetlands and drainage channels. They should be designed and serviced to prevent leakage, overflow and direct discharge into the environment.

Groundwater Abstraction and Depletion

The operation of the EWS will require very limited quantities of water. Water use will mainly be associated with concrete works during installation, dust suppression, cleaning of sensors and solar panels, and the domestic needs of construction and maintenance personnel. The project will therefore not require continuous large-scale groundwater abstraction and is unlikely to cause groundwater depletion or measurable changes in regional groundwater levels. Water required during construction should preferably be obtained from approved existing sources or supplied by water bowsers. Where a new borehole is proposed, the necessary authorisation should be obtained from the relevant water-management authority. Borehole siting and abstraction rates should be informed by hydrogeological investigations and should not adversely affect existing community water supplies, wetlands or groundwater-dependent ecosystems.

A standard separation distance of 250 metres should not be applied automatically to every EWS installation without reference to local regulations and site conditions. Appropriate separation distances should instead be determined according to the type of activity, groundwater-flow direction, aquifer vulnerability, borehole construction, topography and the requirements of the relevant water and public-health authorities.

5.16.11 Groundwater Availability

Unlike the broiler-production project for which the original section was prepared, the proposed EWS will not require a large or continuous water supply. Most EWS installations—including Automatic Rain Gauges, Automatic Water-Level Recorders and sirens—will ordinarily be unmanned and will not consume water during routine operation. Limited quantities of water may be required during construction for concrete mixing, dust suppression, cleaning and the domestic requirements of installation personnel. During operation, only small and intermittent quantities will be required for cleaning solar panels, sensors and equipment enclosures.

Groundwater availability is therefore not expected to constrain the implementation or operation of the EWS. Water requirements should be met through approved local supplies or water bowsers. Abstraction from community boreholes should only occur with the agreement of the responsible authority and should not interfere with community access to water.

5.16.12 Groundwater Quality

The baseline assessment provides limited site-specific groundwater-quality information for the proposed EWS installation locations. Groundwater quality is expected to vary across the project area according to geology, aquifer type, depth, recharge conditions, land use and proximity to potential pollution sources. Groundwater from shallow wells and alluvial aquifers may be affected by turbidity, microbial contamination, agricultural runoff and pollutants transported by floodwater. Groundwater from fractured basement and sedimentary aquifers may contain naturally elevated levels of iron, manganese, magnesium, sodium and other dissolved minerals.

The project is not expected to produce significant wastewater or continuous contaminant discharges. Its potential effects on groundwater quality will therefore be limited mainly to accidental spills, poorly managed sanitary waste, cement wash water, used batteries, lubricants and construction waste. With appropriate storage, sanitation, spill control and waste-management measures, the residual risk to groundwater quality is expected to be low.

Where groundwater is intended for drinking by project personnel, samples should be analysed by an accredited laboratory and compared with applicable Zambian or Zimbabwean drinking-water standards, depending on the installation location. Testing should include physical, chemical and microbiological parameters such as pH, electrical conductivity, turbidity, total dissolved solids, iron, manganese, nitrate, major ions and total and faecal coliforms. Water requiring treatment should not be consumed until suitable treatment and confirmation testing have been completed.

5.16.13 Water Quality Assessment

The water-quality dataset comprises 26 laboratory reports collected from the Kariba Dam/Lakeview area between January 2023 and December 2025. Monitoring locations included:

- Zambia intake;
- Zimbabwe intake;
- a point approximately 500 m from the works;
- site laboratory/campsite;
- minimum cofferdam locations; and
- cofferdam slime locations during parts of 2023.

The reports contain approximately 121 individual sampling-point records covering physical characteristics, major ions, nutrients, selected metals and dissolved oxygen. Results were compared by the laboratory against SAZS 560:1997 and the WHO guideline values reproduced in the reports.

Monitoring coverage was uneven:

Table 18: Water quality testing over the last three years

Year	Reports available	Coverage
2023	12	January–December
2024	8	January–May and October–December
2025	6	January, February, May, October, November and December

Consequently, 2023 provides the most complete basis for evaluating seasonal variation.

Overall interpretation

The results indicate that water quality around the Kariba Dam works area was generally good between 2023 and 2025. Most physical, chemical, nutrient and heavy-metal parameters remained within the recommended or maximum allowable limits presented in the laboratory reports. The water was predominantly neutral to slightly alkaline, weakly mineralised, clear, well oxygenated and low in suspended matter.

There is no consistent spatial pattern showing deterioration between the Zambia intake, Zimbabwe intake and the 500 m monitoring point. Occasional elevated values occurred at individual locations, but these were generally isolated and did not develop into persistent multi-month trends. The results therefore do not indicate sustained contamination attributable to activities at the dam or construction areas.

The main matters requiring attention are:

- isolated copper concentrations above the recommended limit;
- manganese results that occasionally exceeded the recommended limit;
- an analytical detection limit for manganese that was sometimes higher than the recommended guideline;
- one phosphate exceedance;
- reduced oxygen saturation during November 2025;
- relatively high chloride at isolated points;
- incomplete monitoring coverage during 2024 and 2025; and
- the absence of microbiological and several pollution-indicator parameters.

<u>Summary of principal results</u>

Table 19: Summary of principal results

Parameter	Observed range	Laboratory reference	Interpretation
pH	6.65–8.47	6.5–8.5 recommended	Compliant; neutral to slightly alkaline
Temperature	18.5–29.7°C	20–30°C	Generally within range; low values in June 2023 reflect cool-season conditions
Electrical conductivity	23–290 µS/cm	780 µS/cm recommended	Low mineralisation; compliant
Total suspended solids	0–7 mg/L	10 mg/L recommended	Compliant; generally clear water
Total dissolved solids	5–210 mg/L	100–1,500 mg/L recommended	Low concentrations; some values below the aesthetic range are not pollution concerns
Total hardness	25–85 mg/L	20–300 mg/L	Soft to moderately hard; compliant
Total alkalinity	20–120 mg/L	200 mg/L recommended	Compliant
Turbidity	0–3 NTU	1 NTU recommended; 6 NTU maximum	Mostly low; isolated results may exceed the recommended level but remained below the maximum
Chloride	0.37–103 mg/L	200 mg/L	Compliant
Iron	<0.02–0.04 mg/L	0.3 mg/L	Compliant
Manganese	<0.02–0.66 mg/L	0.1 mg/L recommended; 1.0 mg/L maximum	Some recommended-limit exceedances; all confirmed results below maximum
Copper	0.05–1.92 mg/L	1.0 mg/L recommended; 3.0 mg/L maximum	Isolated recommended-limit exceedances; below maximum
Nitrate	<0.35–4.21 mg/L	10 mg/L recommended	Compliant
Sulphate	<5–88.9 mg/L	100 mg/L recommended	Compliant
Phosphate	<0.05–0.63 mg/L	0.5 mg/L recommended	One isolated exceedance

Cadmium	Generally <0.01 mg/L	0.01 mg/L recommended	No confirmed exceedance
Lead	Generally <0.01 mg/L	0.05 mg/L recommended	Compliant
Zinc	Generally <0.02 mg/L	1.0 mg/L recommended	Compliant
Hexavalent chromium	Generally <0.02 mg/L	0.01 mg/L recommended	Compliance cannot always be confirmed because the reporting limit exceeds the guideline
Dissolved oxygen	5.29–8.56 mg/L	Not specified in reports	Generally favourable for aquatic life
Oxygen saturation	Approximately 72.9–106%*	75% minimum	Generally satisfactory; low at all four points in November 2025

*One result appears in the extracted data as “968%” and is likely a transcription or decimal-placement error, probably 96.8%. It should be checked against the signed laboratory report before use.

Physical water-quality characteristics

4.1 pH

The pH ranged from 6.65 to 8.47. All results remained within the laboratory’s recommended range of 6.5–8.5 and the maximum allowable range of 6.0–9.0. The water was therefore consistently neutral to slightly alkaline. There is no evidence of acidification, strongly alkaline discharges or abrupt pH changes between monitoring locations. This is important for the EWS project because installation of monitoring stations, sirens and associated foundations is not expected to introduce processes capable of materially changing water pH.

4.2 Temperature

Water temperatures ranged from 18.5°C to 29.7°C. Values below the laboratory’s stated lower reference value of 20°C were recorded during June 2023, particularly at the Zambia intake and cofferdam-related points. These lower results are consistent with normal cool-season conditions and should not be treated as evidence of pollution. The highest recorded temperatures occurred during the warmer months, reaching approximately 29.7°C in October 2025. No persistent thermal anomaly was identified.

Electrical conductivity and dissolved solids

Electrical conductivity was low, ranging from approximately 23 to 290 µS/cm, well below the recommended value of 780 µS/cm. Total dissolved solids ranged from approximately 5 to 210 mg/L. Together, these results indicate fresh water with relatively low dissolved mineral and salt content. There is no indication of salinisation, concentrated wastewater discharge or sustained contamination by dissolved inorganic substances.

Suspended solids and turbidity

Total suspended solids ranged from non-detectable or near-zero concentrations to approximately 7 mg/L, remaining below the recommended limit of 10 mg/L. Turbidity was generally low, with a maximum of approximately 3 NTU.

These results indicate relatively clear water. Isolated turbidity results above the 1 NTU recommended value remained below the 6 NTU maximum allowable limit. Such short-term variations may result from rainfall, shoreline disturbance, vessel movement or activities around the cofferdam.

For the EWS project, the most relevant construction-phase risk is temporary sediment mobilisation during installation of foundations, access preparation or work close to riverbanks. This should be controlled through erosion and sediment-management measures.

Major ions, hardness and alkalinity

Total hardness ranged from approximately 25 to 85 mg/L, indicating generally soft to moderately hard water. Calcium hardness, magnesium hardness and alkalinity also remained within the reference limits presented in the reports. Chloride concentrations were mostly low, although isolated values reached approximately 103 mg/L. This remained below the recommended limit of 200 mg/L. Sulphate concentrations were also compliant, with a maximum of approximately 88.9 mg/L against a recommended limit of 100 mg/L.

There is no evidence of persistent ionic enrichment. The occasional higher chloride and conductivity values should nevertheless continue to be monitored to determine whether they represent localised operational influences, evaporation effects, laboratory variability or runoff.

Nutrient status

Nitrate concentrations were generally below the laboratory reporting limit of 0.35 mg/L and reached a maximum of approximately 4.21 mg/L in October 2025. All values remained below the recommended limit of 10 mg/L and far below the maximum allowable value of 50 mg/L.

Phosphate was mostly below 0.5 mg/L. A concentration of 0.63 mg/L was recorded at the Zimbabwe intake in March 2023, slightly exceeding the recommended value of 0.5 mg/L. Because this was an isolated result and subsequent values were lower, it does not establish a persistent eutrophication trend.

Nevertheless, nutrient inputs from sewage, food waste, detergents, agricultural runoff and disturbed soil should be controlled, particularly around campsites and operational facilities.

Metals

Iron, lead, zinc, cadmium, arsenic and mercury were generally below their respective recommended limits or laboratory reporting limits. There is no clear evidence of persistent heavy-metal contamination.

Manganese

Manganese requires a qualified interpretation. Confirmed concentrations reached approximately 0.66 mg/L in April 2024, above the recommended level of 0.1 mg/L but below the maximum allowable value of 1.0 mg/L. Other confirmed elevated results included approximately 0.20–0.42 mg/L during parts of 2024 and early 2025.

Many results were reported as “<0.2 mg/L.” Because the recommended guideline is 0.1 mg/L, a reporting limit of 0.2 mg/L is not sufficiently sensitive to demonstrate compliance with the recommended value. A result of “<0.2 mg/L” could represent an actual concentration either below or above 0.1 mg/L. Future testing should use a method detection limit of no more than 0.05 mg/L, preferably lower.

The manganese results may reflect natural geochemical conditions, sediment interaction or localised disturbance rather than project-related pollution.

Copper

Copper ranged from approximately 0.05 to 1.92 mg/L. Several values exceeded the recommended limit of 1.0 mg/L, including:

- March 2023, when several locations recorded approximately 1.08–1.92 mg/L;
- April 2023, with a result of approximately 1.22 mg/L;
- February 2023, with approximately 1.14 mg/L at one cofferdam slime point;
- January 2024, with approximately 1.23 mg/L at the laboratory/site point; and
- February 2024, with approximately 1.20 mg/L at the laboratory/site point.

5.16.14 Surface Water Quality Assessment

Purpose of the Assessment

Surface-water quality was assessed to establish baseline conditions along the Zambezi River downstream of Kariba Dam within the area potentially influenced by the proposed Early Warning System (EWS). The assessment supports the identification of environmental sensitivities associated with installing and maintaining sirens, Automatic Water Level Recorders (AWLRs), Automatic Rain Gauges (ARGs), communication equipment and related minor civil works.

The analysis used historical monitoring data supplied by the Zambezi River Authority (ZRA) for the following stations:

Sampling station	Approximate monitoring period	Number of records	Relevance to the EWS
Kariba Damwall Downstream	July 2025–July 2026	13	Represents water quality immediately downstream of Kariba Dam
Chirundu	July 2025–July 2026	13	Represents the middle downstream reach and an important settlement/receptor area
Zambezi River at Luangwa	February 2025–July 2026	6	Represents the lower downstream reach near the Luangwa–Zambezi confluence

The parameters assessed included temperature, pH, electrical conductivity, dissolved oxygen, total suspended solids, total dissolved solids, alkalinity, nitrite, nitrate, ammonia nitrogen, total phosphorus, hydrogen sulphide, turbidity, chloride, chlorophyll and faecal coliforms.

Methodology

Secondary Data Review

The assessment was based on water-quality monitoring results provided by ZRA in the following datasets:

- WQ Data Damwall_Chirundu.xlsx; and
- Zambezi R_@ Luangwa (1).xlsx.

The datasets were reviewed for monitoring location, sampling date, parameter, unit, reported concentration and temporal variability. Results were grouped by station and evaluated to identify:

- baseline water-quality characteristics;
- spatial differences between upstream and downstream monitoring locations;
- seasonal changes;
- unusual or elevated observations;
- parameters relevant to construction and operation of the EWS; and
- requirements for pollution prevention and future monitoring.

Sampling Approach

The datasets indicate that ZRA applied a repeated-station monitoring approach. Damwall Downstream and Chirundu were sampled approximately monthly, while the Luangwa station was sampled less frequently. This provides a reasonable temporal baseline for the Damwall and Chirundu stations but a more limited dataset for Luangwa.

Treatment of Results Below Detection Limits

Results shown using the “less than” symbol, such as <3, <10 and <47, were treated as non-detects. For calculation of indicative averages only, they were represented by one-half of the reported detection limit. These substituted values are not confirmed concentrations and should not be used for regulatory compliance decisions.

5.16.15 Summary of Water-Quality Results

Parameter	Damwall Downstream	Chirundu	Luangwa	General interpretation
Temperature (°C)	22.53–28.67	22.44–29.62	22.37–29.85	Normal seasonal variation in a tropical river system
pH	7.08–8.11	7.39–8.10	7.69–8.10	Neutral to slightly alkaline
EC (mS/m)	10.2–11.4	10.4–12.6	12.5–17.0	Relatively low mineralisation; slightly higher downstream
DO (mg/L)	3.68–7.75	6.55–7.94	6.34–8.38	Generally supportive of aquatic life, except one lower Damwall value

Parameter	Damwall Downstream	Chirundu	Luangwa	General interpretation
TSS (mg/L)	<1–20	4–190	16–566	Increasing sediment influence downstream
TDS (mg/L)	71.30–79.40	71.90–81.10	85.72–107.50	Low dissolved-solids concentrations
Alkalinity (mg/L as $CaCO_3$)	45–57	47–93	46–70	Moderate buffering capacity
Nitrite-N (µg/L)	<3–73	<3–40	<3–9	Generally low
Nitrate-N (µg/L)	<3–304	<3–100	8–116	Low concentrations overall
Ammonia-N (µg/L)	<47–112	<47–72	<16–50	Generally low, with many non-detects
Total phosphorus (µg/L)	60–258	51–266	49–501	Occasional elevated nutrient pulses
Turbidity (NTU)	0.44–13.33	1.70–120	15.60–350	Strong downstream and seasonal increase
Chloride (mg/L)	<10 throughout	<10 throughout	<10 throughout	Low chloride concentrations
Chlorophyll (µg/L)	0.75–3.56	0.96–5.77	4.02–12.40	Greater biological productivity downstream
Faecal coliforms, MPN/100 mL	<1–74	9–390	Not reported	Intermittent microbial contamination, especially at Chirundu

5.16.16 Interpretation of Results

Temperature

Water temperatures ranged from approximately 22°C to 30°C. The variation is consistent with seasonal changes in air temperature, river flow, solar radiation and reservoir releases. No abrupt or persistent temperature anomaly is evident.

The proposed EWS installations will not involve thermal discharge and are therefore not expected to alter river temperature.

pH

The pH was stable and ranged from neutral to slightly alkaline across all stations. Damwall Downstream had the widest range, from 7.08 to 8.11, while the Chirundu and Luangwa results were slightly more alkaline. These results indicate that the river has adequate buffering capacity and was not experiencing significant acidification during the monitoring period.

Electrical Conductivity and Total Dissolved Solids

Electrical conductivity and TDS were relatively low at all stations. Mean TDS concentrations were approximately:

- 74.4 mg/L at Damwall Downstream;
- 77.1 mg/L at Chirundu; and
- 94.0 mg/L at Luangwa.

The gradual downstream increase may reflect tributary inflows, erosion, evaporation and cumulative inputs from settlements and other catchment activities. The results nevertheless indicate generally low dissolved mineral and salt concentrations.

Dissolved Oxygen

Dissolved oxygen was generally satisfactory, particularly at Chirundu and Luangwa, where values remained above 6 mg/L. Damwall Downstream recorded one comparatively low value of 3.68 mg/L in July 2025. This may have been influenced by reservoir-release conditions, water temperature, sampling time or local hydraulic conditions.

As the remaining Damwall results ranged from 4.47 to 7.75 mg/L, the low result appears isolated rather than indicative of persistent oxygen depletion. Continued monitoring is nevertheless recommended because dissolved oxygen is important for aquatic ecosystem health.

Suspended Solids and Turbidity

The clearest spatial difference was observed in TSS and turbidity.

Damwall Downstream generally had clear water, with TSS mostly below 6 mg/L. The maximum of 20 mg/L occurred in January 2026. Turbidity was generally below 3 NTU, except for a peak of 13.33 NTU during the same period.

Chirundu showed greater variability. TSS rose to 88 mg/L in December 2025 and 190 mg/L in February 2026, while turbidity reached 45.1 and 120 NTU, respectively. These elevated results likely reflect wet-season runoff, sediment mobilisation and tributary or local drainage inputs.

Luangwa recorded the greatest sediment influence. In March 2026:

- TSS reached 566 mg/L;
- turbidity reached 350 NTU;
- total phosphorus reached 501 µg/L; and
- nitrate reached 116 µg/L.

This coordinated increase strongly suggests a high-flow or storm-runoff event that transported sediment and sediment-bound nutrients into the river. The values declined substantially by July 2026, when TSS was 17 mg/L and turbidity was 20 NTU. The proposed EWS works are small in footprint, but excavation near riverbanks could create localised sediment mobilisation if undertaken during rainfall or without erosion controls.

Nutrients

Nitrite, nitrate and ammonia concentrations were generally low. The highest nitrate concentration was 304 µg/L at Damwall Downstream in July 2026, equivalent to 0.304 mg/L. The results do not indicate sustained major inorganic nitrogen enrichment.

Total phosphorus was more variable:

- Damwall Downstream: 60–258 µg/L;
- Chirundu: 51–266 µg/L; and
- Luangwa: 49–501 µg/L.

Elevated phosphorus generally corresponded with periods of increased suspended solids or downstream catchment influence. This suggests that part of the phosphorus load may have been attached to transported sediment.

The EWS will not introduce nutrients during normal operation. Potential nutrient inputs would be limited to poor sanitation, food waste or uncontrolled waste disposal by installation and maintenance personnel.

Chlorophyll

Total chlorophyll was lowest immediately downstream of Kariba Dam and generally increased downstream. Mean indicative concentrations were approximately:

- 2.31 µg/L at Damwall Downstream;
- 2.54 µg/L at Chirundu; and
- 9.15 µg/L at Luangwa.

Higher chlorophyll at Luangwa may reflect greater nutrient availability, warmer shallow-water conditions, slower local flows or tributary influence. The data do not, by themselves, demonstrate a harmful algal bloom.

Microbiological Quality

Faecal coliform results were available for Damwall Downstream and Chirundu but not for Luangwa. Damwall Downstream generally had low concentrations, with MPN results ranging from less than 1 to 74 per 100 mL.

Chirundu recorded higher and more variable concentrations, including:

- 105 MPN/100 mL in November 2025;
- 390 MPN/100 mL in December 2025;
- 161.6 MPN/100 mL in May 2026;
- 150 MPN/100 mL in June 2026; and
- 193.5 MPN/100 mL in July 2026.

These results indicate intermittent faecal contamination at Chirundu, potentially associated with settlement runoff, sanitation conditions, livestock access, boats or other riverbank activities. Untreated river water should not be assumed suitable for drinking.

Hydrogen Sulphide

The spreadsheets report hydrogen sulphide concentrations of up to 30 mg/L. These values appear unusually high for well-oxygenated flowing surface water and are inconsistent with the generally satisfactory dissolved-oxygen results. Some entries also use detection limits of <5 and <10, while others report values of 10–30 mg/L.

The units, analytical method and reporting basis should be verified against the original laboratory certificates. The values may have been reported in µg/L, may represent a different sulphur parameter, or may contain a unit-entry error. No firm compliance conclusion should be drawn for hydrogen sulphide until this matter is resolved.

5.16.17 Spatial and Seasonal Trends

The results demonstrate a general downstream transition:

1. **Damwall Downstream:** comparatively clear, low-mineralised water with low suspended solids and chlorophyll;
2. **Chirundu:** increased variability in sediment, turbidity and microbiological quality, reflecting greater settlement and catchment influence; and
3. **Luangwa:** stronger seasonal sediment and nutrient pulses, particularly during the wet season.

The March 2026 Luangwa result and the December 2025–February 2026 Chirundu results show that wet-season conditions are a principal control on water quality. Consequently, baseline interpretation should not rely on a single sampling event.

5.16.18 Data Quality and Limitations

The following limitations were identified:

- The workbook does not contain sampling protocols, chain-of-custody forms or laboratory certificates.
- Detection limits vary between sampling events.
- Several results are reported as below detection limits and therefore cannot be treated as exact concentrations.
- Damwall and Chirundu have stronger temporal coverage than Luangwa.
- Faecal coliform data are incomplete and were not provided for Luangwa.
- Turbidity was missing from some early Damwall and Chirundu records.
- A date displayed as 16:02:26 at both Damwall and Chirundu appears to be an Excel formatting error and probably represents 16 February 2026.
- The Damwall entry shown as 25 April 2025 occurs within the 2026 sequence and should be checked to determine whether it should read 25 April 2026.
- The Luangwa coordinates appear to be entered as longitude 30.41416 and latitude 15.6254. The latitude likely requires a southern negative sign, but this must be confirmed.
- The reported hydrogen sulphide units and values require laboratory verification.
- The results should be treated as baseline screening data rather than proof of compliance with a particular water-use standard.

5.16.19 Recommended Mitigation and Monitoring Measures

The project should:

- Minimise excavation within riverbanks and drainage channels.
- Undertake river-edge works during low-flow and dry-weather conditions where practicable.

- Use silt barriers, sediment traps or equivalent controls around disturbed ground.
- Prohibit disposal of spoil, concrete, wastewater, litter or sanitary waste into the river.
- Store fuels and lubricants away from the watercourse in bunded areas.
- Refuel equipment at designated areas away from the river.
- Maintain spill kits at active installation sites.
- Stabilise and revegetate disturbed ground immediately after installation.
- Use existing access routes wherever practicable.
- Avoid washing tools or concrete equipment directly in the river.
- Inspect AWLR sites following heavy rainfall for erosion, scour and bank instability.
- Continue periodic monitoring at Damwall Downstream, Chirundu and Luangwa.
- Include pH, EC, DO, TSS, turbidity, nutrients, oils and grease, and faecal indicators in future monitoring.
- Verify the hydrogen sulphide results and units against the original laboratory certificates.
- Conduct wet- and dry-season sampling where construction occurs close to the river.

5.16.20 Conclusion

The ZRA monitoring results indicate that the Zambezi River within the EWS project area is generally neutral to slightly alkaline, well oxygenated and characterised by low dissolved mineral concentrations. Water quality immediately downstream of Kariba Dam is comparatively stable and clear. Chirundu is subject to episodic increases in suspended sediment, turbidity and faecal contamination, while Luangwa experiences pronounced wet-season sediment and nutrient pulses.

No evidence in the dataset suggests that the proposed EWS would face a fundamental water-quality constraint. Nevertheless, riverbank disturbance, sediment mobilisation and accidental pollution must be controlled, particularly at AWLR installation sites. The baseline should also be interpreted with caution until the hydrogen sulphide units, anomalous dates, coordinates and laboratory quality-control information have been verified.

All recorded copper concentrations remained below the stated maximum allowable value of 3.0 mg/L. The pattern appears intermittent rather than progressively increasing. Potential sources may include metal fittings, pipes, construction materials, sample containers, laboratory plumbing or localised construction contact water. Repeat confirmation should include properly preserved samples and quality-control blanks.

Glohe-sci formerly Vermex Water Systems

TEST REPORT

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ATTENTION: Freyssinet

Sample Identification
Number of samples : 4
Sampling method: Grab
Sampling point(s): Kariba Dam Lakeview site

Analysis required: Full Physio-Chemical Analysis
Analysis site: Physical tests done onsite, Chemical tests performed at the Laboratory
Analysis date: 26-Oct-25
Date reported: 30-Oct-25

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1 of 2

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TEST REPORT

Dam/River Water

Parameter	Units	Test Method	ZIMBABWE IN	500m	ZAMBIA IN	LAB	SAZS 560: 1997 Standard/ WHO Guidelines	
							Recommended limits	Maximum allowable limits
pH	pH value	AP 200 Maji Electrode	7.68	7.46	7.52	7.70	**6.5-8.5**	**6.0-9.0**
Temperature	°C	AP 200 Maji Electrode	29.1	28.9	29.5	29.7	**20-30**	
Electrical Conductivity	µS/cm	AP 200 Maji Electrode	187	163	171	182	**700**	**3000**
Total Suspended Solids	mg/l	T2O AN-P384	1.00	0.00	0.00	1.00	**10**	**100**
Total Dissolved Solids	mg/l	AP 200 Maji Electrode	119	88.0	93.0	99.0	**100-1500**	**2000**
Total hardness	mg/l	T2O AN-P200	51.0	47.0	50.0	57.0	**20-300**	**500**
Calcium hardness	mg/l	T2O AN-P191	39.0	31.0	33.0	44.0	**60**	**120**
Magnesium hardness	mg/l	T2O AN-P200	12.0	16.0	17.0	13.0	**70**	
Total Alkalinity	mg/l	T2O AN-P31	52.0	49.0	56.0	63.0	**200**	**500**
Turbidity-NTU	NTU	T2O AN-P386	0.00	0.00	0.00	0.00	**1**	**6.00**
Chloride	mg/l	T2O AN-P90	9.82	17.8	6.23	8.56	**200max**	
Iron	mg/l	T2O AN-P220	0.02	<0.02	<0.02	<0.02	**0.3**	**1**
Manganese	mg/l	T2O AN-P240	<0.2	<0.2	<0.2	<0.2	**0.1**	**1.00**
Copper	mg/l	T2O AN-P150	0.09	0.10	0.09	0.11	**1**	**3.00**
Nitrates	mg/l	T2O AN-P260	4.21	<0.35	<0.35	2.34	**10**	**50.0**
Sulphates	mg/l	T2O AN-P355	56.0	43.0	13.0	49.0	**100**	**250**
Phosphates	mg/l	T2O AN-P321	0.07	0.09	<0.05	<0.05	**0.5**	**5.00**
Cadmium	mg/l	T2O AN-301 Cd, Pb v3	<0.01	<0.01	<0.01	<0.01	**0.01**	**0.05**
Lead	mg/l	T2O AN-301 Cd, Pb v3	<0.01	<0.01	<0.01	<0.01	**0.05**	**0.10**
Zinc	mg/l	T2O AN-P400	<0.02	<0.02	<0.02	<0.02	**1**	**3.00**
Hexavalent Chromium	mg/l	T2O AN-P125	<0.02	<0.02	<0.02	<0.02	**0.01**	**1.00**
Arsenic III	ppb	T2O AN-303 (Arsenic III) v3	<0.01	<0.01	<0.01	<0.01	**0.05**	**1.00**
Mercury	ppb	T2O AN-302 (Mercury) v3	<0.01	<0.01	<0.01	<0.01	**0.01**	**0.05**
% Oxygen Saturation	% saturation	AP 200 Maji Electrode	98.3	98.9	99.5	99.1	**75**	**15.0**
Dissolved Oxygen	mg/l	AP 200 Maji Electrode	7.21	7.34	7.63	7.60	**Not Specified**	

Comments:
N/A

Analysed by: Angelina Mpofu 30-Oct-25
Position *(Analyst)*

Test Report Reviewed by: Emmanuel Hwera 30-Oct-25
Position *(Chief Chemist)*

Test Report Authorised by: Happymore Mbiza 30-Oct-25
Position *(Executive Director)*

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Figure 14: Water Quality Base results

5.17 Air Quality

5.17.1 Background

An assessment of the existing ambient air-quality conditions was undertaken to establish the environmental baseline for the proposed Early Warning System (EWS) project downstream of Kariba Dam. The assessment considered the installation of large sirens, mini sirens, Automatic Rain Gauges (ARGs), Automatic Water Level Recorders (AWLRs), Automatic Dam Monitoring Stations (ADMSs), solar-power equipment and associated communication infrastructure in Zambia and Zimbabwe.

Approximately 80% of the proposed EWS installations are located in villages, agricultural areas, forests, protected areas, tourism facilities and other non-industrial environments. These locations generally have limited permanent sources of industrial air pollution. Existing air quality is mainly influenced by natural dust, unpaved roads, agricultural activities, domestic biomass combustion, veld or forest fires, waste burning, vehicle movements and, at some locations, emissions from boats, generators and tourism operations. More developed locations, including the Kariba Dam area, Siavonga, Chirundu, Kanyemba and Luangwa Central Business District, experience comparatively greater influence from traffic, commercial activities, diesel generators, road dust, construction activities and human movement. However, these areas are not characterised by extensive heavy industrial development.

The EWS will not involve combustion-based industrial processes or continuous production activities. Consequently, its operational phase is not expected to generate significant gaseous or particulate emissions. Potential air-quality impacts will be concentrated mainly in the short construction period and will be associated with excavation, limited vegetation clearance, concrete works, transportation of materials and exhaust emissions from construction vehicles and machinery.

5.17.2 Importance of the Air-quality Assessment

The air-quality assessment is important for the following reasons:

Establishment of Baseline Conditions

The assessment provides an indication of existing ambient air-quality conditions before construction of the EWS installations. This will assist in distinguishing project-related impacts from existing sources such as road dust, biomass burning, veld fires, agricultural activities and vehicle emissions.

Protection of Communities and Sensitive Receptors

A significant proportion of the proposed installations will be located within or near villages, schools, health facilities, lodges, police stations and other community facilities. Dust and exhaust emissions generated during construction must therefore be controlled to protect residents, learners, patients, workers, visitors and other sensitive receptors.

Protection of Wildlife and Natural Habitats

Several proposed installations are within or near forests, game-management areas, national parks and wildlife movement areas. Although the anticipated emissions are minor and temporary, unnecessary dust, smoke and equipment emissions should be prevented to minimise disturbance to vegetation and wildlife habitats.

Worker Health and Safety

Construction workers may be temporarily exposed to dust from excavation, cement handling, foundation preparation and movement on unpaved roads. Appropriate occupational health and safety measures will be necessary to reduce inhalation exposure.

Regulatory Compliance

Construction and operation of the EWS must comply with the applicable environmental-management, pollution-control and occupational health and safety requirements of Zambia and Zimbabwe. Good-practice emission controls will be applied even where the small and temporary nature of the works does not require continuous air-emission monitoring.

5.17.3 5.3.3 Objectives of the Air-quality Assessment

The objectives of the assessment were to:

i. Characterise the existing air-quality conditions within representative parts of the EWS project area;
ii. Identify existing natural and anthropogenic sources of air emissions;
iii. Identify communities, institutions, tourism establishments, workers and ecological resources that may be sensitive to air-quality changes;
iv. Review available Air Quality Index information as a secondary indicator of regional air-quality conditions;
v. Assess potential air-quality impacts associated with construction, operation, maintenance and decommissioning of the EWS installations;
vi. Determine whether the project is likely to cause significant deterioration of ambient air quality; and
vii. Recommend mitigation and monitoring measures for preventing or minimising dust and gaseous emissions.

5.17.4 Assessment Methodology

The air-quality baseline was assessed using a combination of site observations, review of surrounding land uses, identification of potential emission sources and review of secondary Air Quality Index information. The assessment was undertaken at representative locations also used during the baseline noise assessment. This allowed the environmental context at each location to be considered consistently for both air quality and noise. Because the EWS covers an extensive transboundary river corridor and most installation sites are remote from permanent air-quality monitoring stations, secondary AQI information was used only to describe broader regional conditions. It was not treated as a substitute for site-specific instrumental measurements.

The assessment involved the following activities:

- Observation of dust levels and visible emissions;
- Identification of unpaved roads, agricultural fields and exposed soil;
- Identification of domestic cooking, charcoal use, refuse burning and seasonal biomass burning;
- Identification of traffic, boats, generators and construction machinery;
- Review of nearby settlements, schools, clinics, lodges and other sensitive receptors;
- Consideration of vegetation cover and its role in suppressing or intercepting airborne dust;
- Consideration of local topography, wind direction and seasonal weather conditions;
- Review of secondary AQI information for the broader project region; and
- Identification of project activities capable of temporarily affecting air quality.

The assessment focused on pollutants relevant to the proposed works, principally particulate matter, including PM_{10} and $PM_{2.5}$, nitrogen dioxide, sulphur dioxide, carbon monoxide and combustion-related emissions from vehicles and equipment.

5.17.5 Representative Assessment Locations

The air-quality assessment considered the same representative environments examined during the noise survey. These locations capture the mainland-use settings within which the approximately 50 EWS installations will be established.

Table 20: Representative air-quality assessment locations

Monitoring location	Coordinates	General environmental setting	Existing potential emission sources
AQ/N-01	15°49'02.9"S, 29°07'10.3"E	Rural community and agricultural environment in the Chiawa area	Unpaved-road dust, agricultural activities, domestic cooking, occasional refuse or biomass burning and limited vehicle movement
AQ/N-02	15°56'37.4"S, 28°52'26.7"E	Chirundu-area settlement and transport environment	Road traffic, unpaved surfaces, commercial activities, domestic fuel combustion and occasional generator emissions
AQ/N-03	15°28'02.37"S, 28°51'38.5"E	Predominantly forested, lodge or wildlife environment	Natural dust, seasonal fires, lodge generators, boats, maintenance vehicles and limited tourism activities
AQ/N-04	16°20'46.2"S, 28°50'10.5"E	Rural and semi-developed environment near the Kariba-Siavonga area	Vehicle movement, exposed soil, domestic activities and occasional construction or maintenance works
AQ/N-05	16°31'11.8"S, 28°45'39.2"E	Kariba Dam and associated infrastructure area	Traffic, people, machinery, maintenance activities, generators and disturbed surfaces

N.B: The assessment locations are representative samples and do not constitute monitoring at every proposed installation site. The wider EWS network includes villages, farms, forests, protected areas, schools, clinics, police stations, lodges, meteorological stations and a limited number of urban or semi-urban locations.

5.17.6 Use of the Air Quality Index as Secondary Data

The Air Quality Index is a communication tool that converts measured or modelled pollutant concentrations into categories indicating the possible level of public-health concern. The AQI used in this assessment was obtained from available secondary sources and was applied only as supporting regional information.

The AQI does not represent direct measurements undertaken at individual siren or monitoring-equipment locations. Online AQI values may be derived from monitoring stations situated a considerable distance from the EWS sites, satellite observations or air-quality models. Local conditions at remote villages, farms, forests and protected areas may therefore differ from the reported regional value. For interpretation, the commonly used AQI categories are presented below. Under the US EPA system, values from 0-50 are classified as "Good," while values from 51-100 are "Moderate." Values above 100 indicate progressively greater health concern.[5]

Table 14: Air Quality Index interpretation

AQI value	Category	General interpretation
0-50	Good	Air quality is satisfactory, and pollution poses little or no health risk
51-100	Moderate	Air quality is generally acceptable, although unusually sensitive persons may experience effects
101-150	Unhealthy for sensitive groups	Children, older persons and people with respiratory or cardiovascular conditions may experience health effects
151-200	Unhealthy	Some members of the general population may experience health effects
201-300	Very unhealthy	Increased risk of adverse health effects for the entire population
Above 300	Hazardous	Emergency conditions with a high likelihood of adverse health effects

Secondary AQI information was be recorded together with the source, date and time of retrieval because air-quality conditions change according to wind, rainfall, traffic, agricultural activities and seasonal biomass burning. AQI information shall not be compared directly with short-duration site observations unless the underlying pollutant, averaging period and monitoring method are known.

The World Health Organization's 2021 air-quality guidelines has been used as a health-based reference values for $PM_{2.5}$, PM_{10}, nitrogen dioxide, sulphur dioxide, ozone and carbon monoxide. These guideline concentrations should be used when evaluating measured

[5] AirNow—AQI Basics

pollutant concentrations, while the AQI should principally be used to communicate general air-quality conditions.[6]

5.17.7 Existing Air-quality Conditions

The general air quality across the EWS project corridor is considered to be good in most rural, agricultural, forest and protected-area locations. This conclusion is based on the absence of major industrial emission sources, the low density of development and the extensive areas of natural vegetation surrounding most proposed installation sites.

Villages and Rural Settlements

Villages constitute a significant proportion of the proposed siren locations. Existing sources of air emissions in these areas include household cooking using firewood or charcoal, burning of household and agricultural waste, movement of vehicles on unpaved roads, windblown dust and seasonal burning of vegetation. These activities are generally intermittent and dispersed rather than continuous point sources. Dust levels may increase during the dry season, particularly near unpaved roads, exposed fields and areas used by vehicles or livestock. Localised smoke may also occur during cooking periods or where waste and vegetation are burned.

Farms and Agricultural Areas

Agricultural locations generally have limited industrial influence. Potential air-quality effects are associated with land preparation, harvesting, movement of farm vehicles, exposed soils, pesticide application and burning of crop residues. These sources may temporarily increase dust or smoke but are not expected to create continuous high pollutant concentrations.

Forests, Protected Areas and Lodge Environments

Forested and protected-area locations generally have good ambient air quality because of the absence of industrial facilities and low traffic volumes. Potential temporary influences include natural or human-induced veld fires, dust from dirt roads, boat engines, lodge generators and maintenance vehicles. Vegetation helps to stabilise soil and intercept airborne dust. However, smoke from veld or forest fires may cause short-term increases in particulate matter over a wide area, particularly during the dry season.

Urban and Semi-urban Locations

A smaller proportion of the EWS sites is located in or near developed areas such as Kariba, Siavonga, Chirundu, Kanyemba and Luangwa CBD. These locations experience greater influence from road traffic, commercial activity, generators, exposed road surfaces and human movement. At the Kariba Dam monitoring location, traffic, people, machinery and ongoing maintenance activities were observed. The site can therefore be expected to experience higher short-term dust and exhaust emissions than the remote forest, lodge and village locations. Nevertheless, no extensive heavy-industrial emission sources were identified within the immediate surroundings of the sampled EWS sites.

[6] WHO Global Air Quality Guidelines

5.17.8 Sensitive Receptors

Potentially sensitive air-quality receptors within the EWS project area include:

- Residents of villages and scattered homesteads;
- Children and teachers at schools;
- Patients, healthcare workers and visitors at health facilities;
- Police officers and visitors at police stations;
- Lodge employees, tourists and camp residents;
- Roadside vendors, pedestrians and transport operators;
- Construction and maintenance workers;
- Wildlife within national parks, game-management areas and movement corridors; and
- Vegetation, surface-water bodies and terrestrial habitats.

Children, older persons and individuals with asthma or other respiratory conditions may be more sensitive to elevated particulate matter and smoke. Construction near schools, clinics and densely occupied community areas will therefore require additional dust-control measures.

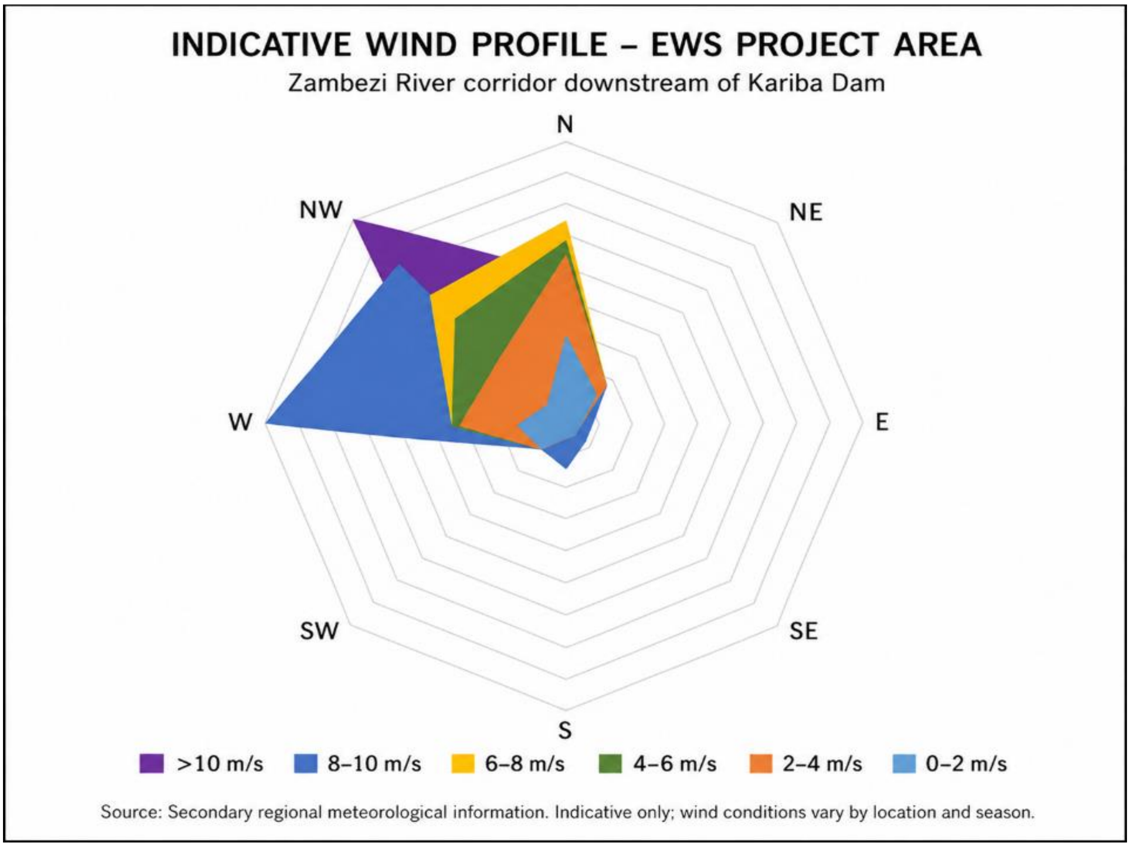

Figure 15: Site Windrose

5.17.9 Summary of Findings

The assessment indicates that ambient air quality across the EWS project area is generally good, particularly because approximately 80% of the proposed installations are located in villages, farms, forests, protected areas and other non-industrial settings. No major industrial emission sources were identified near most of the sampled locations. Secondary Air Quality Index information and field observations indicate that existing air quality is primarily influenced by localised sources such as dust from unpaved roads, agricultural activities, domestic biomass combustion, seasonal veld fires, vehicle movements, generators and activities around developed areas such as Kariba Dam, Chirundu and Luangwa CBD.

The EWS installations will not generate significant atmospheric emissions during normal operation. Potential impacts will mainly comprise temporary dust and vehicle-exhaust emissions during site preparation, foundation excavation, transportation of materials and equipment installation. Considering the small installation footprint and short construction period at each site, these impacts are expected to be minor, localised and reversible.

Implementation of appropriate mitigation measures including controlling vehicle speeds, limiting excavation and vegetation clearance, suppressing dust where necessary, maintaining construction equipment and prohibiting open waste burning will ensure that project activities do not cause significant deterioration of ambient air quality. Routine operational monitoring is not considered necessary at every installation; however, visual inspections and complaint-based monitoring should be undertaken during construction, particularly near schools, clinics, settlements, lodges and other sensitive receptors.

5.18 Noise Analysis

5.18.1 General Information

Sound is generally considered noise when it is unwanted, disruptive or exceeds acceptable health and environmental limits, thereby causing discomfort or disturbance. Noise is commonly associated with vehicular traffic, machinery, construction activities, commercial operations, human movement and recreational activities. Excessive or prolonged exposure to noise may have adverse physiological and psychological effects on people and may also disturb wildlife and the broader ecosystem.

5.18.2 Ambient Noise Environment

No primary ambient noise measurements were undertaken as part of the environmental assessment for the proposed Early Warning System (EWS) Project. The noise baseline has therefore been characterised using secondary information, observations of the prevailing land-use conditions, the nature of activities occurring at the proposed installation locations and internationally recognised environmental-noise guidance. Consequently, no site-specific baseline noise levels in dB(A) are presented, and the discussion should be regarded as a qualitative desktop assessment rather than a measured acoustic baseline.

The EWS installations are geographically dispersed across areas with markedly different environmental and land-use characteristics. These include the Kariba Dam operational area, settlements and tourism facilities in the Lower Zambezi Valley, road and border environments, agricultural areas, forested locations and relatively remote natural environments. Ambient noise conditions are therefore expected to vary considerably between installation sites.

Locations around Kariba Dam are likely to experience a comparatively active acoustic environment influenced by hydropower operations, maintenance activities, vehicles, machinery, human activity and the movement of water through dam infrastructure. Sites near lodges, settlements, border facilities and major roads are likely to be influenced by vehicle movements, boats, generators, tourism activities, commercial operations, livestock and normal community activities. Conversely, remote forested and rural locations are expected to have relatively low background noise levels dominated by natural sounds such as wind, rainfall, flowing water, insects, birds and other wildlife.

The World Health Organization recognises environmental noise as an important public-health issue and identifies road traffic, other transport systems and leisure activities among the principal sources requiring management. Although the WHO Environmental Noise Guidelines were developed for the European Region, WHO states that their health implications and recommended exposure levels may also be considered applicable in other regions.[7]

5.18.3 Secondary Noise Benchmarks

In the absence of primary measurements, the following World Bank Group/IFC guideline values may be used as assessment and monitoring benchmarks. They should not be presented as measured baseline conditions.

Table 21: Secondary Noise Benchmarks

Receptor category	Daytime, 07:00–22:00	Night-time, 22:00–07:00
Residential, institutional and educational receptors	55 dB(A) LAeq	45 dB(A) LAeq
Industrial and commercial receptors	70 dB(A) LAeq	70 dB(A) LAeq

The IFC guidance also recommends that project-generated noise should not increase the existing background level by more than 3 dB(A) at the nearest off-site receptor. These criteria are commonly applied where national numerical standards are unavailable or require supplementation. IFC project assessments consistently apply the 55 dB(A) daytime and 45 dB(A) night-time limits at residential receptors, together with the maximum 3 dB(A) increase criterion.[8]

Within Zambia, environmental pollution and licensing requirements are principally administered through the Environmental Management Act and the Environmental Management (Licensing) Regulations, Statutory Instrument No. 112 of 2013. ZEMA identifies these Licensing Regulations among the applicable national statutory instruments for pollution control.[9] These benchmarks should be applied cautiously because existing ambient noise levels were not measured. Project compliance should ultimately be confirmed through receptor-based noise monitoring during installation and siren commissioning.

[7] (WHO Environmental Noise Guidelines, 2018).
[8] (IFC noise assessment reference).
[9] (ZEMA statutory instruments; UNEP summary of S.I. No. 112 of 2013).

5.18.4 Existing Sources of Ambient Noise

Potential existing noise sources across the EWS project area include:

- hydropower generation, spillway releases, pumps, turbines, workshops and maintenance activities around Kariba Dam;
- light and heavy vehicles on public roads, access roads, dam infrastructure and border routes;
- boats and other motorised watercraft operating on the Zambezi River and Lake Kariba;
- diesel generators, pumps and utility equipment at lodges, camps, offices and settlements;
- tourism and recreational activities around lodges, riverfront areas and national parks;
- community activities, including conversation, music, markets, schools and places of worship;
- agricultural machinery, livestock and other farming activities;
- construction, road maintenance and small-scale commercial activities;
- wind movement through vegetation, rainfall and flowing water; and
- insects, birds and other wildlife, particularly in forested and protected areas.

Noise-sensitive receptors potentially present near the proposed installations include residential properties, schools, health facilities, lodges, tourism camps, offices, places of worship, wildlife habitats and visitors using conservation and recreational areas.

5.18.5 Potential Project-Related Noise Sources

Noise generated by the proposed EWS Project is expected to be most noticeable during installation, testing and maintenance. Potential sources include:

- movement of installation vehicles and delivery trucks;
- excavation and preparation of approximately 4 m × 4 m equipment foundations;
- concrete mixing, drilling, cutting and fixing of structural components;
- use of hand tools, portable generators and small construction machinery;
- installation and maintenance of automatic rain gauges, automatic water-level recorders and associated communication equipment;
- installation of poles, towers, batteries, solar-power systems and control cabinets;
- testing and commissioning of mini and large warning sirens;
- periodic maintenance visits; and
- emergency activation of warning sirens during an actual flood, dam-safety incident or system exercise.

Most construction-related noise will be temporary, intermittent and confined to the immediate installation area. During normal operation, the automatic rain gauges, water-level recorders and data-transmission equipment are expected to generate negligible audible noise. The principal operational noise source will be the warning sirens.

Siren noise will be intentionally loud and audible over a wide area because its purpose is to warn communities of an imminent flood or dam-related emergency. It should therefore be distinguished from routine environmental noise. Nevertheless, unnecessary disturbance can be reduced through advance notification, short and controlled test durations, daytime testing where practicable and coordination with local authorities, community representatives, lodge operators and wildlife-management agencies.

5.18.6 Baseline Conclusion

Based on secondary information, the existing noise environment ranges from relatively active conditions around Kariba Dam, major roads, border facilities, settlements and tourism establishments to quiet conditions in remote rural, forested and protected areas. The absence of primary measurements means that numerical baseline noise levels and the existing margin of compliance with relevant guidelines cannot presently be established.

The project is unlikely to cause significant continuous noise because most EWS equipment will operate silently or at very low sound levels. Temporary noise will occur during installation and maintenance, while short-duration but high-intensity noise will arise during siren testing and emergency activation. Sensitive receptors located close to proposed sirens should therefore be identified before installation, and baseline and commissioning measurements should be undertaken to confirm audibility, avoid unnecessary disturbance and demonstrate compliance with applicable daytime, night-time and incremental-noise criteria.

EWS Sirens and Warning Equipment

The proposed warning sirens will be an intentional source of intermittent high-intensity sound during testing, emergency drills and actual flood-warning events. Although the sirens are necessary for effective warning dissemination, their operation may temporarily increase noise levels within nearby communities, lodges, wildlife habitats and other sensitive areas.

Kariba Dam Operations

Sampling Point NP-05 was located in the Kariba Dam area, where the existing noise environment is influenced by dam-related activities. Sources of noise include the movement of vehicles and people, operation of machinery and equipment, maintenance activities, water releases and spillages, and the general operation of associated infrastructure.

Vehicular Traffic

Road traffic is an important source of intermittent noise within parts of the project area. Noise may arise from private vehicles, buses, trucks, motorcycles and vehicles used by tourists, lodge operators, local communities, contractors and personnel associated with the operation and maintenance of the EWS.

Lodge and Tourism Activities

Some sampling points were located near lodges in the Lower Zambezi area. Existing noise at these locations may arise from guest activities, staff movements, vehicles, boats, generators, entertainment activities and routine lodge operations. Noise levels may vary depending on the number of visitors, time of day and intensity of tourism activities.

Machinery and Equipment

Machinery used at Kariba Dam, lodges, settlements, construction sites and other operational areas may contribute to the existing noise environment. Potential sources include generators, pumps, maintenance equipment, construction machinery and other mechanical installations.

Construction and Installation Activities

Temporary noise will be generated during the installation of siren towers, telemetry systems, communication equipment and associated EWS infrastructure. Likely sources include excavation, drilling, concrete mixing, vehicle movement, lifting operations, use of hand tools and transportation of construction materials.

EWS Maintenance Activities

Routine inspection, repair and maintenance of the EWS installations may generate short-term and localized noise. Such noise may arise from maintenance vehicles, generators, power tools and testing of sirens and other warning equipment.

Natural Habitat Sounds

Several sampling points were located within or near forested and relatively undisturbed environments. The existing acoustic environment in these areas is predominantly influenced by natural sounds, including birds, insects, wildlife, wind movement through vegetation and flowing water. These natural sounds form part of the baseline acoustic conditions of the Lower Zambezi landscape.

Human Activities and Settlements

Noise within populated areas may arise from conversations, children playing, music, domestic animals, household activities, community gatherings, local businesses and other routine activities. Noise levels are generally higher where households and commercial activities are closely concentrated.

Existing Infrastructure and Land Use

Existing roads, dam infrastructure, lodges, settlements, tourism facilities, commercial activities and other land uses may influence ambient noise levels. The nature and intensity of noise vary between sampling locations depending on the surrounding land use, population density, traffic volumes and level of economic activity. Considering the varied environmental and land-use conditions across the project area, establishing baseline noise levels is necessary to understand the existing acoustic environment before implementation of the EWS Project. The baseline information will provide a reference for assessing potential changes associated with construction, operation, siren testing and maintenance activities. It will also assist in developing appropriate measures to minimise disturbance to communities, lodge operators, tourists, workers, wildlife and other sensitive receptors.

5.19 Socio Economic Environment

This section outlines the social and economic baseline pertinent to the Flood Early Warning System project. A critical aspect of this program is the development and integration of an Early Warning System (EWS). To effectively design and implement this system, comprehensive baseline socio-economic data collection is essential. This serves as a foundation to understand the vulnerabilities, adaptive capacities, and specific needs of the local communities across the downstream of Kariba dam and its surrounding population.

The purpose of these activities is to identify key sensitivities and activities that could potentially contribute to or cause significant impacts on environmental and social receptors and resources. Additionally, these activities aim to evaluate site selection, layout, and technology alternatives for the EWS design.

5.19.1 Significance of Baseline Socio-economic Data Collection

Baseline socio-economic data collection is the preliminary step that informs the planning and development of an EWS tailored to the local context. This data helps in:

- Understanding Community Vulnerability: By collecting demographic data, livelihood sources, poverty levels, and access to essential services, stakeholders can identify which areas and populations are most vulnerable to floods, droughts, or other hydrological events.
- Designing Inclusive EWS: Socio-economic data ensure that the EWS considers diverse community characteristics, including literacy levels, communication preferences, and access to technology.
- Risk Perception and Response Capabilities: Gathering information on how local communities perceive and respond to risks highlights the gaps in awareness and preparedness. This insight helps tailor warning dissemination strategies.

5.19.2 The Approach

The preparation of the socio-economic baseline involved collecting and analyzing data from both primary and secondary sources. A participatory and consultative approach was adopted throughout the process, engaging both primary and secondary stakeholders at various stages. This includes descriptions of demography and socio-economic conditions, such as housing, water facilities, healthcare services, transportation, and education. Information on these factors has been gathered to define the socio-economic profile of the study areas.

5.19.3 Methodology

The study adopted an integrated approach of collecting required data / information which includes primary census survey of data, secondary source information collection, physical observation of the situation, stakeholder consultation, meetings in different identified project locations, discussions with key informants and conducting FGDs. Efforts were made to gather necessary information from local residents through discussions on various aspects. The methodologies chosen for the study were designed to meet the objectives and scope outlined in the TOR. The study followed an observational design, incorporating both qualitative and quantitative methods.

The methodology covered under the study are:

i. interview with the local people under project intervention area
ii. focus groups discussion with the local community;
iii. Observation of the physical setup of the target villages living conditions, infrastructure resilience, and environmental changes in the catchment area;
iv. discussion with local authorities and other local institutions; and
v. discussion with other key stakeholders and KII.

5.19.4 Study Design

The main steps used to design the research involved:

i. focusing lower catchment areas of Zambezi River;
ii. Identifying the towns and villages to be visited in each district within the identified lower catchment areas;
iii. developing questions and guidelines for conducting interviews;
iv. stakeholder mapping in national provincial and district level;
v. conducting interviews and follow-ups with additional interviewees;
vi. transect walks and direct observations within the identified lower catchment areas;
vii. analysis of interview notes; and
viii. synthesis of results and drafting of report.

5.19.5 Source of Information

The detailed sources of information for the socio-economic baseline study are presented in the table below:

Table 22: Source of information

Sources	Information
Secondary	• Project development - physical interventions proposed to be taken up under the project. • Published reports regarding the technical studies, socio-economic, health, latest census data, other statistical information etc. • Unpublished information - reports, data, maps, etc., available with the department or other line agencies; and • Any other information as relevant.
Primary	• Socio-economic information about the directly and indirectly affected communities due to the physical interventions to be developed under the project. • Sample Survey of project intervention area. • Gender issues, occupational health issues.
Public Consultations	• Socio-economic profile of the demarcated project area. • Gender and vulnerable population issues identified through focus group discussions. • Village/town/area information from local administration; and • Any other issues that may need to be addressed under the project.
Key Informant Interviews (KIIs)	The objectives of the key informant interviews were to solicit information regarding the local community, to identify potential impacts and mitigation measures and to discuss community needs.

5.19.6 Tools Used to Gather Information

A combination of structured and unstructured field-study tools was developed to collect socio-economic, institutional and community-level information relevant to the proposed Early Warning System Project. The tools were designed to assess community characteristics, flood-risk awareness, access to communication channels, preferred warning methods, vulnerable population groups, emergency-preparedness capacity and the suitability of proposed siren locations.

Table 23: Detailed Tools Used For the Field Study

Item	Description
Structured questionnaire	A pre-tested questionnaire was administered to selected households and community members within the EWS project area. It was used to collect information on household characteristics, previous flood experiences, access to mobile phones and radio, preferred warning methods, understanding of warning messages, evacuation arrangements and the presence of vulnerable household members.
Key-informant interview guide	This guide was used during consultations with representatives of the Zambezi River Authority, government departments, local authorities, disaster-management institutions, traditional leaders, lodge operators, tourism establishments and other relevant stakeholders. It focused on institutional responsibilities, existing communication systems, emergency-response capacity and coordination requirements.
Village information checklist	The checklist was used to obtain general information about each settlement, including population distribution, settlement patterns, social infrastructure, access roads, communication coverage, flood-prone areas, evacuation routes, assembly points and available community emergency structures.
Institutional consultation checklist	This tool was used to record information from national, provincial, district and local institutions concerning flood-risk management, monitoring systems, warning dissemination, emergency response, regulatory requirements and institutional coordination.
Community consultation checklist	The checklist guided community meetings and focus-group discussions. It was used to document community concerns, previous flood experiences, preferred warning channels, local knowledge, evacuation practices and recommendations concerning the siting and operation of warning sirens.
Vulnerability and inclusion checklist	This tool was used to identify the warning and evacuation needs of children, older persons, women, persons with disabilities, people with limited literacy, tourists and other groups who may require tailored warning messages or additional evacuation assistance.
Siren-location and accessibility checklist	The checklist was used to assess proposed installation sites in relation to settlement coverage, proximity to sensitive receptors, road accessibility, security, land ownership, power availability, terrain, vegetation and potential barriers to sound transmission.
Direct-observation checklist	Field observations were undertaken to document existing land uses, community facilities, roads, communication infrastructure, environmental conditions, flood-risk features and activities surrounding the proposed EWS installations.

Item	Description
GPS and photographic records	Geographic coordinates and photographs were collected to record proposed installation locations, environmental sampling points, access routes and other relevant project features.

5.19.7 Tools Used to Gather Information

A combination of structured and participatory field tools was used to collect socio-economic, institutional and community information relevant to the proposed Early Warning System Project in Zambia and Zimbabwe.

Table 24: Detailed Tools Used During The Field Study

Particulars	Purpose
Structured household questionnaire	Used to collect information on household characteristics, previous flood experiences, access to communication channels, preferred warning methods, evacuation arrangements and vulnerable household members.
Key-informant interview guide	Used during consultations with the Zambezi River Authority, disaster-management institutions, local authorities, government departments, lodge operators and traditional leaders.
Community consultation checklist	Used to document community concerns, local flood knowledge, preferred warning channels, understanding of siren signals, evacuation practices and recommendations on the proposed EWS.
Village information checklist	Used to profile settlements, populations, access roads, communication coverage, flood-prone areas, evacuation routes, assembly points and available emergency structures.
Institutional consultation checklist	Used to obtain information on institutional responsibilities, existing warning systems, emergency-response capacity and coordination arrangements in Zambia and Zimbabwe.
Vulnerability and inclusion checklist	Used to identify the warning and evacuation needs of children, older persons, persons with disabilities, tourists, people with limited literacy and other vulnerable groups.
Siren-site assessment checklist	Used to assess accessibility, settlement coverage, security, power availability, surrounding land uses, terrain, vegetation and potential barriers to sound transmission.
Direct observation, GPS and photographic records	Used to document proposed EWS installation sites, surrounding activities, access routes, environmental conditions and other relevant project features.

5.19.8 Governance and Administration - Zambia and Zimbabwe

The EWS Project covers communities and installations in both Zambia and Zimbabwe. Its implementation will therefore require coordination among binational, national, provincial, district, local and traditional governance institutions. These structures will support project approvals, installation of warning equipment, stakeholder engagement, warning dissemination, evacuation planning and emergency response.

Binational and National Governance

The Zambezi River Authority is the principal binational institution responsible for the management of the Kariba Dam complex and sections of the Zambezi River shared by Zambia and Zimbabwe. For the EWS Project, the Authority will coordinate hydrological monitoring, flood-risk analysis, operation of the warning system and communication of technical information to the responsible authorities in both countries.

At national level, the Governments of Zambia and Zimbabwe operate through their respective executive, legislative and judicial structures. Relevant ministries and agencies in the two countries will provide policy direction, regulatory oversight and technical support for the EWS.

In Zambia, the key institutions include the Zambezi River Authority, Disaster Management and Mitigation Unit, Water Resources Management Authority, Zambia Environmental Management Agency, Ministry of Local Government and Rural Development, Zambia Meteorological Department, local authorities and emergency services. Zambia's decentralisation framework recognises local authorities and Ward Development Committees as important structures for coordinating development and community participation.[10]

In Zimbabwe, implementation will involve the Zambezi River Authority, Department of Civil Protection, Zimbabwe National Water Authority, Environmental Management Agency, Meteorological Services Department, relevant ministries, local authorities and emergency services. Zimbabwe's Civil Protection Act provides the institutional framework for disaster preparedness and establishes civil-protection structures at national and subnational levels.[11]

Coordination between the two countries will be necessary to ensure that:

- Monitoring and forecasting information is shared promptly;
- Warning thresholds and messages are consistent;
- Communities on both sides receive warnings without delay;
- Siren testing is coordinated;
- Emergency-response institutions understand their responsibilities; and
- Flood events affecting both countries are managed through coordinated response arrangements.

Provincial and District Governance

Provincial and district authorities provide the link between national institutions, local authorities and communities. Zambia is divided into ten provinces and 116 districts, while Zimbabwe is divided into ten provinces that are further subdivided into administrative districts.[12]

[10] Zambia National Decentralisation Policy

[11] .Zimbabwe Civil Protection framework

[12] Zambia Statistics Agency, Zimbabwe National Statistics Agency

Within the EWS project area, provincial and district administrations will:

- Coordinate government departments and emergency services;
- Integrate the EWS into disaster-preparedness and response plans;
- Facilitate stakeholder engagement and public sensitisation;
- Assist in identifying evacuation routes, assembly points and shelters;
- Coordinate emergency drills and siren tests;
- Mobilise personnel and resources during emergencies; and
- Communicate local conditions and response needs to national authorities.

In Zambia, District Development Coordinating Committees provide platforms for coordination among government departments, councils, traditional leaders, civil-society organisations and private-sector stakeholders.

In Zimbabwe, Provincial and District Civil Protection Committees coordinate disaster preparedness and emergency response. District Civil Protection Committees are activated to assess emergencies and coordinate response activities within affected districts.[13]

Local Authorities, Wards and Villages

Local authorities in Zambia and Zimbabwe are responsible for local planning, public services, roads, drainage, development control and community-level coordination. The project will involve the relevant city, municipal, town and rural district councils depending on the location of each EWS installation.

For the EWS Project, local authorities will assist with:

- Verification and approval of siren locations;
- Land-access arrangements;
- Community consultations and sensitisation;
- Identification of flood-prone settlements;
- Selection of evacuation routes, shelters and assembly points;
- Mobilisation of communities during drills and emergencies;
- Maintenance of local emergency contact lists; and
- Reporting damage or malfunction of warning equipment.

Wards and villages represent the most immediate governance structures for warning dissemination and evacuation. Ward councillors, community committees, village development structures and community volunteers will help translate technical warnings into local action.

Their responsibilities will include:

- Disseminating warnings through community networks;
- Confirming that warnings have been received and understood;
- Identifying people requiring evacuation assistance;

[13] Zimbabwe disaster-response arrangements

- Mobilising households during emergency drills and flood events;
- Directing residents to safe routes and assembly points; and
- Providing feedback on the effectiveness of sirens and warning messages.

The EWS should use several communication methods, including sirens, mobile-phone messages, radio, public-address systems, community volunteers, lodge communication systems and traditional leadership networks. This will ensure that people who cannot receive one form of warning can be reached through another.

Traditional Governance

Traditional leaders remain important governance actors in rural communities in both Zambia and Zimbabwe. Chiefs, headmen, headwomen and village leaders administer customary matters, represent community interests, support land-access processes and mobilise communities for development and emergency activities.

Traditional leaders will support the EWS Project by:

- Facilitating access to customary land for EWS installations;
- Advising on culturally appropriate installation locations;
- Mobilising communities for consultations and sensitisation;
- Disseminating warnings through established community networks;
- Identifying vulnerable households and people requiring assistance;
- Supporting evacuation drills and emergency response;
- Resolving community-level concerns relating to the project; and
- Communicating community feedback to local and district authorities.

Traditional leaders should receive clear information on warning levels, siren signals, evacuation routes, assembly points and emergency communication procedures. Their participation will help strengthen community trust and ensure that warnings issued by the Zambezi River Authority and national disaster-management institutions result in timely action.

Overall, the EWS governance arrangement should integrate the statutory and traditional structures of Zambia and Zimbabwe. Technical information generated by the Zambezi River Authority should flow through national, provincial, district and community structures so that vulnerable populations on both sides of the Zambezi River receive accurate warnings and respond appropriately.

5.19.9 Social Area of Influence

The proposed Early Warning System Project will be implemented along the Zambezi River corridor downstream of Kariba Dam and will cover vulnerable communities in both Zambia and Zimbabwe. On the Zambian side, the project area extends through parts of Southern and Lusaka provinces, including communities within Siavonga, Chirundu, Kafue and Luangwa districts. On the Zimbabwean side, the social area of influence includes communities and administrative areas situated along the Zambezi River in Mashonaland West and Mashonaland Central provinces.

The project area comprises wards, villages, tourism establishments, fishing areas, agricultural communities and other settlements that may be exposed to riverine flooding, controlled or uncontrolled water releases and potential dam-related emergencies. It also includes communities that may receive warnings, use evacuation routes or depend upon local emergency-response services.

Selection of communities and installation sites will consider:

- Proximity to the Zambezi River and flood-prone areas;
- Historical exposure to flooding and riverine hazards;
- Modelled flood-inundation areas;
- Population size and settlement distribution;
- Location of schools, health facilities, lodges and other sensitive receptors;
- Existing communication coverage;
- Accessibility and evacuation options;
- Presence of vulnerable population groups; and
- Proposed siren coverage and audibility.

The project aims to establish an integrated binational warning network that improves flood-risk awareness, warning dissemination, evacuation preparedness and emergency coordination among communities and institutions in Zambia and Zimbabwe.

Project Area of Influence

For this assessment, the Area of Influence is defined as the geographical and social area within which communities, institutions, livelihoods and infrastructure may be directly or indirectly affected by the construction, operation, testing and maintenance of the EWS. The Area of Influence is not restricted to the physical footprint of siren towers and monitoring installations. It also includes communities that will receive warnings, areas affected by flood hazards, evacuation routes, assembly points, emergency shelters, communication networks and locations used for project access and maintenance.

For assessment purposes, the Area of Influence is divided into direct and indirect areas.

Direct Area of Influence

The Direct Area of Influence includes:

- The physical footprints of sirens, monitoring stations and associated infrastructure;
- Communities located within the modelled flood-inundation area;
- Settlements within the effective coverage of the warning sirens;
- Areas exposed to controlled or uncontrolled water releases;
- Access roads used during installation and maintenance;
- Evacuation routes, assembly points and emergency shelters; and
- Sensitive receptors situated close to the proposed installations.

These areas will receive priority during community sensitisation, warning-system testing, evacuation planning and emergency drills.

Indirect Area of Influence

The Indirect Area of Influence includes surrounding communities and institutions that may not be directly inundated but may experience secondary effects or participate in emergency response. It includes:

- Communities located outside the immediate flood-risk area but within the wider warning network;
- Settlements receiving displaced or evacuated people;
- Health facilities, schools and emergency-service centres;
- Local authorities and disaster-management institutions;
- Tourism establishments and lodges;
- Fishing, agricultural and commercial areas dependent on the river;
- Roads and transport routes that may be disrupted by flooding; and
- Communities affected by noise from siren testing or emergency operation.

Using hazard exposure and siren coverage to define the Area of Influence is more appropriate than applying a fixed distance from the river. Flooding may extend beyond five kilometres in some low-lying areas, while settlements located close to the river may remain outside the modelled inundation zone because of elevation and terrain. The Project Area of Influence will therefore, be refined using flood-risk modelling, site verification, stakeholder consultations and the final locations of EWS installations.

Village and Community Profiles

Profiles were prepared for selected villages and communities in Zambia and Zimbabwe. Information was collected through key-informant interviews, community consultations, direct field observations and discussions with traditional leaders, ward representatives, lodge operators and local authorities.

The village and community profiles documented:

- Estimated population and household numbers;
- Settlement patterns and administrative location;
- Previous flood experiences;
- Main livelihood activities;
- Access roads and transport arrangements;
- Schools, health facilities and other community infrastructure;
- Existing communication channels;
- Mobile-phone and radio coverage;
- Preferred flood-warning methods;
- Evacuation routes and assembly points;
- Available shelters and emergency facilities;
- Vulnerable population groups; and
- Existing community disaster-preparedness structures.

Field teams and moderators were trained to collect and record information consistently in both countries. Where necessary, interviews and consultations were conducted in locally understood languages with the assistance of community representatives.

5.19.10 Population and Demography

This section presents demographic information relevant to the EWS Project in Zambia and Zimbabwe. Particular attention is given to the distribution of people within flood-prone settlements, siren-coverage areas and communities that may require evacuation assistance.

Zambia recorded a population of approximately **19.6 million people** during the 2022 Census. The population increased at an average annual rate of approximately 3.4% between 2010 and 2022. The EWS project area on the Zambian side falls principally within Southern and Lusaka provinces and includes communities in Siavonga, Chirundu, Kafue and Luangwa districts.[14]

Zimbabwe recorded a population of approximately **15.2 million people** during the 2022 Population and Housing Census. The Zimbabwean component of the project includes riverine communities along the Zambezi Valley, particularly within relevant administrative areas of Mashonaland West and Mashonaland Central provinces.[15]

Population distribution across the project area is uneven. Some people live in concentrated settlements and district centres, while others are dispersed across rural villages, fishing camps, farming areas, conservation areas and tourism establishments. Seasonal workers, fishers and tourists may also be present temporarily and may not be reflected fully in resident population figures.

The demographic assessment will therefore consider both resident and temporary populations. Particular attention will be given to:

- Children and school populations;
- Older persons;
- Persons with disabilities;
- Pregnant women and people with medical conditions;
- Households without access to mobile phones or radio;
- People with limited literacy;
- Fishers, farmers and other people working away from settlements;
- Tourists and lodge employees;
- People living in remote or isolated locations; and
- Households requiring assistance during evacuation.

5.19.11 Demographic and Socio-Economic Profile of the Project Districts

The Early Warning System Project is a single binational initiative covering the Zambezi River corridor downstream of Kariba Dam through selected areas of Zambia and Zimbabwe. On the Zambian side, the principal administrative districts are Siavonga, Chirundu, Kafue and

[14] Zambia Statistics Agency
[15] Zimbabwe National Statistics Agency

Luangwa. On the Zimbabwean side, the project corridor includes Kariba Urban, Kariba Rural, Hurungwe and Mbire.

The direct project population comprises communities within modelled flood-inundation zones, siren-coverage areas, evacuation corridors and locations that may be affected by controlled releases, uncontrolled releases or dam-related emergencies. The entire population of each district is not necessarily directly exposed to flooding. District population figures provide the wider demographic context within which vulnerable wards, villages, lodges, fishing camps and other activity areas will be identified.

Table 25: Combined Demographic Profile Of The Principal Ews Project Districts In Zambia And Zimbabwe, 2022

Country	District or administrative area	Male	Female	Total population
Zambia	Kafue	106,552	113,022	219,574
Zambia	Luangwa	17,514	18,419	35,933
Zambia	Chirundu	38,215	40,565	78,780
Zambia	Siavonga	32,701	33,329	66,030
	Zambia subtotal	**194,982**	**205,335**	**400,317**
Zimbabwe	Hurungwe	194,897	196,000	390,897
Zimbabwe	Kariba Rural	22,523	23,251	45,774
Zimbabwe	Kariba Urban	13,687	14,223	27,910
Zimbabwe	Mbire	41,012	42,708	83,720
	Zimbabwe subtotal	**272,119**	**276,182**	**548,301**
	Combined total	**467,101**	**481,517**	**948,618**

SOURCES: ZAMBIA 2022 CENSUS OF POPULATION AND HOUSING AND ZIMBABWE 2022 POPULATION AND HOUSING CENSUS.

The eight principal administrative areas have a combined population of approximately 948,618 people. Zimbabwe accounts for approximately 548,301 people, while the Zambian districts account for approximately 400,317. Females represent a slightly larger share of the combined population, with approximately 481,517 females compared with 467,101 males.

These figures represent the total populations of the administrative districts and should not be treated as the number of people directly at risk. The population requiring direct warning coverage will be determined through flood-inundation modelling, siren audibility studies, settlement mapping, village profiling and field verification.

Population Growth in the Zambian Project Districts

Between 2010 and 2022, the combined population of Kafue, Luangwa, Chirundu and Siavonga increased from 234,932 to 400,317, representing growth of approximately 70.4%. Kafue experienced the largest absolute and proportional increase, growing from 120,415 to 219,574 people, or approximately 82.3%. Chirundu grew by approximately 66.4%, Siavonga by 54.0% and Luangwa by 47.8%. This population growth increases the number of households, schools, health facilities, businesses and livelihood areas that may require warning and evacuation support. It also places additional pressure on roads, communication infrastructure, emergency shelters and local disaster-response institutions.

Urban Population Context in Zimbabwe

In addition to the district populations within the immediate project corridor, the Zimbabwean component operates within a wider national network of urban centres. These centres may support government coordination, emergency services, communication, transport, supplies and technical operations during major emergencies.

Table 26: Estimated Population Of Major Urban Areas In Zimbabwe, 2025

Rank	Urban area	Estimated population
1	Harare	2,117,195
2	Bulawayo	492,771
3	Ruwa	185,224
4	Mutare	149,231
5	Kwekwe	135,991
6	Masvingo	122,019
7	Chinhoyi	97,159
8	Norton	90,287
9	Kadoma	88,029
10	Marondera	87,722
11	Chegutu	69,833
12	Gweru	67,301
13	Mkoba	56,561
14	Zvishavane	55,721
15	Rusape	52,605

SOURCE: 2025 URBAN-AREA ESTIMATES BASED ON UNITED NATIONS URBANISATION DATA, COMPILED BY Worldometer.

Harare is Zimbabwe's largest urban area, with an estimated population exceeding 2.1 million, followed by Bulawayo. Chinhoyi is of particular administrative relevance because it is the provincial capital of Mashonaland West, which includes parts of the Zimbabwean EWS project corridor. Most urban centres listed above are outside the direct flood-risk and siren-coverage area. They are included to provide wider socio-economic and administrative context and should not be added to the directly exposed project population. Kariba Urban, although not included among the 15 largest urban areas, remains the most directly relevant urban centre because of its proximity to Kariba Dam and its concentration of residential, tourism, commercial and dam-related activities.

The 2025 urban figures are projections and may refer to urban agglomerations rather than formal administrative boundaries. They should therefore be interpreted separately from the official 2022 district census figures.

The project area contains a mixture of densely populated urban settlements, small towns, rural villages, tourism facilities, fishing camps, farming areas and remote conservation landscapes. Population distribution is therefore uneven, and the warning system cannot rely on a single communication method.

The demographic profile indicates the need to:

- Install sirens where they can reach concentrated settlements and major activity areas;
- Use mobile-phone alerts and radio for dispersed or isolated communities;
- Engage lodge operators in warning tourists and employees;
- Establish community-based warning arrangements for fishers and farmers working away from settlements;
- Provide accessible warnings for persons with disabilities and people with limited literacy;
- Identify children, older persons and people requiring evacuation assistance;
- Coordinate evacuation across district and national boundaries; and
- Regularly update population and household information in high-risk communities.

5.19.12 Sectoral Analysis of the Project Area

The EWS Project covers communities and economic activity areas along the Zambezi River downstream of Kariba Dam in both Zambia and Zimbabwe. The project area includes urban and rural settlements, border facilities, tourism establishments, farming areas, fishing communities, conservation areas and transport corridors. The socio-economic conditions vary considerably across the project corridor. Chirundu and Kariba contain concentrated urban, commercial and administrative activities, while Luangwa, Mbire, Hurungwe, Kariba Rural and parts of Siavonga and Kafue are characterised by dispersed rural settlements and natural landscapes. These differences shall be considered when designing warning coverage, communication methods and evacuation arrangements.

5.19.13 Settlement Patterns

Settlement patterns within the project area range from established urban centres to small and geographically isolated villages.

Chirundu Border Area

Chirundu is situated on both the Zambian and Zimbabwean sides of the Zambezi River and functions as an important border, trade and transport centre. The One-Stop Border Post supports the movement of people, vehicles and goods between the two countries.

The settlement pattern includes:

- Administrative and commercial areas around the border facilities;
- Low-, medium- and high-density residential areas;
- Transport and logistics facilities;
- Markets, restaurants, retail outlets and other businesses; and
- Villages located on customary land beyond the formal urban settlement.

The concentration of residents, travellers, truck drivers, traders and border personnel means that the EWS must provide warnings to both permanent and temporary populations. Siren placement should consider border facilities, residential areas, markets, parking areas and major transport routes.

Kariba Urban Area

Kariba Urban is an important residential, tourism, commercial and dam-operation centre on the Zimbabwean side. The town contains government offices, residential suburbs, tourism facilities, businesses, transport infrastructure and installations associated with Kariba Dam. The presence of workers, tourists, vehicles, machinery and dam-related operations creates a population that may require rapid warning during controlled releases, uncontrolled releases or dam-related emergencies. Warning arrangements should cover residential areas, commercial centres, tourism facilities, dam installations and major access routes.

Rural Settlements

Rural settlements in Siavonga, Kafue, Luangwa, Kariba Rural, Hurungwe and Mbire are generally dispersed. Some communities are located close to the river, tributaries, fishing areas, floodplains and agricultural land, while permanent villages may be situated on higher ground. Dispersed settlement patterns may reduce siren audibility and mobile-network coverage. These communities will require a combination of sirens, radio, mobile-phone messages, community volunteers, traditional leaders, lodge communication systems and other locally appropriate warning methods.

5.19.14 Employment and Income-Generating Activities

Livelihoods within the binational project area include formal employment, cross-border trade, small businesses, agriculture, livestock production, fishing, tourism and transport services. Many of these activities take place close to the river and may be disrupted by flooding.

Formal Employment

Formal employment is concentrated in district administrations, local authorities, border agencies, health and education institutions, lodges, conservation organisations, dam operations and private businesses. Kariba and Chirundu have comparatively higher levels of formal employment because of border, tourism, transport and dam-related activities. Formal workplaces should be incorporated into EWS communication and evacuation arrangements, including designation of responsible focal persons.

Business and Cross-Border Trade

Chirundu supports significant commercial and cross-border activity involving people from Zambia, Zimbabwe and the wider region. Common enterprises include:

- Clearing and forwarding agencies;
- Transport and logistics services;
- Restaurants and accommodation facilities;
- Retail shops and markets;
- Taxis and other passenger-transport services;
- Informal vending and hawking;
- Money-changing and financial services; and
- Casual labour supporting travellers and commercial vehicles.

Traders, drivers and travellers may be unfamiliar with local warning signals and evacuation routes. Warning messages should therefore be simple, multilingual and supported by visible signs at border facilities, markets, parking areas and other public locations.

Agriculture and Livestock Production

Smallholder agriculture and livestock production are important across the project area. Common crops include maize, sorghum, groundnuts, beans, rice, vegetables, cotton, bananas and citrus fruits. Livestock production includes cattle, goats, pigs, sheep, donkeys and poultry. Low-lying riverbanks and floodplains are used for crop cultivation, grazing and livestock watering. Farmers and herders may therefore be exposed to flooding while working away from permanent settlements. The EWS should include measures for warning people in fields, gardens and grazing areas and should consider the safe movement of livestock during emergencies.

Fisheries

Fishing and fish trading are important livelihood activities along Lake Kariba and the Zambezi and Luangwa rivers. Fishers may spend extended periods on the river, islands, riverbanks or in temporary fishing camps where conventional sirens may not be audible.

Warning arrangements for fishing communities should include:

- Mobile-phone messages;
- Radio communication;
- Lodge and harbour communication networks;
- Community focal persons;
- Boat-based warning arrangements; and
- Clear procedures for returning to safe landing points.

Tourism and Hospitality

Tourism is an important economic activity in Siavonga, Chirundu, Luangwa, Kariba, Hurungwe and Mbire. The project corridor includes lodges, safari camps, conservation areas, national parks and wildlife-management areas. Major tourism resources include Lake Kariba, Lower Zambezi National Park, Mana Pools National Park, the Zambezi and Luangwa rivers, game-management areas and associated wildlife and scenic landscapes. Tourists may not understand local languages, flood risks or siren signals. Lodges and tourism operators should therefore:

- Receive warnings directly from the EWS;
- Maintain guest registers and emergency contact lists;
- Display evacuation instructions;
- Train staff in warning and evacuation procedures;
- Identify safe assembly points; and
- participate in emergency drills and siren testing.

5.19.15 Infrastructure and Social Services

Transport and Accessibility

The project area is served by major highways, district roads, feeder roads, township roads, bridges, boats and limited airstrips. Important transport infrastructure includes the Chirundu border crossing, roads serving Kariba and the D145 road connecting Luangwa to the Great East Road. Some feeder roads and low-lying routes become difficult or impassable during the rainy season. Flooding may isolate settlements, interrupt access to health facilities and delay emergency services.

The project proponent has already identified:

- Roads vulnerable to flooding;
- Alternative evacuation routes;
- Safe river crossings;
- Boat-access points;
- Locations suitable for emergency shelters; and
- Communities likely to become isolated.

Energy and Communication

Urban and administrative areas such as Chirundu and Kariba are generally connected to national electricity networks. Rural communities may depend on solar systems, batteries, generators, firewood and charcoal. EWS installations should use reliable power sources and include backup systems where electricity supply is unavailable or unstable. Solar power and battery storage may be appropriate for remote siren and monitoring sites. Communication services vary across the project corridor. Urban areas generally have stronger mobile and radio coverage, while remote valleys, forests and conservation areas may experience weak or unavailable signals. The EWS should therefore use several communication methods rather than relying solely on mobile networks.

Water Supply and Sanitation

Urban centres are served through combinations of piped water, yard connections, communal water points, boreholes and institutional systems. Rural settlements rely on boreholes, wells, rivers and other surface-water sources. Flooding may contaminate water sources, damage sanitation facilities and increase the risk of waterborne diseases. Flood warnings should therefore be linked to public-health messages concerning safe water, sanitation, food handling and disease prevention.

5.19.16 Education Services

Schools are important social institutions and may serve as warning dissemination points, assembly areas or temporary emergency shelters. Luangwa District recorded a total enrolment of 12,668 learners in 2022, comprising 6,109 boys and 6,559 girls.

Table 27: LUANGWA DISTRICT SCHOOL ENROLMENT BY LEVEL, 2022

Education level	Male	Female	Total
Early Childhood Education	506	542	1,048
Primary education	3,779	3,896	7,675
Grades 8-9	931	1,205	2,136
Grade 10 and above	893	916	1,809
Total	**6,109**	**6,559**	**12,668**

Equivalent education facilities are present in the Zimbabwean project districts, including Kariba, Hurungwe and Mbire. Schools in both countries shall be integrated into the EWS because children may be separated from their families when a warning is issued. Each school within the flood-risk or siren-coverage area should have:

- A designated EWS focal person;
- Clear evacuation procedures;
- Safe assembly points;
- Accessible warning methods;
- Procedures for accounting for learners;
- Arrangements for learners with disabilities; and
- Regular emergency drills.

Where schools are designated as temporary shelters, their water supply, sanitation, accessibility and accommodation capacity should be assessed in advance.

5.19.17 Health Services

Health facilities in the project area range from hospitals and health centres to rural health posts and community-based primary healthcare units. On the Zambian side, facilities include Mtendere Mission Hospital, Katondwe Mission Hospital, Luangwa District Hospital and several health centres and health posts. Luangwa District has 17 formal health facilities supported by community-based primary healthcare structures. Some rural communities are located more than five kilometres from the nearest health facility, and access may become more difficult when roads are flooded. Similar accessibility constraints occur in remote parts of Kariba Rural, Hurungwe and Mbire in Zimbabwe.

Health facilities will have several important EWS responsibilities:

- Receiving and confirming emergency warnings;
- Supporting evacuation of patients;
- Providing first aid and emergency treatment;
- Preparing for flood-related injuries and disease outbreaks;
- Supporting vulnerable persons and people with medical conditions;
- Providing public-health information; and
- Coordinating ambulance and referral services.

5.19.18 Natural Resources and Environmental Livelihoods

Forestry

Large parts of Luangwa, Kafue, Hurungwe, Mbire and the wider Zambezi Valley contain woodland and forest resources. These areas support biodiversity, wildlife, household energy, timber and non-timber forest products. Deforestation, charcoal production, agricultural expansion and wildfires may reduce vegetation cover and increase erosion and runoff. Forested terrain may also reduce siren audibility and restrict access to remote installations.

Conservation and Wildlife

The project corridor contains national parks, game-management areas, safari areas and other wildlife habitats. Human-wildlife conflict may affect evacuation and access, particularly during the rainy season when animals and people use the same routes or water points. EWS infrastructure shall be positioned to avoid unnecessary disturbance to wildlife and sensitive habitats. Emergency plans should also consider the safety of people evacuating through conservation areas.

5.19.19 Implications for the Early Warning System

The sectoral profile shows that the EWS will serve a diverse and mobile population consisting of residents, traders, truck drivers, farmers, fishers, lodge employees, tourists, schoolchildren and public-sector workers. The system should therefore:

- Provide consistent warning messages in Zambia and Zimbabwe;
- Use sirens together with mobile phones, radio, public-address systems and community networks;
- Cover permanent settlements and major activity areas;
- Include border posts, markets, schools, health facilities, lodges and fishing locations;
- Provide multilingual and accessible warning messages;
- Identify alternative evacuation routes where roads are flood-prone;
- Engage traditional leaders and community volunteers;
- Establish direct communication with tourism and transport operators;
- Include backup energy and communication systems; and
- Conduct coordinated binational testing and emergency drills.

5.20 Built Environment and land use

The noticeable built up area near the project site are industries block making, construction and processing companies, such as China Xin Xua, Langani Safaris, Geno Enterprises, Janam Industries Limited including the Katuba Toll Plaza.

5.21 Land Use

The Land Use Land Cover (LULC) analysis for an area downstream of the Kariba Dam, showing potential inundation impacts and potential hotspots if a dam break occurs. The Zambezi River Authority previously completed the Dam Break Analysis study which identified communities and infrastructure at risk. Based on available data, Chikankata, Chirundu, Siavonga, Kafue, Luangwa, and Rufunsa districts could be affected during dam breach scenario. The largest portion of the land is classified as rangeland, covering 2568.79 square kilometers, which accounts for 48.79% of the total area. Forested areas make up the second-largest category with 1966.43 square kilometers or 37.35%. Water bodies occupy 319.19 square kilometers (6.06%), while crop areas cover 238.01 square kilometers (4.52%). Smaller portions of the landscape include flooded vegetation (94.32 square kilometers or 1.79%), bare ground (42.99 square kilometers or 0.82%), and built-up areas (3535.13 square kilometers or 0.67%). This distribution highlights the predominance of rangelands and forests in the potentially affected region. Given the extent of potential inundation, Chirundu, Siavonga, and Luangwa districts would be among the most severely impacted areas in the event of a catastrophic flood following a dam break at Kariba. The flooding could extend to significant portions of protected areas, including Lower Zambezi National Park and Mana Pool National Park, as well as various safari and game reserves along the Zambezi River. These areas are not only vital habitats for diverse wildlife but also support local tourism and conservation efforts.

The installation of Early Warning Systems in these areas is crucial. By providing timely alerts, EWS can help safeguard both human populations and wildlife, enabling rapid evacuations and response measures to minimize loss of life and property. For wildlife, especially in protected parks and game reserves, EWS can allow for the implementation of measures to guide protected area manager to keep eyes on animals located at high-risk zones. Therefore, establishing EWS would play an essential role in managing flood risks, offering communities and conservation areas a critical window to prepare and act before floodwaters arrive. LULC map of inundated area at dam break scenario is depicted in Figure 17while Vulnerability of Settlements Along the Zambezi River in a Dam Break Scenario is shown below.

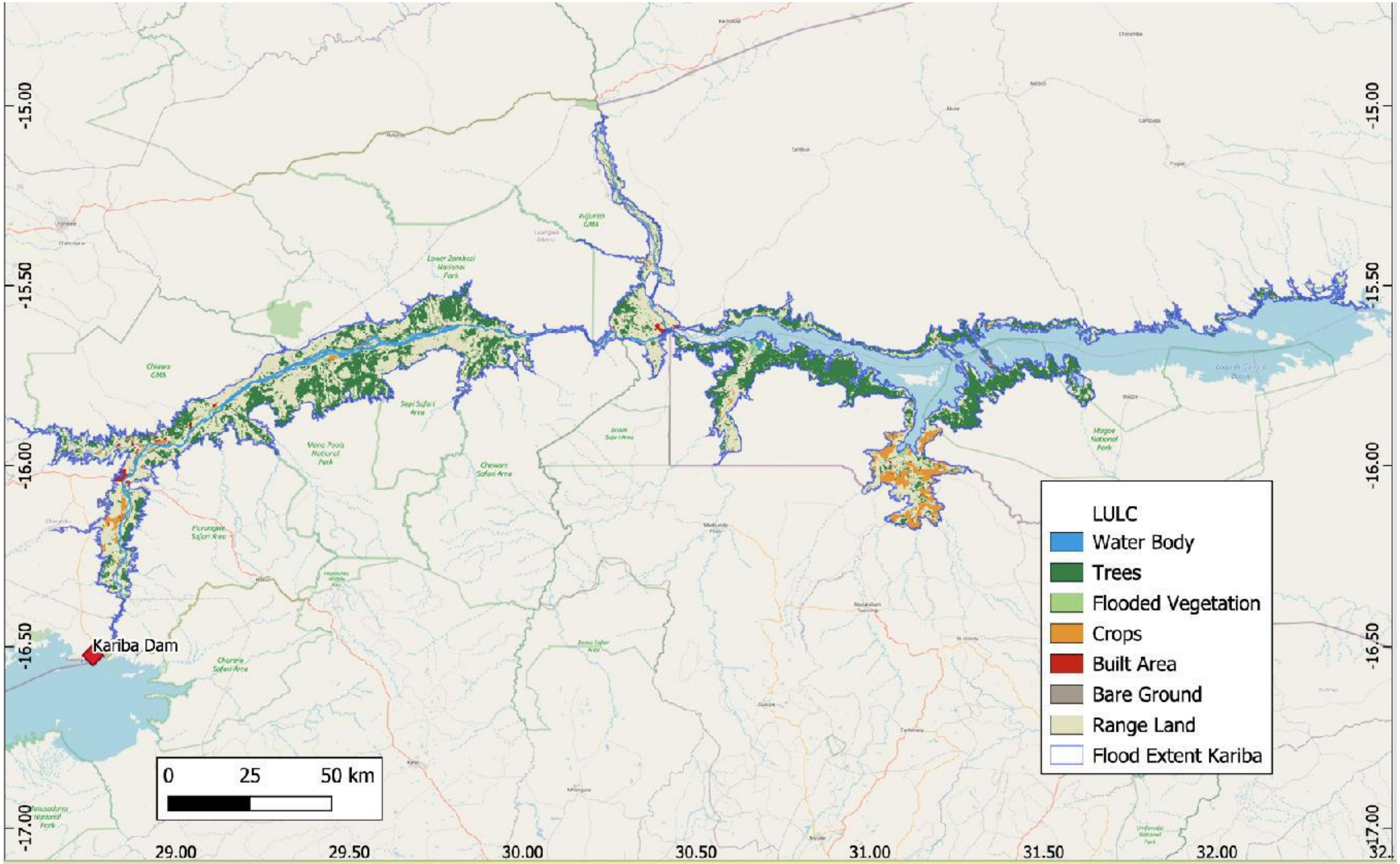

Figure 16: LULC map of inundated area in Dam Break Scenario

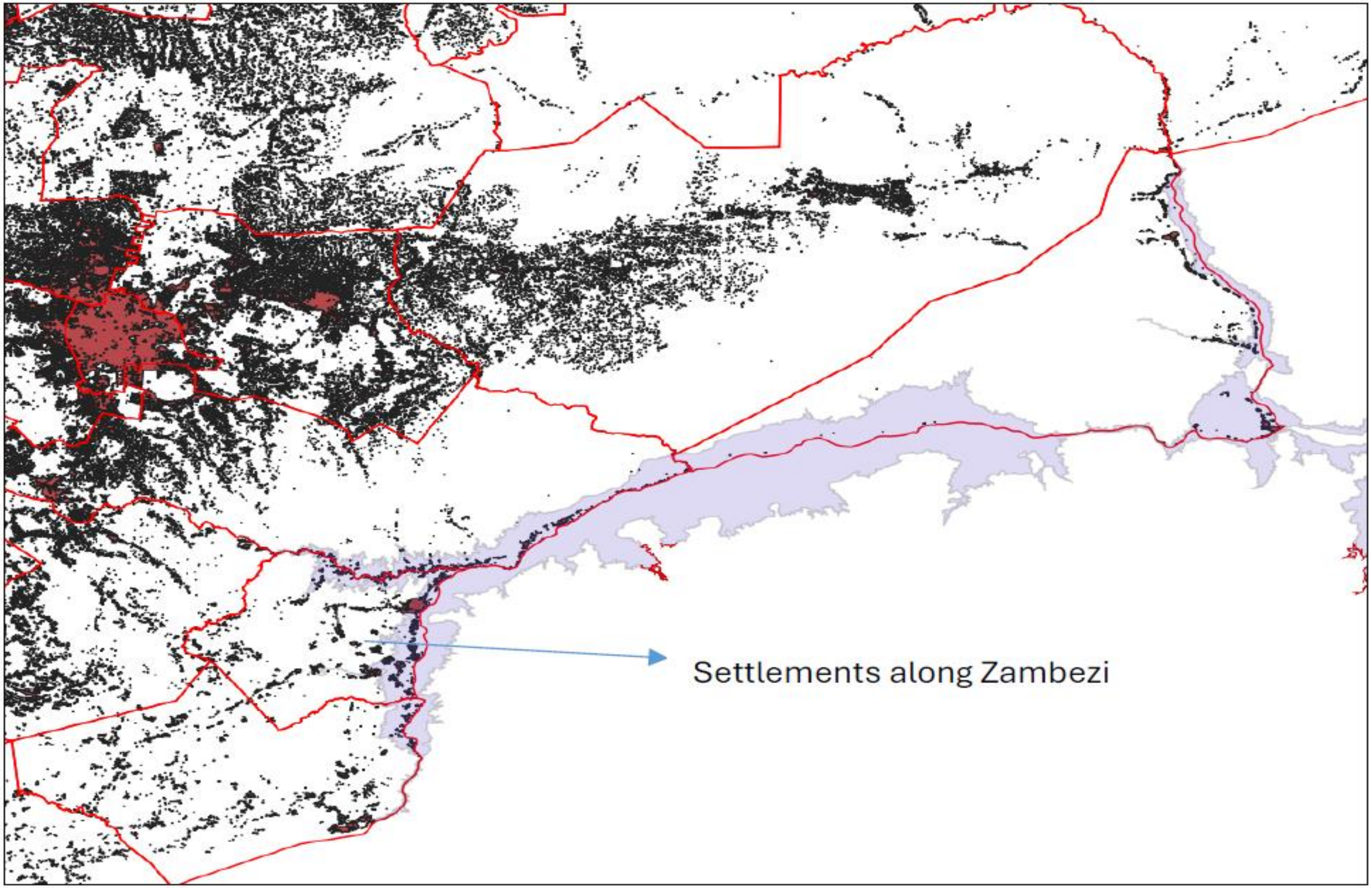

Figure 17: Showing settlement on the Zambezi stretch

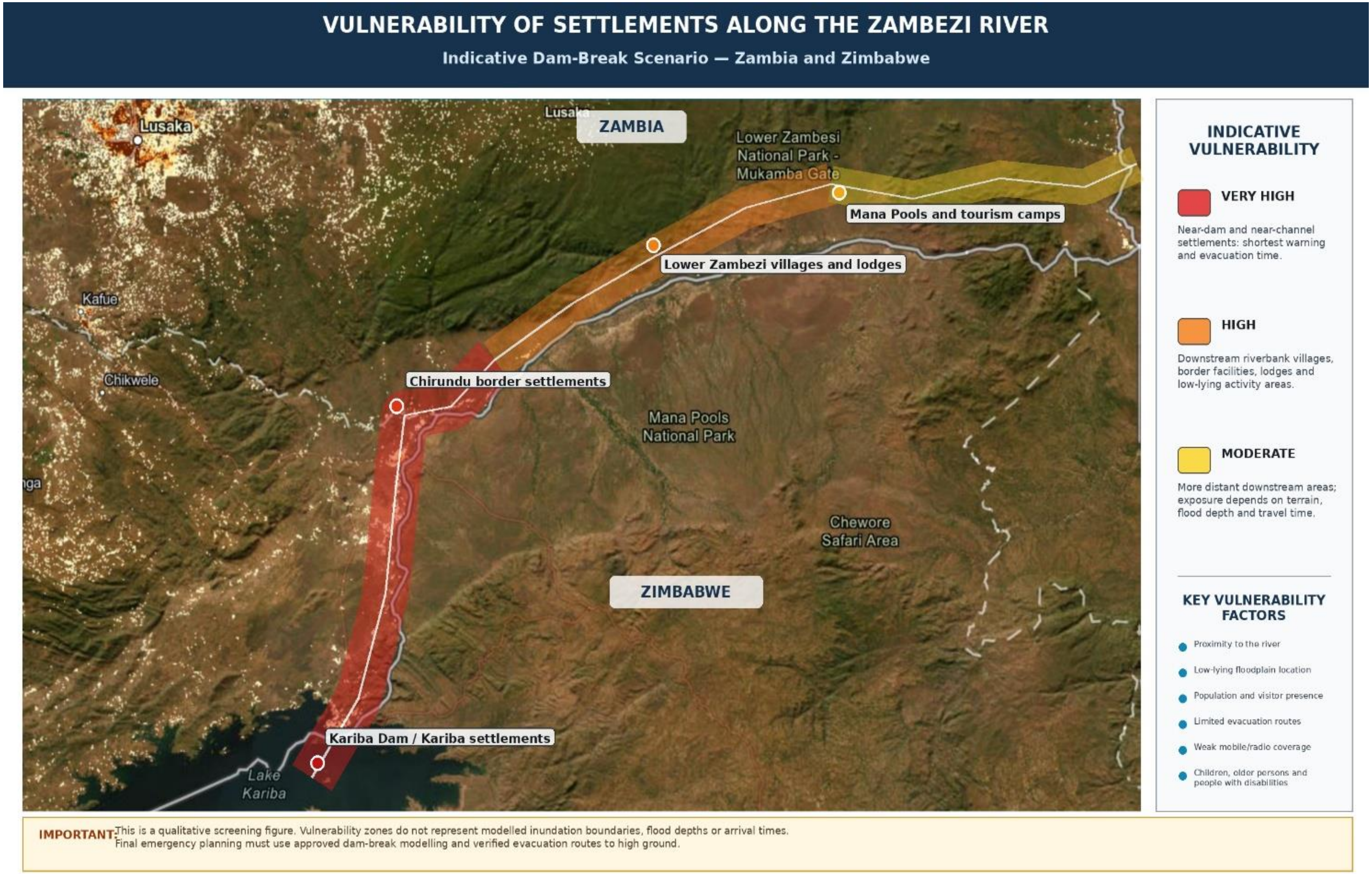

Figure 18: Showing settlement on the Zambezi stretch

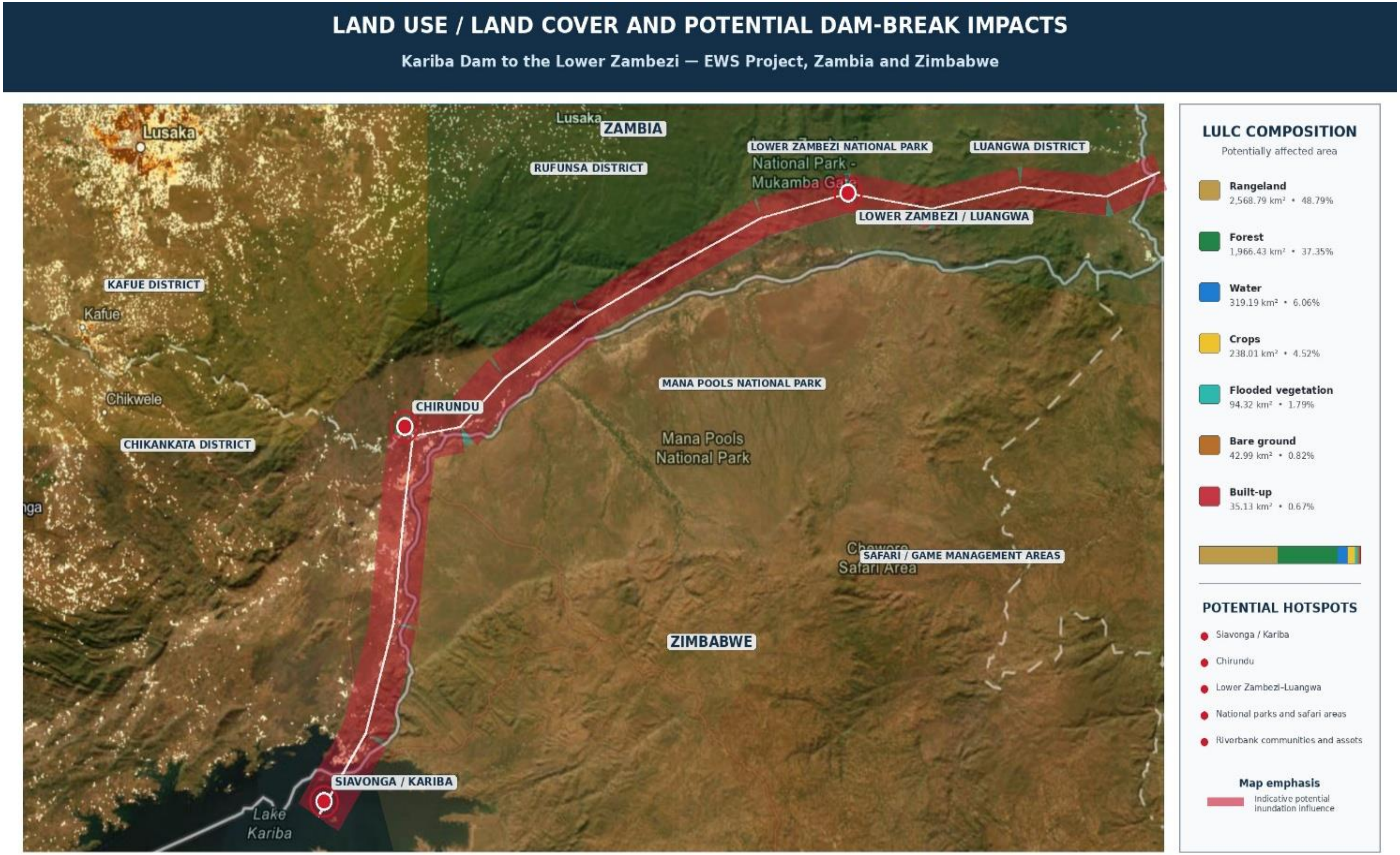

Figure 19: EWS project area Land use Land Cover

5.22 Available cultural, historical or archaeological resources

The proposed EWS Project is a transboundary initiative covering sections of the Zambezi River Basin in Zambia and Zimbabwe. The project will involve the installation and operation of sirens, river-monitoring equipment, telemetry systems, communication infrastructure, control facilities and associated power supplies and access works. Although most installations will occupy relatively small areas, excavation, vegetation clearance, vehicle movement and construction activities could affect known or previously unrecorded cultural, archaeological, historical, sacred or natural heritage resources.

The Zambezi Valley has supported human settlement, trade, migration, spiritual practices and political interaction for centuries. It also contains important geological formations, palaeontological deposits, protected landscapes and places associated with the liberation histories of Zambia and Zimbabwe. Heritage management must, therefore, be addressed as a shared transboundary responsibility. The heritage sites listed below constitute a preliminary inventory based on available project information. Their exact coordinates, boundaries, legal status and relationship to individual EWS installations must be verified through consultation with the National Heritage Conservation Commission (NHCC) in Zambia, the National Museums and Monuments of Zimbabwe (NMMZ), traditional authorities and local communities.

5.22.1 Notable Heritage Resources within the Project Area of Influence

Table 28: Heritage Resources within the Project Area of Influence

Country	Heritage resource	Type and significance	Project relevance
Zambia	Ing'ombe Ilede	An important archaeological site near the confluence of the Lusitu and Zambezi rivers. It contains settlement and burial evidence associated with regional trade networks involving copper, gold, ivory, salt, glass beads and other commodities.	Located within the wider Siavonga-Kariba area. Installations, access routes and emergency infrastructure should avoid the site and its protected surroundings.
Zambia	Kavalamanja-Kakaro Liberation Heritage Site	A nationally protected liberation heritage landscape associated with Zambia's role in supporting regional liberation movements. The site and its surroundings were	Proposed installations near Kavalamanja or Kakaro require prior heritage screening and consultation with NHCC and local custodians.

Country	Heritage resource	Type and significance	Project relevance
		declared a national monument in 2019.	
Zambia	Chirundu Fossil Forest	A palaeontological and geological heritage site containing fossilised tree trunks associated with the Karoo geological sequence.	Relevant to EWS installations, access routes and excavation activities within the Chirundu area. Ground disturbance must be carefully controlled.
Zambia	Chatenta Hot Springs	A natural heritage and culturally valued landscape associated with geothermal springs and local environmental or spiritual traditions.	Installation siting must avoid disturbance to spring outlets, hydrological pathways, associated vegetation and areas of community cultural importance. The official name and protected boundary should be verified with NHCC.
Zambia	Zambezi riverbank sacred and cultural places	These may include burial grounds, shrines, ceremonial areas, sacred trees, traditional crossing points, fishing areas and places associated with oral histories.	Such places may not appear in formal heritage registers. Community consultation is necessary before confirming installation sites.
Zimbabwe	Mana Pools National Park, Sapi and Chewore Safari Areas	A UNESCO World Heritage property covering approximately 6,766 km^2 and recognised for its Zambezi floodplain, geological processes, wildlife concentrations and wilderness values.	EWS installations must protect the property's Outstanding Universal Value, landscape character and ecological integrity. Visual intrusion and disturbance from towers, sirens, access works and power systems should be minimized.
Zimbabwe	Big Tree, Victoria Falls	A prominent old baobab associated with the natural and historical landscape of Victoria Falls. It is also an established tourism and landmark feature.	Installations in the Victoria Falls area should avoid physical damage, visual intrusion and changes to the setting of the tree and associated visitor areas.
Zimbabwe	Ngamo Village, Hwange District,	A living cultural landscape associated	Community engagement should document sacred

Country	Heritage resource	Type and significance	Project relevance
	Matabeleland North	with the traditions, livelihoods, settlement history and social identity of communities near Hwange National Park.	places, graves, traditional structures, oral histories and culturally important landscape features before installation works begin.
Zimbabwe	Kennedy Vlei, Hwange National Park	A natural heritage landscape consisting of an open fossil drainage or vlei system associated with pans, wildlife movement and tourism activities.	Installation works should avoid disturbance to drainage patterns, wildlife movement, scenic qualities and visitor experiences.
Zimbabwe	Chirundu historical landscape and bridges	A transboundary settlement and transport landscape containing the historic and modern bridges connecting Zambia and Zimbabwe.	EWS equipment should be positioned without affecting bridge operations, historically important structures or the visual character of the border landscape.
Zimbabwe	Kariba lakeshore and riverbank heritage resources	These may include former settlement areas, fishing places, sacred sites, graves, archaeological deposits and places associated with the construction of Kariba Dam and the displacement of Tonga communities.	Consultation with affected communities and traditional authorities is required because many culturally important places may be undocumented or submerged.
Both countries	Intangible cultural heritage of Zambezi communities	Includes oral traditions, flood knowledge, river-based beliefs, ceremonies, traditional warning practices, fishing knowledge, place names and community memories of displacement and previous floods.	EWS messages, siren locations, evacuation routes and emergency procedures should incorporate local knowledge and culturally appropriate communication methods.

The Zimbabwean resources at Ngamo Village, Kennedy Vlei, Hwange and Victoria Falls lie within the wider EWS project landscape but may not fall within the direct downstream Kariba inundation corridor. Their relevance should therefore be determined against the final location of proposed EWS installations.

5.22.2 Potential Heritage Impacts

The relatively small footprint of individual EWS components reduces the likelihood of extensive heritage disturbance. However, impacts may occur through excavation for foundations, erection of towers and sirens, construction or improvement of access tracks, installation of underground cables, removal of vegetation and movement of vehicles and machinery.

Potential impacts include:

- accidental disturbance of archaeological deposits, graves, fossils or historical structures;
- damage to sacred trees, shrines, hot springs and ceremonial places;
- visual intrusion within protected landscapes, tourism areas and heritage settings;
- noise disturbance from siren testing near sacred places, cultural sites, lodges and protected areas;
- restricted community access to fishing areas, burial grounds or ceremonial places;
- disturbance of wildlife and landscape values within Mana Pools, Sapi, Chewore, Hwange and other protected areas; and
- loss of undocumented oral histories and traditional knowledge where local communities are not adequately consulted.

5.22.3 Relevant Legal and Administrative Framework

Zambia

Heritage resources in Zambia are principally protected under the National Heritage Conservation Commission Act, Chapter 173 of the Laws of Zambia, as amended. The Act establishes the NHCC and provides for the identification, conservation and management of archaeological, cultural, historical, palaeontological and natural heritage resources. It also regulates archaeological investigations and activities that could alter or damage protected heritage.

The project must obtain guidance or approval from NHCC before undertaking works within or near a declared national monument or known archaeological site. Any suspected archaeological material, fossils, human remains or cultural objects discovered during construction must be protected and reported to NHCC.

Zimbabwe

Heritage resources in Zimbabwe are administered principally through the National Museums and Monuments of Zimbabwe under the National Museums and Monuments Act [Chapter 25:11]. The legislation provides for the protection of monuments, archaeological sites, historical places, relics and other heritage resources. EWS installations proposed near known or suspected heritage places must be screened in consultation with NMMZ. No archaeological object, grave, historical structure or protected monument should be excavated, removed, damaged or altered without the required authorization.

International Standards and Conventions

Both Zambia and Zimbabwe are States Parties to the 1972 UNESCO Convention Concerning the Protection of the World Cultural and Natural Heritage. Zambia became a State Party in 1984 and Zimbabwe in 1982. Other applicable international instruments and standards include:

Instrument or standard	Application to the EWS Project
UNESCO World Heritage Convention, 1972	Requires protection of World Heritage properties and their Outstanding Universal Value, particularly Mana Pools, Sapi and Chewore Safari Areas.
UNESCO Convention for the Safeguarding of the Intangible Cultural Heritage, 2003	Supports the protection of traditional knowledge, oral histories, cultural practices and community relationships with the Zambezi River.
UNESCO Recommendation on International Principles Applicable to Archaeological Excavations, 1956	Provides principles for archaeological investigation, documentation, conservation and control of artefact removal.
ICOMOS Charter for the Protection and Management of the Archaeological Heritage, 1990	Promotes archaeological surveys, integrated planning, in-situ conservation and appropriate management of archaeological resources.
IFC Performance Standard 8: Cultural Heritage	Requires identification and protection of tangible and intangible heritage and consultation with affected communities and traditional custodians.
African Development Bank environmental and social safeguards	Require the assessment and management of impacts on cultural heritage, communities and protected landscapes.

5.22.4 Heritage Management and Compliance Measures

Before construction begins, all proposed EWS installation sites, access routes and associated infrastructure should be screened against available heritage registers. NHCC and NMMZ should be consulted on installations near known monuments, archaeological sites, protected landscapes or culturally sensitive areas.

The project should implement the following measures:

- avoid Ing'ombe Ilede, Kavalamanja-Kakaro, Chirundu Fossil Forest and other protected sites;
- consult traditional leaders, village representatives, cultural custodians, tourism operators and heritage authorities;
- confirm the location of graves, sacred trees, shrines, ceremonial areas and other undocumented heritage;
- minimize the visibility of towers, solar panels and communication structures within sensitive heritage landscapes;
- schedule siren testing to avoid ceremonies, tourism-sensitive periods and unnecessary disturbance;
- prohibit workers from collecting fossils, artefacts or cultural objects;
- train workers to recognise potential archaeological discoveries and human remains;
- establish a transboundary chance-find procedure applicable in both countries; and

- maintain a project heritage register containing site coordinates, photographs, protection requirements and responsible authorities.

If archaeological material, fossils, graves or other suspected heritage resources are discovered, work must stop within the immediate area. The location should be secured, the discovery should not be moved or disturbed, and the relevant authority—NHCC in Zambia or NMMZ in Zimbabwe—must be notified. Construction should resume only after written authorization and completion of any required investigation, recovery or protection measures.

5.22.5 Archaeological Survey Summary

An archaeological and cultural heritage reconnaissance survey was undertaken at selected locations proposed for the installation of Early Warning System infrastructure in Zambia and Zimbabwe. The assessment focused on the immediate footprints of proposed sirens, monitoring stations, communication equipment, control facilities, solar-power installations and associated access routes.

The survey involved pedestrian inspection of accessible areas, examination of exposed ground surfaces and consultation with local representatives where possible. Particular attention was given to:

- proposed equipment foundations and installation areas;
- existing access tracks and areas where new access may be required;
- riverbanks, terraces and other elevated surfaces overlooking the Zambezi River;
- exposed soil profiles, erosion channels and previously disturbed ground;
- anthills and animal burrows that could expose subsurface material;
- quartz concentrations, stone alignments and other possible archaeological indicators;
- old settlement areas, charcoal-burning locations and abandoned activity areas;
- graves, sacred trees, shrines and places of traditional or spiritual importance; and
- soil excavated during previous construction, road, utility-pole and infrastructure works.

Photographs and GPS coordinates were recorded for inspected locations and features requiring further assessment. No previously unrecorded archaeological artefacts, archaeological structures or human remains were identified on the ground surface within the specific EWS installation footprints inspected during the baseline survey.

This finding should not be interpreted as confirmation that the entire transboundary project area is free of archaeological or cultural heritage resources. The EWS project covers an extensive landscape along the Zambezi River with a long history of human occupation, trade, migration, settlement, fishing, ritual activity and political interaction. Surface visibility was also limited in some areas by vegetation, accumulated sediments, existing infrastructure and previous ground disturbance.

Known heritage resources within the wider project area include Ing'ombe Ilede, the Kavalamanja-Kakaro Liberation Heritage Site, Chirundu Fossil Forest, Chatenta Hot Springs and culturally significant riverbank landscapes on the Zambian side. On the Zimbabwean side, relevant resources include the Kariba cultural landscape, Chirundu historical landscape, Mana Pools, Sapi and Chewore Safari Areas, the Big Tree at Victoria Falls, Ngamo Village, Kennedy Vlei and other natural and cultural places associated with communities along the Zambezi Valley.

Some proposed EWS locations occur within or near lodges, settlements, border facilities, protected areas and previously developed sites. Disturbance at these locations may have reduced the visibility or integrity of surface archaeological material. Conversely, less-disturbed river terraces, floodplains and woodland areas may retain buried archaeological deposits even where no surface artefacts are visible.

Accordingly, the absence of surface discoveries does not eliminate the possibility of subsurface archaeological deposits, graves, fossils or culturally significant features being encountered during excavation.

5.22.6 Summary of Archaeological and Cultural Heritage Findings

No previously unrecorded archaeological sites or artefacts were identified within the specific EWS installation footprints examined during the field reconnaissance. However, the broader Zambia-Zimbabwe project area contains documented archaeological, historical, liberation, palaeontological, natural and living cultural heritage resources.

The Zambezi Valley has supported human communities from the Stone Age through the Iron Age and into the historical period. Archaeological resources that may occur within the wider landscape include:

- Stone Age occupation sites and stone-tool scatters;
- Iron Age settlements and metalworking areas;
- burial grounds and isolated graves;
- historical settlements and abandoned villages;
- trade and river-crossing locations;
- liberation heritage sites;
- rock shelters and rock-art locations;
- palaeontological and fossil-bearing deposits;
- sacred trees, springs, pools and riverbank places;
- traditional fishing, ceremonial and spiritual sites; and
- places associated with the displacement of communities during construction of Kariba Dam.

Although some archaeological material may have been disturbed by road construction, agriculture, tourism development, settlement expansion, utility installation and other previous activities, intact deposits may remain beneath the surface. River sediments can also bury and preserve archaeological material, making it difficult to identify during surface inspection.

Before construction begins, the final coordinates of all EWS installations should be submitted to the National Heritage Conservation Commission in Zambia and the National Museums and Monuments of Zimbabwe for review. Additional investigation may be required where an installation falls near a registered monument, burial place, sacred site, protected area or archaeologically sensitive landform. A chance-find procedure must be implemented throughout construction. If artefacts, fossils, graves, human remains, historical structures or other suspected heritage resources are discovered, work must stop within the immediate area. The discovery must be protected and reported to the relevant national heritage authority before work resumes.

5.22.7 Geomorphological, Geological and Palaeontological Heritage Resources

No previously unrecorded geomorphological, geological or palaeontological heritage resources were identified within the immediate footprints of the EWS installations inspected. However, important resources are present within the broader transboundary project area. These include the Chirundu Fossil Forest, which contains fossilised tree remains associated with the Karoo geological sequence, as well as hot springs, river terraces, gorges, escarpments, former river channels, floodplains, wetlands and fossil drainage systems along the Zambezi Valley.

On the Zimbabwean side, Mana Pools represents a significant geomorphological landscape formed by historical channels of the Zambezi River and continuing processes of erosion, sediment deposition and floodplain development. Kennedy Vlei and associated pans within Hwange also form part of a fossil drainage landscape with ecological, scenic and natural heritage value.

Potential impacts from EWS development are expected to be limited because of the small physical footprint of individual installations. Nevertheless, excavation, access-road construction and foundation works could affect fossil-bearing deposits, spring systems, river terraces or other sensitive landforms if installations are poorly located.

The following measures should therefore be implemented:

- avoid known fossil, hot-spring and geological heritage sites;
- prohibit excavation or collection of fossils without authorization;
- avoid altering natural drainage channels and spring outlets;
- minimize excavation on undisturbed river terraces and exposed geological formations;
- use existing access routes wherever practicable;
- immediately report suspected fossil or geological discoveries; and
- obtain clearance from the relevant heritage authority before undertaking work near a protected geological or palaeontological site.

6 ENVIRONMENTAL IMPACT OF THE PROJECT

6.1 Overview

The proposed EWS project is a distributed, small-scale monitoring and warning infrastructure project rather than a conventional large civil works, industrial, mining or extractive development. The principal physical components comprise ARGs, radar-based AWLRs, non-contact flow/discharge monitoring stations, large and mini sirens, communication equipment, solar-power systems, batteries, small equipment enclosures and associated foundations. The project also includes the establishment/upgrading of the Command and Control Centres.

The EWS does not involve large-scale excavation, river diversion, dam construction, quarrying, mineral extraction, industrial processing or continuous operation of heavy machinery. Field installation works will generally be limited to small foundations, mounting structures, poles/masts, equipment cabinets, solar panels, communication antennas, fencing and short cable/conduit connections. The permanent footprint of individual field installations is therefore very small, generally within an approximately 4 m × 4 m core area, subject to the final engineering design and site conditions.

Construction activities will mainly comprise mobilisation, transport of equipment and materials, minor vegetation clearance where unavoidable, foundation excavation, concrete preparation and placement, erection of poles/masts, installation of monitoring and communication equipment, electrical connections, fencing, testing and commissioning. Most equipment, including ARGs, AWLRs, radar sensors, sirens, solar panels, batteries and communication units, will be procured as manufactured equipment and assembled, mounted and commissioned at the site, rather than fabricated or produced there. Consequently, the construction phase will involve limited quantities of construction materials, water, fuel and energy and relatively small amounts of waste. The use of heavy machinery will be limited and generally short-duration. Where practicable, existing roads, tracks, institutional premises, tourism facilities and previously disturbed locations will be used to avoid opening new access routes and unnecessary vegetation clearance.

The operational phase will have an even smaller environmental footprint. The ARGs, AWLRs and flow-monitoring stations are automated installations requiring only periodic inspection, calibration and maintenance. Remote stations are expected, where provided in the final design, to use solar photovoltaic systems and battery storage, resulting in low routine energy consumption and minimal dependence on diesel generators. The principal operational activities will comprise remote monitoring, data transmission, control-centre operation, periodic equipment inspection, maintenance, testing and emergency activation of warning systems.

The environmental impacts are therefore expected to be predominantly localised, low in intensity and short-term during construction, with limited ongoing impacts during operation. Nevertheless, individual sites may have higher sensitivity where they are close to rivers, riparian areas, protected areas, wildlife habitat, settlements, schools, health facilities, tourism establishments or cultural resources. Site-specific controls will therefore be applied rather than treating all EWS locations as having the same environmental and social sensitivity. The assessment considers impacts during:

1. Pre-construction
2. Construction, installation and Testing & commissioning
3. Operation and routine maintenance; and
4. Replacement/decommissioning and site restoration.

Where unanticipated impacts occur, corrective measures will be implemented in accordance with applicable environmental, social and heritage legislation in Zambia and Zimbabwe, permit conditions and the project ESMP.

6.2 Core Area and Buffer/Influence Area

- **Core Area:** The core area for each EWS installation is approximately 4 m × 4 m (16 m^2) and represents the permanent physical footprint of the siren, ARG or AWLR, including its foundation, equipment, solar panel/battery, communication components and associated infrastructure. The existing Common Control Centre will be used for system integration, control and monitoring, with no additional land requirement.
- **Buffer/Influence Area:** A 100 m buffer/assessment area around each EWS installation is considered for assessing potential construction-related and operational effects, including temporary access, movement of workers and vehicles, dust, construction noise, minor vegetation disturbance, wildlife disturbance and interactions with nearby communities or sensitive receptors. The 100 m buffer is an assessment/influence area only and does not represent a permanent project footprint, land requirement or land acquisition area. For sirens, the acoustic influence area may extend beyond 100 m and will be considered separately based on the siren's sound output and relevant sensitive receptors.

  For sirens, the acoustic influence extends beyond the physical footprint. Nearby residences, schools, health facilities, tourism facilities, workplaces, protected areas and other sensitive receptors will therefore be considered based on site-specific acoustic propagation and the manufacturer's certified performance. Emergency activation is a life-safety function; management will focus primarily on controlled testing, advance notification, access control and worker hearing protection.

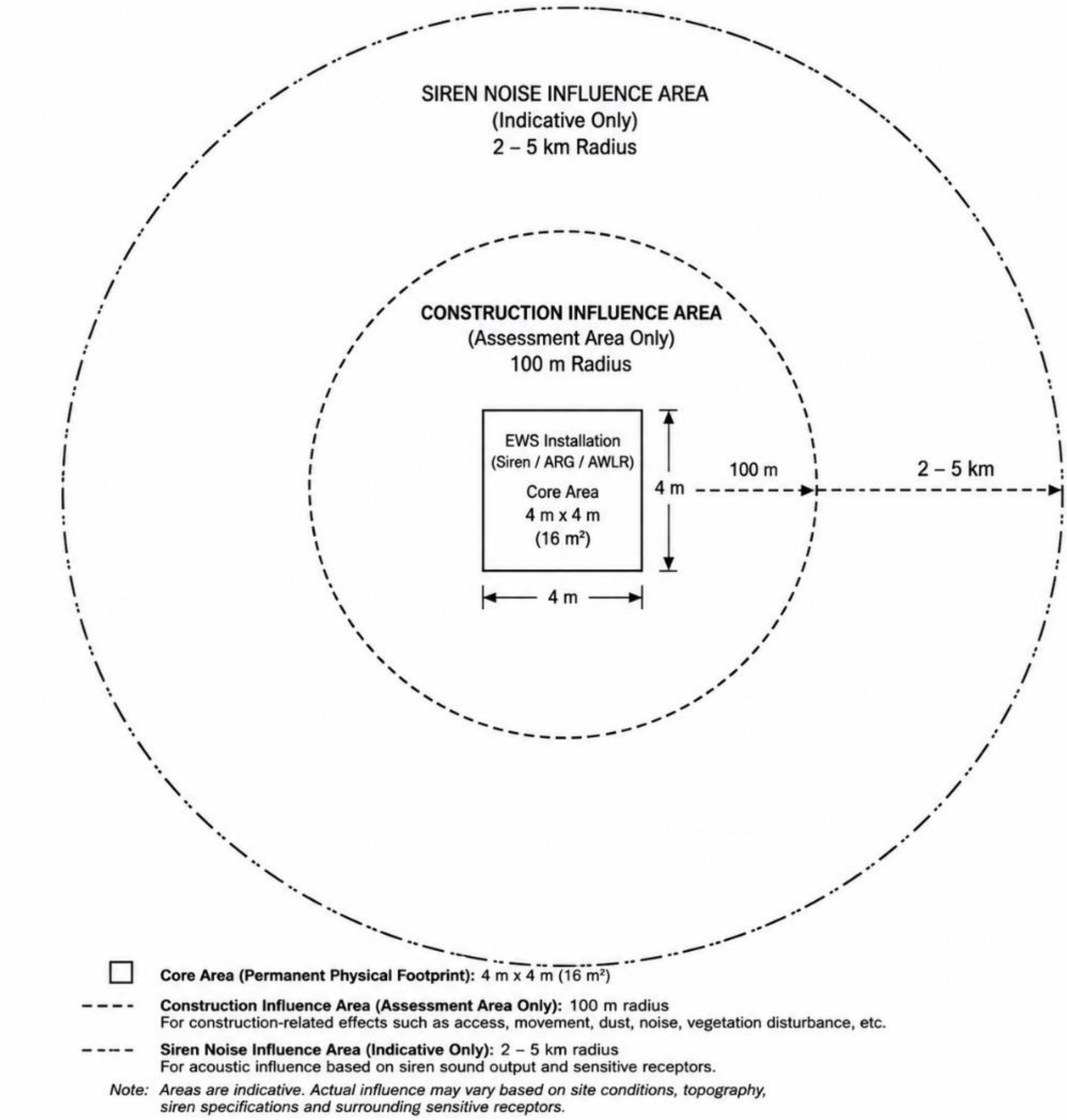

Figure 20: Core and Buffer Area Considered for Impact Assessment

6.3 Impact Assessment Methodology

6.3.1 Approach

The assessment identifies the relationship between project activities and potentially affected environmental and social receptors. Impacts have been assessed based on available baseline information, site observations, proposed EWS infrastructure, project activities, stakeholder considerations, applicable regulatory requirements and professional judgement. The assessment considers both positive and negative impacts and distinguishes between the impact expected before mitigation and the residual impact after mitigation.

6.3.2 Types of Impact

- A direct impact results immediately from a project activity, such as vegetation clearance during foundation construction or noise from construction equipment.

- An indirect impact occurs as a secondary consequence, such as improved community preparedness resulting from warning dissemination.
- A cumulative impact occurs where project effects interact with existing or planned activities such as tourism development, settlements, roads, communication infrastructure and other activities along the Zambezi corridor.
- A transboundary impact is particularly relevant to the EWS because the Zambezi River and associated flood hazards cross the Zambia-Zimbabwe boundary. Improved warning coordination is a positive transboundary impact, while inconsistent warnings, failure of critical communication systems or inadequate coordination could create transboundary safety risks.

6.3.3 Significance Classification

Table 29: Significance Classification

Significance	Interpretation
Negligible	No meaningful change or change within normal background variation
Low	Localised, short-term and readily manageable impact
Moderate	Noticeable impact requiring specific mitigation, monitoring and management
High	Significant impact on an important or sensitive receptor requiring priority management
Critical	Potentially unacceptable impact requiring avoidance, redesign or fundamental additional controls

For positive impacts, Minor, Moderate and Major Positive categories are used.

6.3.4 Impact Evaluation Criteria

The potential environmental and social impacts associated with the EWS project are evaluated using the following criteria. The potential environmental and social impacts associated with the EWS project are evaluated using the following criteria. Each impact is assessed in terms of its nature, extent, duration, intensity, likelihood, receptor sensitivity, reversibility and overall significance, including the residual significance after mitigation.

Criterion	Evaluation
Status/Nature	Positive, negative or neutral
Type	Direct, indirect, induced, cumulative or transboundary
Spatial extent	Site, local, district, national or transboundary
Frequency	Once, occasional, periodic, repeated, continuous or emergency-related
Duration	Temporary, short-term, medium-term, long-term or permanent
Intensity/Severity	Negligible, low, moderate, high or very high
Probability	Unlikely, possible, probable or almost certain
Receptor sensitivity	Low, moderate, high or very high
Significance	Negligible, Low, Moderate, High or Critical
Residual significance	Significance remaining after mitigation

The evaluation of identified impacts on the socio-economic, physical, and biological environments is presented in the following tables. The tables provide the assessment of each impact against the defined evaluation criteria, including its type, spatial extent, status, frequency, duration, intensity/severity, probability, and receptor sensitivity.

Table 30: Evaluation of Impacts on Socio-economic Environment

Project phase	Description of impact	Type	Spatial extent	Status	Frequency	Duration	Intensity / severity	Probability	Receptor sensitivity	Significance before mitigation	Residual significance
Negative Impacts											
Pre-construction	Failure/delay in obtaining required Consents, Permits, Clearances and NOCs	Direct/ indirect	Local/national	Negative	Once	Short-medium term	Moderate	Possible	-	Moderate	Low
Pre-construction	Inadequate site-specific Construction Plan covering material sources, labour, machinery/equipment, access and transportation logistics	Direct/indirect	Site/local	Negative	Once	Short term	Moderate	Possible	-	Moderate	Low
Pre-construction	Temporary land access and use of installation sites	Direct	Site/local	Negative	Once/occasional	Short term	Low	Probable	Moderate	Low	Low
Pre-construction	Community concerns regarding installation locations and land ownership	Direct/indirect	Local	Negative	Occasional	Short term	Moderate	Possible	Moderate	Moderate	Low
Pre-construction	Exclusion of vulnerable groups from consultation and warning-system planning	Indirect	Local/transboundary	Negative	Periodic	Medium-long term	Moderate-high	Possible	High	High	Moderate-Low
Pre-construction	Disturbance of cultural, archaeological, burial or sacred resources through inappropriate siting	Direct	Site/local	Negative	Once	Long term	High	Possible	High	High	Low
Construction	Construction traffic and road-safety risks	Direct	Local	Negative	Repeated	Short term	Moderate	Probable	Moderate	Moderate	Low
Construction	Occupational accidents, work at height and electrical hazards	Direct	Site	Negative	Occasional	Short term	High	Possible	High	High	Moderate-Low
Construction	Drowning and wildlife encounters during river-based work	Direct	Site/local	Negative	Occasional	Short term	High	Possible	High	High	Moderate-Low
Construction	Worker exposure to dust, noise, heat and adverse weather	Direct	Site/local	Negative	Repeated	Short term	Moderate	Probable	Moderate	Moderate	Low
Construction	Community health and safety risks from open excavations, vehicles and equipment	Direct	Site/local	Negative	Repeated	Short term	Moderate	Possible	Moderate	Moderate	Low

Table 30: Evaluation of Impacts on Socio-economic Environment

Project phase	Description of impact	Type	Spatial extent	Status	Frequency	Duration	Intensity / severity	Probability	Receptor sensitivity	Significance before mitigation	Residual significance
Construction	Social conflict arising from employment, procurement or site selection	Direct/indirect	Local	Negative	Occasional	Short term	Moderate	Possible	Moderate	Moderate	Low
Construction	GBV, SEA/SH and inappropriate worker behaviour	Direct/indirect	Local	Negative	Occasional	Short term	High	Possible	High	High	Moderate-Low
Construction/operation	Fire affecting communities or facilities from hot works, electrical systems or equipment	Direct/indirect	Local	Negative	Occasional	Short-long term	High	Possible	High	High	Low-Moderate
Operation	Warning-system failure or malfunction during an emergency	Direct/indirect	Local/transboundary	Negative	Occasional/emergency	Short term but high consequence	Very high	Unlikely-possible	Very high	High/Critical consequence	Moderate-Low Risk
Operation	False or inconsistent warnings	Direct/indirect	Local/transboundary	Negative	Occasional	Short term	High	Possible	High	High	Low-Moderate
Operation	Unequal access to warnings	Indirect	Local/transboundary	Negative	Emergency-related	Medium-long term	High	Possible	High	High	Moderate-Low
Operation	Electric fencing and potential safety risks to people	Direct	Site/local	Negative	Periodic	Long term	High	Possible	High	High	Low-Moderate
Operation	Theft, vandalism or deliberate damage to EWS equipment	Direct	Local/transboundary	Negative	Occasional	Long term	High	Possible	High	High	Low-Moderate
Operation	Siren testing and emergency activation noise affecting communities	Direct	Local/acoustic influence area	Negative	Periodic/emergency	Short term	High but temporary	Definite	Moderate-high	Moderate	Low
Maintenance	Temporary noise, traffic and access disturbance	Direct	Site/local	Negative	Periodic	Short term	Low	Probable	Moderate	Low	Negligible-Low
Maintenance	Work-at-height, electrical and battery-replacement risks	Direct	Site	Negative	Periodic	Long term	High	Possible	High	High	Moderate-Low Risk
Positive Impacts											
Construction	Temporary employment opportunities	Direct	Local	Positive	Repeated	Short term	Moderate	Probable	Moderate	Moderate Positive	Moderate Positive
Construction	Local procurement and economic opportunities	Direct/indirect	Local	Positive	Repeated	Short term	Moderate	Probable	Moderate	Moderate Positive	Moderate Positive
Operation	Improved community safety and disaster preparedness	Direct/indirect	Local/transboundary	Positive	Emergency-related	Long term	Very high	Probable	Very high	Major Positive	Major Positive
Operation	Improved detection and monitoring of	Direct	Transboundary	Positive	Continuous	Long term	High	Almost certain	High	Major Positive	Major Positive

Table 30: Evaluation of Impacts on Socio-economic Environment

Project phase	Description of impact	Type	Spatial extent	Status	Frequency	Duration	Intensity / severity	Probability	Receptor sensitivity	Significance before mitigation	Residual significance
	dangerous river conditions										
Operation	Improved dissemination of flood and dam-emergency warnings	Direct	Local/transboundary	Positive	Periodic/emergency	Long term	High	Almost certain	High	Major Positive	Major Positive
Operation	Reduced risk of loss of life and injury	Indirect	Local/transboundary	Positive	Emergency-related	Long term	Very high	Probable	Very high	Major Positive	Major Positive
Operation	Protection of livelihoods, property, livestock and community assets	Indirect	Local/transboundary	Positive	Emergency-related	Long term	High	Probable	High	Major Positive	Major Positive
Operation	Improved safety of tourism facilities and visitors	Indirect	Local/transboundary	Positive	Emergency-related	Long term	High	Probable	High	Major Positive	Major Positive
Operation	Improved community awareness and preparedness	Direct/indirect	Local/transboundary	Positive	Periodic	Long term	High	Probable	High	Major Positive	Major Positive
Operation	Strengthened institutional and transboundary coordination	Indirect	National/transboundary	Positive	Continuous	Long term	High	Probable	High	Major Positive	Major Positive
Operation	Skills development and institutional capacity	Direct/indirect	Local/national	Positive	Periodic	Long term	Moderate	Probable	Moderate	Moderate Positive	Moderate Positive

Table 31: Evaluation of Impacts on Physical Environment

Project phase	Description of impact	Type	Spatial extent	Status	Frequency	Duration	Intensity / severity	Probability	Receptor sensitivity	Significance before mitigation	Residual significance
Negative Impacts											
Construction	Soil disturbance and compaction	Direct	Site	Negative	Repeated	Short term	Low-moderate	Probable	Moderate	Moderate	Low
Construction	Soil erosion on slopes, riverbanks and access routes	Direct/indirect	Site/local	Negative	Occasional	Short-medium term	Moderate	Possible	High	Moderate	Low
Construction	Fuel, oil and chemical spills and soil contamination	Direct	Site	Negative	Occasional	Short-medium term	Moderate	Possible	Moderate	Moderate	Low
Construction	Surface-water and groundwater contamination	Direct/indirect	Local	Negative	Occasional	Short term	Moderate	Possible	High near rivers	Moderate-High	Low
Construction	Dust emissions from excavation, roads and material handling	Direct	Site/local	Negative	Repeated	Short term	Low-moderate	Probable	Moderate	Low-Moderate	Negligible-Low
Construction	Vehicle and equipment exhaust emissions	Direct	Site/local	Negative	Repeated	Short term	Low	Probable	Moderate	Low	Negligible
Construction	Construction noise and vibration	Direct	Site/local	Negative	Repeated	Short term	Moderate	Probable	Moderate-high	Moderate	Low
Construction	Construction and domestic waste generation	Direct	Site/local	Negative	Repeated	Short term	Low-moderate	Probable	Moderate	Low-Moderate	Low
Construction	Temporary visual disturbance from construction activities	Direct	Site/local	Negative	Repeated	Short term	Low	Probable	Moderate	Low	Negligible-Low
Construction	Accidental fire from construction activities, hot works or equipment	Direct/indirect	Site/local	Negative	Occasional	Short-medium term	High	Possible	High	High	Low-Moderate
Operation	Used batteries, electronic waste and damaged solar/electrical components	Direct	Site/national	Negative	Periodic	Long term	Moderate	Probable	Moderate	Moderate	Low
Operation	Flood/extreme-weather damage to EWS infrastructure	Direct	Site/local/transboundary	Negative	Occasional	Long term	High	Possible	High	High	Low-Moderate Risk
Decommissioning	Scrap metal, batteries, cables, concrete and electronic waste	Direct	Site/national	Negative	Once	Short term	Moderate	Definite	Moderate	Moderate	Low
Positive Impacts											
Operation	Improved hydrological and meteorological monitoring	Direct	Transboundary	Positive	Continuous	Long term	High	Almost certain	High	Major Positive	Major Positive
Operation	Improved flood and climate resilience	Indirect	Local/transboundary	Positive	Emergency-related	Long term	High	Probable	High	Major Positive	Major Positive
Operation	Improved decision-making and flood-risk management	Direct/indirect	Local/transboundary	Positive	Continuous	Long term	High	Probable	High	Major Positive	Major Positive
Operation	Low operational energy and resource demand	Direct/indirect	Site/national	Positive	Continuous	Long term	Moderate	Probable	Moderate	Moderate Positive	Moderate Positive

Table 32: Evaluation of Impacts on Biological Environment

Project phase	Description of impact	Type	Spatial extent	Status	Frequency	Duration	Intensity / severity	Probability	Receptor sensitivity	Significance before mitigation	Residual significance
Negative Impacts											
Construction	Vegetation clearance and habitat disturbance	Direct	Site	Negative	Once	Short-medium term	Low-moderate	Probable	Moderate-high	Moderate	Low
Construction	Fragmentation or disturbance of sensitive habitats	Direct/ indirect	Site/local	Negative	Occasional	Medium-long term	Moderate	Possible	High	Moderate-High	Low
Construction	Wildlife disturbance from vehicles, workers lights, and construction noise	Direct	Site/local	Negative	Repeated	Short term	Moderate	Probable	High in protected areas	Moderate-High	Low-Moderate
Construction	Injury or mortality of small animals and hunting	Direct	Site	Negative	Occasional	Short term	Moderate	Possible	Moderate	Moderate	Low
Construction	Aquatic and riparian habitat disturbance near AWLR/flow-monitoring sites	Direct/indirect	Local	Negative	Occasional	Short-medium term	Moderate	Possible	High	Moderate-High	Low
Construction	Introduction or spread of invasive alien plant species	Indirect	Site/local	Negative	Occasional	Long term	Moderate	Possible	Moderate-high	Moderate	Low
Construction	Accidental veld/forest fire affecting vegetation and habitat	Direct/indirect	Local	Negative	Occasional	Short-medium term	High	Possible	High in protected areas	High	Low-Moderate
Operation	Permanent loss of small areas of vegetation beneath installations	Direct	Site	Negative	Continuous	Long term	Low	Definite	Moderate	Low-Moderate	Low
Operation	Wildlife disturbance from siren testing and emergency activation	Direct	Local/acoustic influence area	Negative	Periodic/emergency	Short term	Moderate-high	Definite	High in protected areas	Moderate-High	Low-Moderate
Operation	Wildlife disturbance from maintenance activities	Direct	Site/local	Negative	Periodic	Short term	Moderate	Possible	High	Moderate-High	Low
Operation	Visual and landscape mismatch of EWS installations with surrounding	Direct	Site/local	Negative	Continuous	Long term	Low-moderate	Possible	Moderate	Moderate	Low
Operation	Disturbance from security and maintenance lighting	Direct	Site/local	Negative	Periodic	Long term	Low-moderate	Possible	Moderate-high	Moderate	Low
Operation	Bird collision with communication towers, masts or wires	Direct	Site/local	Negative	Occasional	Long term	Moderate	Possible	High	Moderate-High	Low
Operation	Electric fencing and potential wildlife injury, electrocution or disturbance	Direct	Site	Negative	Occasional	Long term	Moderate	Possible	High	Moderate-High	Low
Maintenance	Disturbance to protected areas and sensitive habitat during maintenance access	Direct	Site/local	Negative	Periodic	Short term	Moderate	Possible	High	Moderate-High	Low

Table 32: Evaluation of Impacts on Biological Environment

Project phase	Description of impact	Type	Spatial extent	Status	Frequency	Duration	Intensity / severity	Probability	Receptor sensitivity	Significance before mitigation	Residual significance
Maintenance	Wildlife disturbance from maintenance vehicles and personnel	Direct	Site/local	Negative	Periodic	Short term	Low-moderate	Probable	High	Moderate	Low
Decommissioning	Disturbance of vegetation and wildlife during removal of equipment	Direct	Site/local	Negative	Once	Short term	Moderate	Probable	Moderate-high	Moderate	Low
Decommissioning	Generation of electronic, battery and other waste with potential ecological effects	Direct/indirect	Site/national	Negative	Once	Short term	Moderate	Definite	Moderate-high	Moderate	Low
Positive Impacts											
Operation	Improved protection of wildlife, protected areas and personnel	Indirect	Local/transboundary	Positive	Emergency-related	Long term	High	Probable	High	Moderate-Major Positive	Major Positive
Operation	Low direct physical disturbance during operation	Direct/indirect	Site/local	Positive	Continuous	Long term	Moderate	Almost certain	High in protected areas	Moderate Positive	Moderate Positive
Decommissioning	Site restoration and recovery of vegetation	Direct	Site	Positive	Once	Medium-long term	Moderate	Probable	Moderate	Moderate Positive	Moderate Positive

6.4 Positive Impacts

The proposed Kariba Dam EWS is expected to provide important long-term benefits for downstream communities, institutions, tourism facilities and the natural environment. The project is primarily a monitoring and warning system with a small physical footprint, its main value will come from improving the availability of timely rainfall, river-level and flow information and converting this information into practical warnings for people at risk.

The benefits will be particularly important along the downstream of Kariba Dam along the Zambezi corridor, including Chirundu, Chiawa, Luangwa, Kanyemba and surrounding villages and communities, where people, livelihoods and tourism activities are closely linked to the river. Around Luangwa, the system will also improve preparedness for flooding associated with high Zambezi River levels and backflow into the Luangwa River. The EWS will also support schools, hospitals and health facilities, markets, lodges and resorts, as well as protected areas such as Lower Zambezi National Park, Mana Pools and Chewore etc.

In addition to improving flood preparedness and reducing risks to life and property, the project will strengthen institutional coordination, community awareness, tourism safety, hydrological monitoring and environmental management. The following sections describe these positive impacts across the socio-economic, physical and biological environments.

6.4.1 Socio-economic Environment

Improved Community Safety and Disaster Preparedness

The main benefit of the EWS will be improved safety and preparedness of communities downstream of Kariba Dam. The system will provide rainfall, river-level and flow information and support timely warnings for extreme rainfall, rapidly rising river levels, high flows and dam-related emergencies. This will be particularly important for communities along the downstream of Kariba dam along the Zambezi River including Chisamu, Kabwadu, Manyepa, Kavalamanja, Chiawa, Luangwa and Kanyemba etc. Around Luangwa, the system will also help address flooding associated with high Zambezi levels and backflow into the Luangwa River.

Warnings will be communicated through large and mini sirens and supported by SMS, radio, VHF, public-address systems, local authorities and community networks, providing several ways to reach dispersed communities.

Reduced Risk of Loss of Life and Injury

Early warning will provide additional time for residents, workers, tourists and emergency responders to move away from areas that may become unsafe. The benefit will be particularly important for communities close to the Zambezi and Luangwa rivers, including Chirundu, Chiawa, Luangwa and Kanyemba, and for vulnerable groups such as children, older persons, persons with disabilities and people requiring medical assistance. Schools, hospitals and health facilities will also have an opportunity to activate their emergency arrangements before flood conditions become severe.

Protection of Livelihoods, Property and Community Assets

Advance warning will allow households and businesses to take practical measures to protect livestock, boats, fishing equipment, agricultural produce, vehicles and other movable assets.

This will be particularly useful for fishing and agriculture-dependent communities along the Zambezi, including areas around Chiawa and Luangwa etc., where livelihoods are closely linked to the river and surrounding floodplain. Markets, shops and other community businesses will also have more time to secure goods and equipment before flooding occurs.

Improved Safety of Tourism Facilities and Visitors

Tourism facilities on both the Zambia and Zimbabwe sides of the downstream Zambezi, particularly within and around the Lower Zambezi National Park in Zambia and the Mana Pools landscape in Zimbabwe, including lodges and safari camps and game reserve may be exposed to rapidly changing river and flood conditions. The EWS will provide these operators with timely warnings, allowing them to activate their emergency procedures, including restricting access to riverbanks and other exposed areas, moving guests and staff to safer locations, securing boats and other equipment, and coordinating with the relevant park and emergency authorities. This will improve the ability of tourism operators on both sides of the Zambezi to manage flood events in an orderly and timely manner, rather than responding only after conditions have become dangerous.

Strengthened Institutional and Transboundary Coordination

The EWS will improve coordination between ZRA, water-resource and meteorological institutions, disaster-management agencies, local authorities, emergency services, protected-area authorities, tourism operators and communities in Zambia and Zimbabwe. A common monitoring and warning system will provide a more consistent understanding of developing flood conditions and support coordinated decisions for communities around Chirundu and Luangwa, as well as tourism and protected areas further downstream.

Improved Community Awareness and Preparedness

The project will include community awareness activities, siren demonstrations, drills and emergency simulations. These activities will help people understand warning signals, evacuation routes, safe locations, emergency contacts and actions to take before, during and after flooding. This will be particularly useful in dispersed communities around Chirundu, Chiawa, Luangwa and Kanyemba, where people may have different levels of access to formal emergency information.

Audible drills will sometimes be required to demonstrate the warning signal and build community familiarity. Routine technical checks may use silent or low-noise testing where appropriate, while planned drills will be communicated in advance so that communities understand that they are tests and not actual emergencies.

Temporary Employment and Local Economic Opportunities

The project will create limited short-term employment during site preparation, transport, minor civil works, equipment installation, security and commissioning. Local businesses around Chirundu, Luangwa and other downstream communities may also benefit from transport, accommodation, catering, construction materials and other support services. These benefits will be temporary and relatively localised because the EWS installations are small and dispersed.

Skills Development and Institutional Capacity

The project will provide opportunities for technicians, emergency responders, local authorities, protected-area staff and community representatives to gain experience in equipment operation, monitoring, warning procedures, maintenance, communication and emergency coordination. Training and repeated drills will also help local institutions and communities become more familiar with their responsibilities during a flood emergency, providing benefits beyond the construction period.

6.4.2 Physical Environment

Improved Hydrological and Meteorological Monitoring

The proposed 20 ARGs, 10 radar-based AWLRs and 7 non-contact flow/discharge monitoring stations will provide additional rainfall, water-level and flow observations along the downstream system. This will improve understanding of changing conditions between upstream to Kariba dam and downstream areas such as Chirundu and Luangwa. The use of non-contact radar monitoring also reduces the need for physical structures within the active river channel.

Improved Flood and Climate Resilience

The EWS will strengthen the ability of downstream communities and institutions to prepare for extreme rainfall, high river flows and dam-related emergencies. This is particularly relevant around Luangwa, where high Zambezi levels may contribute to backflow into the Luangwa River. The system will not prevent flooding, but it will provide additional time to prepare and reduce its potential consequences. Because the monitoring network will operate over many years, it will provide a continuing contribution to disaster-risk reduction and climate resilience.

Improved Flood-risk Management and Decision-making

The EWS Data Management System will integrate rainfall, water-level and flow observations with forecasting and relevant dam and operational information. This will provide authorities with a better basis for deciding when warnings are needed and for managing emergency response in areas such as Chirundu, Chiawa, Luangwa and Kanyemba and other villages located along Zambezi suspectable to flooding. The recorded information will also be useful for reviewing flood events and improving future forecasting, warning thresholds and emergency planning.

Low Operational Energy and Resource Requirements

The field EWS equipment will operate automatically and require relatively little energy and routine intervention. Where provided in the final design, solar PV systems and batteries will support remote installations without continuous fuel-based power generation. Routine operation will mainly involve inspection, calibration, maintenance and replacement of batteries or electronic components. The Command-and-Control Centres will have higher energy requirements because of servers and communication equipment but will operate from established facilities.

6.4.3 Biological Environment

Improved Protection of Wildlife, related Tourism and Conservation Facilities

The EWS will provide early flood information to managers of the Lower Zambezi National Park in Zambia and Mana Pools National Park, Sapi and Chewore Safari Areas in Zimbabwe, allowing them to restrict access to vulnerable areas, protect conservation and research equipment, and take timely action where wildlife may be at risk. Early warning can also reduce risks to wildlife concentrated around river channels, floodplains, islands and backwater areas by allowing park staff to restrict human activities and avoid exposing staff and vehicles to hazardous conditions. This is particularly relevant to the Lower Zambezi-Mana Pools conservation landscape.

Tourism facilities such as Chiawa Camp, Old Mondoro, Sausage Tree Camp and other lodges and safari camps on both sides of the Zambezi can use the warning to secure equipment and move staff and visitors to safer areas, thereby reducing wildlife disturbance and the risk of wildlife mortality.

6.5 Negative Impacts and Mitigation Measures

The potential adverse impacts of the project are mainly associated with short-duration installation activities rather than long-term operation. The construction programme will involve limited excavation and concrete works, installation of poles and masts, equipment assembly, cable connections, fencing and testing. These activities will generally occur within a small working area and will not require large-scale earthmoving or permanent changes to the surrounding landscape. The project will also use relatively small quantities of construction materials, water, fuel and electricity. Consequently, the potential for pollution, waste generation and emissions is substantially lower than for conventional major construction projects. Nevertheless, because several installations may be located close to rivers, protected areas, tourism facilities and dispersed settlements, even a small activity can become significant if it is poorly located or poorly controlled. Potential negative impacts on socio-economic, physical and biological environment are summarized below:

Socio-economic Environment

The proposed EWS is a relatively small-footprint project, but the individual installations are distributed across a range of downstream land uses. Some sites are located within or close to villages and community areas, while others are associated with schools, hospitals/health facilities, markets, lodges, resorts, protected areas and the Zambezi River. The nature of the potential impact will therefore depend largely on the immediate surroundings of each installation.

I- Pre-construction

Failure/delay in obtaining required Consents, Permits, Clearances and NOCs

The EWS network will involve installations on land under different ownership, management and administrative arrangements. ZRA is consulting the respective landowners, institutions and authorities to obtain the required land-use permissions and access rights for the proposed sites. The majority of locations are associated with institutions such as DNPW, ZimParks, lodges, resorts, schools and health facilities, as well as community areas and other land users. At community locations, Chiefs, Headmen and other community leaders are also being consulted to obtain their permission, support and agreement for site access and installation. Some sites close to the Zambezi River may require additional arrangements for access and installation.

Any delay in obtaining the required land-use permissions, access rights or community-level agreements could delay site mobilisation and construction. Where permissions are required from several institutions or stakeholders, prolonged delays could affect the project implementation schedule and result in additional mobilisation, remobilisation and other project costs, with associated economic implications for the project.

Mitigation measures

- The project shall confirm the required approvals and site-access arrangements before construction starts at each individual location.
- ZRA shall obtain the required land-use rights and site-access permissions/NOC from the respective landowners, lodge or resort owners, institutions, authorities and community representatives before handing over the sites for construction.
- A site-specific approvals register shall identify the permits, NOCs, land permissions and institutional approvals required for each EWS site.
- Sites within or close to Lower Zambezi National Park, Mana Pools, Sapi and Chewore shall comply with the requirements of the relevant protected-area authorities (Dept. of National Parks & WL and Zimparks)
- At community locations access and site arrangements shall be discussed with the relevant local representatives and community leaders before mobilisation.
- No physical work shall begin until the applicable permissions for that location have been confirmed.

Inadequate site-specific Construction Plan covering material sources, labour, machinery/equipment, access and transportation logistics

Although the EWS installations are small, construction arrangements will vary considerably between sites. Some installations are close to villages, schools, markets, lodges or resorts, while others are remotely located along the Zambezi or within protected areas and may have limited access. Remote sites may require 4×4 vehicles, careful planning of equipment transport and advance arrangements for construction materials.

Particular attention will be required to identify reliable and approved sources of construction materials in advance. Where suitable materials are not available near remote sites, they may need to be procured from nearby towns from government-approved/licensed sources and transported to the site.

Mitigation measures

- The Contractor shall prepare a simple, site-specific construction arrangement covering access, materials, labour, equipment and transportation before mobilising to each site.
- Material sources shall be identified in advance and to be procured from government-approved/licensed local sources.

- For remote river-side locations, boat access could also be used where it is safe and practical, particularly where it provides faster and more efficient access than overland routes. Boat transport may be planned considering river conditions, weather, boat capacity, loading requirements and appropriate safety arrangements.
- Construction routes shall avoid unnecessary movement through villages and densely occupied areas.
- Access to schools, hospitals and markets shall remain open throughout construction.
- At lodges and resorts, delivery and construction timing shall be agreed with management.
- At protected-area sites, vehicle movement shall follow the requirements of DNPW or ZimParks.
- Equipment shall be transported using vehicles suitable for the actual site access conditions.
- Where long poles cannot be safely transported as one piece, sectional transport and assembly at site shall be considered.
- Material storage and unloading shall be restricted to the approved work area.
- Seasonal river conditions and access constraints at river-shore and AWLR sites shall be considered before mobilisation.

Temporary land access and use of installation sites

The permanent footprint of each EWS installation will be small, but construction will temporarily require space for workers, vehicles, foundations, pole/tower erection and material storage. This could temporarily interfere with normal activities where sites are close to villages, schools, markets or other public facilities. At lodges and resorts, temporary occupation could affect guest movement or facility operations. At river-shore sites, construction activities may temporarily overlap with areas used by local residents, fishermen, tourism operators or other river users.

Mitigation measures

- Temporary occupation shall be kept as small and as short-lived as practicable, with existing developed areas used wherever possible.
- The approximate 4 m × 4 m siren footprint shall be maintained while temporary working areas shall be clearly marked before construction.
- Existing disturbed areas should be used for storage and assembly wherever practicable.
- At schools, hospitals and markets, construction areas shall be separated from public movement.
- At lodges and resorts, temporary access restrictions shall be agreed with management.
- Community access routes shall not be blocked unnecessarily.
- River access used by local communities or tourism operators shall be maintained wherever practicable.
- Temporary fencing, disturbed ground and access areas shall be removed or restored after construction.

Community concerns regarding installation locations and land ownership

The location of a siren or tower can sometimes become a sensitive issue even though the installation occupies only a small area. Communities may question why a particular location has been selected, whether land is being taken permanently, or whether the equipment will interfere with existing activities. This may be relevant in villages around Chirundu and Luangwa, particularly where installations are close to community land, river-access areas, markets or other commonly used locations. Similar concerns may arise where EWS equipment is proposed within a lodge or resort, where management may have concerns about visual appearance, guest movement or future development.

Mitigation measures

- The project shall explain the purpose of each installation and the reason for its location before construction begins.
- Affected communities and local representatives shall be informed about the proposed location and small permanent footprint.
- The technical reason for selecting the location, including warning coverage and proximity to people at risk, shall be explained in simple terms.
- Chief, headman and affected land users shall be consulted before finalising community-facing locations.
- At schools, hospitals and markets, the responsible institution shall be consulted.
- At lodges and resorts, the final location shall be agreed with management.
- At protected-area locations, the relevant authority shall determine applicable site and access requirements.
- Where a minor relocation can reduce a land-use concern without reducing warning coverage, the alternative shall be considered.
- Any unresolved concern shall be handled through the project GRM.

Exclusion of vulnerable groups from consultation and warning-system planning

The effectiveness of the EWS will depend on whether people can hear, understand and respond to a warning. Vulnerable groups may not always receive or respond to warnings in the same way as the wider community.

This is particularly relevant in downstream communities including people living close to the Zambezi or low-lying areas affected by flooding and, around Luangwa, potential backflow from the Zambezi into the Luangwa River during high Zambezi flows. Schools, hospitals and markets also require special attention because many people may be present at the time of a warning.

Mitigation measures

- Consultation shall focus not only on where a siren should be installed but also on who may not hear or respond to the warning and what additional arrangements may be needed.
- Women, elderly persons, persons with disabilities and other vulnerable groups shall be included in community consultations.
- Local leaders and village representatives shall be involved in warning-system planning.
- Schools shall be consulted on arrangements for warning students and teachers.
- Hospitals and health facilities shall consider patients who may require assistance during evacuation.

- Market representatives shall be included where sirens are located near market areas.
- People with hearing impairments shall be considered in alternative warning arrangements.
- Communities shall be informed about what the siren means and what action they should take.
- Alternative communication channels shall be considered where siren coverage alone is not sufficient.

Disturbance of cultural, archaeological, burial or sacred resources through inappropriate siting

The EWS foundations and cable/earthing works will involve only minor excavation, but there remains a possibility of encountering graves, sacred locations or archaeological materials, particularly near established communities. This should be considered during site verification around Chirundu, Luangwa and other downstream settlements, as well as at locations where local communities have longstanding cultural associations with the river or surrounding land.

Mitigation measures

- The project shall use local knowledge and site screening to avoid known culturally sensitive locations.
- Proposed sites shall be discussed with local leaders and relevant authorities.
- Known graves, sacred locations and culturally important areas shall be avoided.
- Existing disturbed land shall be preferred where practicable.
- Excavation shall be restricted to the approved foundation and cable areas.
- If human remains or potential archaeological materials are encountered, work shall stop immediately and chance-find procedure shall be implemented before work resumes.

II- Construction Stage

Construction traffic and road-safety risks

Construction vehicles will transport poles, sirens, solar panels, batteries, cables, concrete and other equipment. These vehicles may use roads shared with villagers, pedestrians, schoolchildren, patients, market users, tourists and lodge vehicles. The risk is more relevant at sites close to schools, hospitals and markets, and where narrow community roads are used to access EWS sites. In protected areas, vehicle movement also needs to account for wildlife.

Mitigation measures

- Traffic management shall reflect the actual activities and receptors around each site.
- Vehicle speeds shall be reduced near villages, schools, hospitals and markets.
- Construction traffic shall avoid school arrival and departure periods where practicable.
- Hospital and emergency access shall remain clear.
- Deliveries to markets shall be scheduled to minimise disruption to trading activities.
- Lodge and resort access shall be coordinated with management.
- Traffic marshals shall be used where construction vehicles enter busy public areas.
- Vehicles carrying poles and tower sections shall be appropriately secured.

- Drivers shall follow protected-area speed and access requirements.
- Construction vehicles shall not unnecessarily use informal community tracks.

Occupational accidents, work at height and electrical hazards

Installation of sirens, towers, poles, solar panels and communication equipment will involve lifting operations, work at height and electrical connections. Some sites are remote or close to schools, hospitals, markets, lodges and resorts, increasing the need to keep workers and the public safely separated from the work area. River-side and protected-area locations may also require additional care because of difficult access and weather conditions.

Mitigation measures

The Contractor shall implement appropriate occupational health and safety measures, with particular attention to work at height, lifting and electrical activities.

- Only trained, competent and authorised personnel shall undertake specialised activities such as tower erection, work at height and electrical installation.
- Workers shall be provided with and required to use appropriate PPE, including safety helmets, safety footwear, gloves, high-visibility clothing, eye protection and full-body harnesses/fall-arrest equipment for work at height.
- Appropriate lifting equipment and safe lifting procedures shall be used for poles, towers, sirens, solar panels and other heavy components.
- Exclusion zones, barriers and warning signs shall be provided during lifting and tower/pole erection.
- Electrical works shall be undertaken by competent personnel, with electrical systems isolated before work and appropriate lock-out/tag-out procedures applied where required.
- Batteries, solar panels and other electrical components shall be safely transported, stored and installed.
- At schools, hospitals, markets, lodges and resorts, additional barriers and controls shall be provided to prevent public access to the work area.
- Workers shall receive site-specific induction and toolbox talks covering working at height, lifting, electrical safety, heat, weather and emergency procedures.
- Emergency arrangements shall be maintained for falls, electrical incidents, lifting accidents and other occupational emergencies.

Drowning and wildlife encounters during river-based work

Some AWLR and flow-monitoring installations will be close to the Zambezi River and may require workers to approach the riverbank. These sites present risks from deep or fast-moving water, slippery banks, sudden changes in water level and encounters with crocodiles or hippopotamuses etc.

Mitigation measures

- River-based work shall be planned around the actual river conditions at the time of the visit. Riverbank access shall be assessed before work begins.
- Workers shall receive specific training on drowning and wildlife risks.
- Workers shall not enter the river unless specifically required by the installation method.
- Appropriate life-saving equipment shall be available where necessary.

- Work shall stop during unsafe river levels, strong currents or severe weather.
- Safe distances from crocodiles and hippopotamuses shall be maintained.
- Local knowledge and protected-area requirements should be considered at wildlife-sensitive river locations.
- At Luangwa sites, changing river and backflow conditions shall be considered when planning access and work timing.

Worker exposure to dust, noise, heat and adverse weather

Construction will involve short-duration excavation, drilling, vehicle movement and equipment installation. Dust and noise will therefore be temporary but may be noticeable near villages, schools, hospitals, markets, lodges and resorts.

Workers will also be exposed to high temperatures, direct sunlight and sudden weather changes, particularly at exposed river-shore sites.

Mitigation measures

- Dust-generating activities shall be controlled at sites located sensitive receptors.
- Noisy work shall be restricted to appropriate daytime periods.
- Workers shall be provided with drinking water, rest periods and appropriate PPE.
- Work shall stop during lightning, severe storms or other unsafe conditions.
- Construction near schools and hospitals shall be planned to minimise disruption.
- Lodge and resort management shall be consulted on appropriate working hours.
- Workers shall receive toolbox talks on heat stress, hydration and adverse weather.

Community health and safety risks from open excavations, vehicles and equipment

Open foundation excavations, construction vehicles and equipment could present temporary hazards to members of the public. This is particularly relevant where EWS installations are located near villages, schools, hospitals, markets, lodges or resorts. Children may be particularly attracted to construction equipment at community sites.

Mitigation measures

- The Contractor shall maintain a clearly defined and controlled construction area.
- Excavations shall be fenced or barricaded.
- Warning signs shall be provided where appropriate.
- Construction materials shall not obstruct public access.
- At schools, construction areas shall be securely separated from students.
- At hospitals, emergency and patient access shall remain open.
- At markets, pedestrian and trading areas shall be kept clear.
- At lodges and resorts, guests shall be kept away from construction activities.
- Excavations shall be backfilled as soon as the installation work is completed.

Social conflict arising from employment, procurement or site selection

Construction may create expectations that local residents will receive employment or that local businesses will supply materials and services. This may be particularly relevant around Chirundu, Luangwa and other downstream communities, where people may expect the EWS project to provide local economic opportunities. There may also be questions about why a siren is located in one village, school or facility rather than another.

Mitigation measures

The project will be transparent about both employment opportunities and the technical basis for site selection.

- Local workers shall be used where suitably skilled people are available.
- Employment opportunities shall be communicated fairly and transparently.
- Contractors shall not make informal promises of jobs.
- Local procurement shall be considered where it meets project requirements.
- Communities shall be informed that siren locations are primarily based on warning coverage, population at risk, access, safety and technical requirements.
- Site-selection decisions shall not be based on individual or political preferences.
- Employment, procurement and site-selection grievances shall be managed through the GRM.

GBV, SEA/SH and inappropriate worker behaviour

Workers will interact with local communities, businesses, schools, tourism facilities and other people during construction. Poor worker behaviour could create social tension or expose community members to harassment or other inappropriate conduct.

Mitigation measures

The Contractor will establish clear expectations for worker behaviour before mobilisation.

- All workers will sign a Code of Conduct covering GBV, SEA/SH, harassment and respectful behaviour.
- Workers will receive induction and refresher training.
- Workers will be prohibited from harassment, exploitation and inappropriate interaction with community members.
- A confidential mechanism will be available for reporting concerns.
- Workers will not unnecessarily enter villages, schools, markets, lodges or other community facilities outside their work.
- Worker accommodation and transport shall be managed to minimise nuisance to surrounding communities.
- Reported incidents shall be addressed through the project procedures.

Construction/operation

Fire affecting communities or facilities from hot works, electrical systems or equipment

During construction, welding, cutting and other hot works could cause a fire. During operation, batteries, solar systems and electrical equipment create a low but continuing fire risk. The consequence could be more serious where EWS equipment is located near a school, hospital, market, lodge, resort or densely settled community, particularly where dry vegetation is present.

Mitigation measures

Fire prevention shall continue from construction through the operational period.

- Hot works shall be controlled and monitored.
- Fire extinguishers shall be available during construction.
- Electrical and battery systems shall be installed according to manufacturer requirements.
- Dry vegetation shall not be allowed to accumulate immediately around electrical equipment.
- At schools, hospitals, lodges and resorts, EWS installations shall be integrated with existing fire-safety arrangements where appropriate.
- Electrical systems shall be isolated before maintenance.
- Workers shall know how to report and respond to a fire.
- Damaged batteries, wiring or electrical components shall be repaired or replaced promptly.

III- Operational Stage

Warning-system failure or malfunction during an emergency

The most important socio-economic risk during operation would be failure of the EWS when a flood warning is actually required. This could affect communities living downstream of Kariba, including people in the Chirundu and Luangwa areas, settlements close to the Zambezi and people living near areas where the Zambezi can cause backflow into the Luangwa River during high flows. Failure of the system could also affect schools, hospitals, markets, lodges, resorts and tourism facilities within the warning area. In protected areas, reliable warnings may also support the response of park authorities and tourism operators.

Mitigation measures

- The EWS shall be maintained as a functioning system rather than as a collection of individual pieces of equipment.
- Sirens, AWLRs, weather stations, communication equipment and power systems shall be included in a maintenance and inspection programme.
- Batteries and solar systems shall be checked regularly.
- Communication links shall be tested periodically.
- Faults affecting areas with high populations or vulnerable receptors shall receive priority.
- Backup communication arrangements shall be maintained where practicable.
- Schools, hospitals, markets, lodges and resorts shall be included in relevant emergency-warning arrangements.
- Communities shall be informed about how to report a malfunction.
- The siren system shall operate as part of the wider emergency-warning arrangement rather than as the sole means of communication.

False or inconsistent warnings

False or inconsistent warnings can create confusion and may eventually reduce confidence in the EWS. This is particularly important for communities where residents need to distinguish between an actual flood warning, a planned drill and routine system testing. A poorly communicated drill could also cause unnecessary movement of people from schools, hospitals, markets, lodges or resorts.

Mitigation measures

- The project shall establish a simple and consistent distinction between tests, drills and actual emergency warnings.
- Only authorised personnel should activate the emergency warning system.
- Planned tests and drills shall be communicated in advance.
- The community shall be told clearly when a siren activation is a drill rather than an emergency.
- Schools, hospitals, markets, lodges and resorts shall be informed of planned drills in advance.
- Emergency messages issued through other communication channels shall be consistent with the siren warning.
- Any false or unintended activation shall be investigated promptly.
- Community awareness activities shall explain the meaning of the warning signal and the expected response.

Unequal access to warnings

Not everyone within a warning area will necessarily hear a siren equally well. Audibility can be affected by distance, buildings, terrain, vegetation, weather and background noise. This is particularly relevant to dispersed downstream communities and to households located away from the main settlement.

People inside schools, hospitals, markets, lodges or other buildings may also experience different levels of audibility. Persons with hearing impairments may not hear an audible siren.

The issue is particularly important around Luangwa, where warning arrangements need to cover communities that may be affected by high Zambezi levels and associated backflow into the Luangwa River.

Mitigation measures

- Warning coverage shall be assessed based on where people actually live and work, rather than simply the location of the siren.
- Audibility shall be checked during commissioning and periodic testing.
- Particular attention shall be given to low-lying and river-adjacent communities around Luangwa.
- Areas outside adequate siren coverage shall be considered for alternative warning arrangements.
- Schools and hospitals shall establish internal arrangements for receiving and responding to warnings.
- Alternative communication methods shall be considered for people who cannot hear the siren.
- Community leaders shall be included in warning dissemination.
- Warning coverage shall be reviewed if settlement or tourism patterns change.

Electric fencing and potential safety risks to people

At some EWS locations, a solar-powered electric fence may be installed around the equipment to deter elephants and other animals from damaging sirens, solar panels, batteries and communication equipment. Where the installations are close to community areas, lodges, resorts or other places accessed by people, an improperly designed or poorly maintained fence could result in accidental contact, particularly for workers, visitors or children.

Mitigation measures

- The solar-powered fence shall be designed as a low-risk, non-lethal deterrent, with appropriate controls to prevent accidental contact by people. The fence should use a solar-powered, battery-backed pulsed energiser designed for animal fencing and installed by competent personnel.
- The energiser shall comply with applicable electrical safety requirements
- The energiser and battery shall be housed in a secure, weatherproof enclosure, with live components protected from unauthorised access.
- Appropriate warning signs shall be provided around the fenced area.
- The fenced area shall be kept as small as practicable and limited to the immediate EWS equipment.
- Access to the fenced area shall be restricted to authorised personnel.
- Workers shall be informed about the electrical hazard during site induction.
- The fence shall be regularly inspected for damaged wires, insulators or other exposed components.
- The system shall be safely isolated before maintenance or repair.
- Barbed wire, razor wire or other entangling materials shall not be used as part of the electric fence.

Theft, vandalism or deliberate damage to EWS equipment

Remote EWS equipment may be vulnerable to theft or vandalism, particularly solar panels, batteries, cables and communication components. This risk can be relevant at isolated downstream locations as well as sites close to public access areas. Equipment located within a lodge, resort, school, hospital, public institution or protected-area facility may benefit from existing security arrangements.

Mitigation measures

Equipment security will combine appropriate siting, physical protection and community awareness.

- Equipment shall be located within secure or managed premises where technically feasible.
- Batteries and communication equipment shall be kept in lockable enclosures.
- Solar panels and cables shall be protected against unauthorised access where practicable.
- Communities shall be informed that the equipment is part of a life-safety system.
- Lodge and resort security arrangements shall be used where appropriate.
- Equipment shall be inspected regularly for damage or tampering.

- Repeated theft or vandalism shall trigger a review of the site's security arrangement.

Siren testing and emergency activation noise affecting communities

The sirens need to be tested periodically so that the project team can confirm that they work and, importantly, that communities can actually hear and recognise the warning signal. Some sirens will be close to villages, schools, hospitals, markets, lodges and resorts, so an unexpected activation could cause concern or interfere with normal activities. EWS is intended to help warn communities affected by flooding associated with high Zambezi levels and backflow into the Luangwa River. People need to recognise the warning and understand what action they are expected to take.

Routine technical checks of communication, power supply and system status may use silent or low-noise testing where technically appropriate. However, this does not replace audible drills. From time to time, an audible drill will be necessary to confirm the actual warning coverage and to familiarise communities with the sound and required response.

Mitigation measures

- Testing shall therefore combine routine technical checks with planned audible drills and community awareness.
- Silent or low-noise testing shall be used where technically sufficient for routine system checks.
- Audible tests shall be undertaken when necessary to verify actual siren performance.
- Planned audible tests shall be communicated in advance to affected communities and local leaders.
- At schools, testing shall be coordinated with school management to avoid unnecessary disruption to classes.
- At hospitals and health facilities, testing shall be coordinated with facility management, taking account of patients and essential activities.
- At markets, testing shall be planned to minimise disruption during busy trading periods.
- At lodges and resorts, management shall be informed in advance and testing shall avoid peak visitor periods where practicable.
- At Lower Zambezi National Park, Mana Pools, Sapi and Chewore etc. planned audible testing shall be coordinated with the relevant protected-area authority.
- Community drills shall include an awareness component explaining the meaning of the siren and the expected response.
- Prior information and agreement/consensus on the timing and duration of planned drills shall be sought from affected communities and relevant facility managers.
- The duration of audible testing shall be limited to what is necessary to verify the system and undertake the awareness activity.
- Communities shall be clearly informed that a planned activation is a drill/test and not an actual emergency.
- During an actual flood emergency, the siren shall be activated as required because protection of downstream people is the primary purpose of the EWS.

Maintenance Phase

Temporary noise, traffic and access disturbance

Maintenance will involve periodic visits by technicians to sirens, towers, weather stations, solar systems and AWLR installations. Although these visits will be short, vehicles and personnel could temporarily affect access to community roads, lodge entrances, park tracks or river-monitoring sites. The impact may be more noticeable where equipment is close to schools, hospitals, markets or tourism facilities.

Mitigation measures

- Maintenance visits shall be planned in advance and coordinated with the people using the affected site.
- Existing roads and access tracks shall be used.
- Maintenance vehicles shall not block school, hospital, market or emergency access.
- Lodge and resort management shall be informed before planned maintenance where appropriate.
- Maintenance shall be scheduled to avoid peak activities where practicable.
- Noisy maintenance activities shall be kept as short as possible.
- At protected-area sites, access shall be coordinated with the relevant authority.
- Temporary disturbance to roads, fencing or other facilities shall be restored after the work.

Work-at-height, electrical and battery-replacement risks

Maintenance will sometimes require technicians to work at height on poles or towers or to replace batteries and electrical components. These activities can create risks to workers and, if the area is not controlled, to nearby members of the public.

Mitigation measures

Maintenance shall be carried out by trained personnel using appropriate safe-work procedures.

- Only trained personnel shall undertake work at height or electrical work.
- Appropriate fall-arrest equipment shall be used.
- An exclusion zone shall be established below elevated work.
- Electrical systems shall be isolated before maintenance.
- Lock-out/tag-out procedures shall be used where required.
- Battery replacement shall follow manufacturer requirements.
- Maintenance shall not be undertaken during lightning, strong winds or other unsafe weather.
- At schools, hospitals, markets and tourism facilities, public access to the work area shall be controlled.
- Used batteries shall be removed from the site and sent for appropriate management.
- The equipment shall be tested after maintenance to confirm that it is operational.

A. Physical Environment

The proposed EWS will have a relatively low physical footprint because the installations mainly consist of sirens, poles/towers, automatic rain gauges, weather stations, water-level monitoring equipment, solar panels, batteries, communication equipment and small foundations. Most sites will use existing roads, tracks and already disturbed or developed locations wherever practicable. Consequently, impacts on soil, water, air quality, noise and waste generation are expected to be localised and generally short-term, provided that site-specific construction controls are followed.

Wastewater and waste generation during construction and operation is also expected to be very limited, as the project does not involve large construction camps, process activities or water-intensive operations. Where workers are present at remote sites, sanitation will be managed through portable/mobile arrangements or existing facilities, rather than constructing permanent wastewater systems.

Construction Stage

Soil disturbance and compaction

Although the EWS installations have a small footprint, some soil disturbance will occur during foundation excavation, earthing, cable installation, pole/tower erection and temporary access. Vehicle movement and storage of materials may also compact soil, particularly at remote locations with unpaved access. The extent of disturbance will generally be limited to the immediate installation area and temporary working space.

Mitigation measures

The Contractor shall keep ground disturbance to the minimum area required for safe installation and shall avoid unnecessary clearing or movement of vehicles outside approved access routes.

- Existing disturbed ground, developed areas and existing access tracks shall be used wherever practicable for sirens, monitoring stations and associated equipment.
- The typical siren installation footprint of approximately 4 m × 4 m (16 m^2) shall be maintained, with no unnecessary expansion of the working area.
- Excavation shall be limited to the dimensions required for foundations, poles, earthing and cables.
- Topsoil from excavated areas shall be separately stored where practicable and reused during site restoration.
- Heavy vehicles and machinery shall remain on designated access routes and working areas, particularly at riverbanks, protected areas and tourism facilities.
- After installation, surplus excavated material shall be removed or suitably reused, and disturbed surfaces shall be reinstated.
- New access roads shall not be created unless specifically justified and approved, existing roads and tracks will be used wherever feasible.

Soil erosion on slopes, riverbanks and access routes

Some monitoring equipment may be installed near the Zambezi River, reservoir margins, drainage channels or on sloping terrain. Excavation and vehicle movement can expose soil and increase erosion, particularly during heavy rainfall. Poorly controlled runoff from temporary access routes could also carry sediment towards rivers or drainage channels.

Mitigation measures

The Contractor shall plan earthworks around local terrain and rainfall conditions and shall avoid unnecessary disturbance of slopes and riverbanks.

- Installation sites shall be positioned away from unstable slopes and sensitive riverbank areas wherever technically feasible.
- Excavation shall be undertaken during relatively dry periods where practicable and shall not be left open for longer than necessary.
- Excavated soil shall be placed away from drainage paths and river channels and protected from being washed into water bodies.
- Temporary silt barriers, berms, check structures or other simple erosion controls shall be installed where site conditions require them.
- Vehicle movement along steep or erosion-prone tracks shall be minimised.
- Disturbed areas shall be levelled, compacted where appropriate and revegetated or otherwise stabilised after construction.
- At river-adjacent monitoring locations, the Contractor shall follow the site-specific access method approved by the relevant authority and avoid unnecessary disturbance to the riverbank.

Fuel, oil and chemical spills and soil contamination

Construction equipment, vehicles, generators and machinery may use diesel, petrol, lubricants, hydraulic oils and other maintenance materials. Accidental leakage during refuelling, equipment maintenance or storage could contaminate soil. The risk is particularly important at remote sites and locations close to the Zambezi River.

Mitigation measures

The Contractor shall minimise the quantity of fuels and chemicals stored at EWS sites and shall ensure that any unavoidable storage or handling is properly controlled.

- Fuel and oils shall preferably be brought to site in the quantities required for the planned work rather than stored for long periods.
- Refuelling and equipment maintenance shall be undertaken away from rivers, drainage channels and sensitive areas wherever practicable.
- Fuels, lubricants and chemicals shall be stored in sealed and clearly labelled containers on suitable secondary containment.
- Spill kits shall be available in construction vehicles and at locations where fuel or oil is handled.
- Workers shall be trained in spill prevention and immediate response procedures.
- Any spill shall be contained promptly, contaminated soil collected and managed appropriately, and the incident recorded.
- Equipment showing significant oil or fuel leakage shall not be operated until the defect has been repaired.

Surface-water and groundwater contamination

The EWS project will involve only small-scale civil works, but sediment, cement washout, fuel, oil, litter or improperly managed wastewater could enter nearby drainage channels, rivers or groundwater. This is particularly relevant to monitoring locations close to the Zambezi River and other water bodies.

The project is expected to generate very limited wastewater because there will be no process wastewater and no large permanent construction camp associated with individual EWS installations.

Mitigation measures

The Contractor shall maintain separation between construction activities and water bodies and shall prevent sediment, wastewater and construction materials from reaching surface water or groundwater.

- No cement mixing, concrete washout, fuel storage or equipment maintenance shall be undertaken immediately adjacent to rivers or drainage channels.
- Concrete and cement materials shall be handled in designated areas, with wash water prevented from entering natural drainage.
- Excavated soil and construction materials shall be stored away from watercourses.
- Portable toilets or existing sanitary facilities shall be used for workers where required, direct discharge of sewage or wastewater to the ground or water bodies shall not be permitted.
- Construction wastewater, if generated, shall be collected and managed through an appropriate temporary arrangement rather than discharged untreated.
- Silt controls shall be provided where excavation occurs near drainage paths or water bodies.
- Water quality incidents, including visible sediment release, spills or accidental discharge, shall be reported and corrective action taken immediately.

Dust emissions from excavation, roads and material handling

Excavation, movement of vehicles on unsealed roads, handling of soil and delivery of construction materials may generate temporary dust. The impact is expected to be limited because the construction footprint at each EWS site is small and construction activities will generally be short in duration.

Mitigation measures

- The Contractor shall control dust at source, with additional measures applied where sites are close to communities, tourism facilities or frequently used roads.
- Exposed soil and active work areas shall be lightly wetted during dry and windy conditions where necessary.
- Vehicle speeds shall be controlled on unsealed access roads and within work areas.
- Fine materials such as cement and sand shall be covered during transportation and storage.
- Excavated material shall not be unnecessarily stockpiled for extended periods.

- Vehicles transporting loose materials shall use suitable covers.
- Dust-generating activities shall be avoided during particularly strong winds where practicable.
- At tourism facilities and community locations, dust-generating activities shall be scheduled to minimise disturbance to visitors and nearby receptors.

Vehicle and equipment exhaust emissions

Construction will require light vehicles, 4×4 vehicles, trucks and, depending on the site, lifting equipment, generators or small machinery. These will generate short-term exhaust emissions. Given the small size of the installations and limited duration of works, emissions are expected to be low and localised.

Mitigation measures

- The Contractor shall minimise unnecessary vehicle movements and ensure that machinery is properly maintained and operated efficiently.
- Existing roads and access routes shall be used to minimise the need for new vehicle movements.
- Vehicles and equipment shall be maintained in good working condition and shall not be allowed to operate with excessive visible smoke.
- Engines shall be switched off when vehicles or machinery are stationary for extended periods.
- Deliveries shall be planned to combine loads and reduce repeated trips to remote sites.
- Where technically practicable, low-emission or fuel-efficient equipment shall be selected.
- Generators shall be used only where necessary, with renewable/solar power used for permanent EWS operation wherever feasible.

Construction noise and vibration

Noise will mainly arise from vehicle movement, drilling, excavation, concrete work, pole/tower erection and use of small construction equipment. The duration of noisy activities will generally be short. However, noise could be noticeable at tourism facilities, nearby communities or sensitive locations.

Mitigation measures

- The Contractor shall control noise at source and plan noisy activities around the surrounding land use and site sensitivity.
- Construction activities shall generally be undertaken during normal daytime working hours.
- Machinery and equipment shall be properly maintained to avoid unnecessary noise.
- Engines and generators shall not be left running when not required.
- Noisy activities shall be kept to the shortest practical duration.
- At tourism facilities, noisy works shall be coordinated with facility management to avoid peak visitor periods.

- Where construction occurs close to residences or other sensitive receptors, advance information shall be provided regarding the timing and duration of particularly noisy activities.
- Equipment generating excessive vibration shall not be used unless necessary and appropriately controlled.

Construction and domestic waste generation

Construction will generate relatively small quantities of waste, including packaging, cement bags, cable off-cuts, metal pieces, timber, plastic, excavated surplus material and general domestic waste from workers. Because the project does not involve large construction camps or industrial processes, waste quantities are expected to be relatively low.

Mitigation measures

- The Contractor shall apply waste minimisation and segregation at source so that recyclable and reusable materials are recovered and disposal is kept to a minimum.
- Waste shall be separated into recyclable, reusable, general and hazardous categories where appropriate.
- Packaging, scrap metal, cable off-cuts and other recoverable materials shall be collected and sent for reuse or recycling where facilities are available.
- Batteries, oils, contaminated materials and other hazardous wastes shall not be mixed with general waste.
- Construction sites shall be kept clean and waste shall not be buried or burned at the site.
- Food and domestic waste shall be stored in closed containers and removed regularly to prevent attracting animals.
- Surplus excavated soil suitable for reuse shall be used for backfilling and site restoration where appropriate.
- Waste shall be transported to authorised or approved disposal/recovery facilities in accordance with the applicable requirements in Zambia or Zimbabwe.

Temporary visual disturbance from construction activities

Construction materials, vehicles, temporary fencing, excavated soil and equipment may temporarily alter the appearance of EWS sites. This could be noticeable at tourism facilities, viewpoints, riverfront locations and other visually sensitive areas. The effect will generally be temporary and limited because of the small installation footprint.

Mitigation measures

The Contractor shall keep construction areas orderly and shall restore the site promptly once installation is completed.

- Construction materials and equipment shall be kept within the defined work area.
- Unnecessary stockpiling of soil, materials or waste shall not be permitted.
- Temporary fencing, barriers and signs shall be maintained in good condition.
- At tourism locations, equipment and materials shall be positioned away from important visitor viewpoints wherever technically practicable.

- Existing vegetation shall be retained wherever it does not compromise the safe operation of the EWS.
- Temporary construction areas shall be cleared and restored immediately after completion.
- Permanent EWS equipment shall be installed in the smallest practical footprint while maintaining required warning coverage and operational safety.

Accidental fire from construction activities, hot works or equipment

Fire could occur during welding, cutting, electrical installation, fuel handling or operation of generators and other equipment. The risk may be higher during hot and dry periods, particularly where sites are surrounded by dry grass or vegetation. A fire could damage nearby vegetation, buildings, tourism facilities or EWS equipment.

Mitigation measures

The Contractor shall apply basic but effective fire-prevention measures at all sites, with additional controls at locations close to dry vegetation or buildings.

- Hot works shall be controlled and monitored, particularly where dry vegetation is present.
- Flammable materials shall be kept away from welding, cutting and other ignition sources.
- Suitable fire extinguishers shall be available during construction and hot-work activities.
- Vehicles and machinery shall be checked for fuel or oil leaks before use.
- Open burning of construction or domestic waste shall not be permitted.
- Dry vegetation immediately around the work area shall be managed only to the extent necessary to establish a safe working area, without unnecessary clearing.
- Workers shall be briefed on emergency fire response and the location of the nearest emergency assistance.

Operation Stage

Used batteries, electronic waste and damaged solar/electrical components

During operation, EWS installations will generate small quantities of maintenance waste rather than continuous process waste. The principal wastes will include spent batteries, damaged solar panels, electronic components, cables, sensors, communication equipment and other electrical parts. Improper disposal could result in soil or water contamination, particularly at remote sites.

Mitigation measures

- The project proponent shall establish a controlled system for collection, storage, transport and final disposal or recycling of EWS-related electronic and battery waste.
- Used batteries and damaged electrical/electronic components shall not be discarded at the installation site.
- Spent batteries shall be collected in suitable secure containers and transported to approved recycling, recovery or disposal facilities.

- Damaged solar panels, cables, sensors and electronic components shall be segregated from general waste.
- Temporary storage of hazardous or electronic waste shall be in secure, weather-protected areas.
- Maintenance contractors shall maintain records of replaced batteries and other significant EWS waste.
- Wherever technically and commercially feasible, components with longer service lives and repairable/recyclable characteristics shall be selected.
- Waste generated during maintenance at remote sites shall be removed by the maintenance team and shall not be left at the EWS installation.

Flood/extreme-weather damage to EWS infrastructure

The EWS infrastructure is intended to operate in an environment where heavy rainfall, flooding, strong winds and other extreme weather conditions may occur. River monitoring equipment and installations close to the Zambezi or reservoir may be particularly exposed. Damage could affect equipment performance and, in severe cases, could result in debris, damaged batteries, electrical components or structural materials entering the surrounding environment.

Mitigation measures

The EWS design and maintenance arrangements shall consider the environmental conditions at each site so that equipment remains secure and functional during extreme events.

- Site selection shall consider historical flood levels, drainage, slope stability, wind exposure and accessibility for maintenance.
- River monitoring equipment shall be installed using appropriate structural and anchoring arrangements for the expected water conditions.
- Electrical and communication components shall be protected against water ingress and weather exposure.
- Solar panels, poles, towers and equipment enclosures shall be securely anchored and designed for local wind and weather conditions.
- After major flood or extreme-weather events, critical installations shall be inspected for structural damage, exposed wiring, displaced equipment or environmental disturbance.
- Any damaged batteries, electrical components or other materials shall be removed promptly and managed as appropriate waste.
- Where an installation is repeatedly affected by flooding or erosion, the site shall be reviewed and relocation considered if technically feasible.

Decommissioning

Scrap metal, batteries, cables, concrete and electronic waste

At the end of the EWS project life or when individual installations are replaced, removal of poles, sirens, towers, solar panels, batteries, cables, foundations and electronic equipment will generate a range of solid wastes. If not properly removed and managed, these materials could remain as long-term visual and physical hazards or contaminate soil and water.

Mitigation measures

Decommissioning shall be planned so that the site is left safe, clean and, wherever practicable, in a condition similar to its pre-installation state.

- All redundant sirens, poles/towers, solar panels, batteries, cables, communication equipment and other components shall be removed from the site.
- Scrap metal and other recyclable materials shall be segregated and transferred to appropriate recycling or recovery facilities.
- Batteries and electronic equipment shall be handled as controlled/hazardous or e-waste as applicable and shall not be disposed of with general waste.
- Concrete foundations shall be removed where practicable and where their retention is not required for safety or future use.
- Any excavated areas shall be backfilled, compacted and stabilised, with topsoil reinstated where available.
- Temporary access routes and disturbed areas shall be restored to the extent practicable.
- No construction, demolition or electronic waste shall be abandoned at remote, protected-area, riverbank or tourism sites.
- A decommissioning waste inventory and disposal record shall be maintained to demonstrate that removed EWS components have been appropriately managed.

B. Biological Environment

The proposed EWS is a low-footprint project consisting primarily of sirens, poles/towers, automatic rain gauges, weather stations, AWLR/flow-monitoring equipment, solar panels, batteries and communication equipment. The installations do not involve major permanent civil works, large buildings or extensive land development. Consequently, the potential impacts on biological resources are expected to be relatively small in area and mostly associated with the short construction period and periodic maintenance access.

The biological setting downstream of Kariba Dam is, however, highly sensitive. The Zambezi River downstream of the dam passes through a largely natural landscape containing protected areas and important wildlife habitats. The downstream conservation landscape includes Lower Zambezi National Park in Zambia and Mana Pools National Park, Sapi Safari Area and Chewore Safari Area in Zimbabwe, which together form an extensive transboundary conservation landscape. Mana Pools, Sapi and Chewore are recognised as a UNESCO World Heritage property, while Lower Zambezi National Park lies on the opposite bank of the Zambezi.

The downstream Zambezi also supports extensive riverine vegetation, floodplains, sandbanks, pools and aquatic habitats. Mana Pools is particularly important for elephant, buffalo, zebra, antelope, hippopotamus, crocodile, lion, cheetah, wild dog and a large diversity of bird species. The ecological importance of the downstream river is also linked to the regulated flow from Kariba Dam, and studies have documented changes in downstream floodplain hydrology at Mana Pools associated with upstream reservoir operation.

Some proposed EWS installations, however, will be located in already developed or modified areas, including downstream lodges, resorts, tourism facilities and other sites with existing human activity. These locations generally present lower habitat-disturbance risk than installations requiring access into intact natural habitat. The preferred approach will therefore be to locate equipment within existing developed areas wherever this does not compromise the technical requirements for flood-warning coverage.

The project will also apply an avoid-minimise-restore approach, with particular attention to protected areas, riverine habitats, wildlife movement areas and tourism facilities.

Construction Stage

Vegetation clearance and habitat disturbance

The installation of EWS equipment will require only limited ground disturbance for foundations, poles/towers, sirens, cables, earthing systems and monitoring equipment. The overall area of vegetation loss will therefore be small. At downstream sites within or near Lower Zambezi National Park, Mana Pools National Park, Sapi Safari Area and Chewore Safari Area, natural woodland, riverine vegetation and floodplain habitats can occur immediately adjacent to access tracks and proposed installation locations.

Mitigation measures

- The Contractor shall keep vegetation clearance to the minimum practical footprint (4 m × 4 m) with site selection used as the first and most important mitigation measure.
- Existing developed, cleared or previously disturbed areas shall be prioritised for EWS installations wherever they provide adequate warning coverage.
- At downstream lodges and resorts, the EWS shall preferably be located within existing developed areas rather than clearing natural vegetation.
- For towers and poles, the foundation and erection area shall be restricted to the minimum required for safe installation.
- Mature trees and significant riverine vegetation shall be retained wherever practicable.
- Vegetation shall not be cleared simply to improve the appearance or visibility of the installation.
- Within or adjacent to Lower Zambezi National Park, Mana Pools National Park, Sapi Safari Area and Chewore Safari Area, any vegetation clearance shall be undertaken only after consultation and approval from the relevant protected-area authority.
- Temporary disturbance areas shall be restored following completion of the works.

Fragmentation or disturbance of sensitive habitats

The permanent EWS structures will be too small to create meaningful landscape-scale habitat fragmentation. The greater concern is the possibility that construction and maintenance access could gradually disturb natural habitat, particularly if new informal tracks are created or vehicles move outside existing roads.

Mitigation measures

- The project shall avoid creating new disturbance corridors and shall use existing access infrastructure wherever practicable. Existing Park roads, lodge roads, maintenance tracks and previously disturbed access routes shall be used wherever feasible.

- New access tracks shall not be created solely for an EWS installation unless technically unavoidable and approved.
- Vehicles shall remain on designated tracks and shall not drive through undisturbed vegetation.
- The construction footprint shall be clearly marked before work starts.
- Wildlife movement routes and areas of particularly sensitive vegetation identified during site verification shall be avoided where practicable.
- At protected-area sites, access arrangements shall be agreed with the responsible park authority.
- Where shifting a tower, siren or monitoring point slightly can avoid sensitive habitat without affecting warning coverage, the alternative location shall be considered.

Wildlife disturbance from vehicles, workers, lights and construction noise

Construction will temporarily introduce workers, vehicles, drilling equipment and lifting operations into areas that may otherwise experience limited human disturbance. This may result in temporary avoidance of the immediate work area by wildlife. The risk will be high for sites within or close to Lower Zambezi National Park, Mana Pools National Park and the Sapi and Chewore Safari Areas, where wildlife is abundant and the natural environment is relatively undisturbed. However, at downstream lodges and resorts, the additional disturbance is expected to be lower because these areas already experience regular vehicles, visitors, staff activities and general tourism-related noise.

Mitigation measures

- Construction shall be planned so that disturbance is short-term, predictable and limited to the immediate installation area.
- Construction shall only be undertaken during daylight hours. Use of artificial lights should be avoided.
- Vehicle speeds shall be restricted on park and wildlife-sensitive access roads.
- Workers shall remain within the approved work area.
- Workers shall not feed, chase, capture or deliberately approach wildlife.
- Unnecessary vehicle horns, loud music and other avoidable noise shall be prohibited.
- Drilling, cutting and tower erection shall be limited to the shortest practical period.
- Construction activities within protected areas shall be coordinated with the relevant park authority.
- At lodges and resorts, noisy activities shall be coordinated with management to avoid peak visitor periods.
- If large animals or other sensitive wildlife enter the immediate work area, work shall be paused where necessary until the animals have moved to a safe distance.

Injury or mortality of small animals and hunting

Small mammals, reptiles, amphibians and other ground-dwelling animals may enter foundation excavations, cable trenches or earthing pits. The risk will be limited because the EWS footprint and excavations are small, but it may occur at sites within or close to natural habitats and protected areas. There is also a risk of workers opportunistically hunting, capturing or harming wildlife, particularly at remote sites.

Mitigation measures

- The Contractor shall keep excavations open for the shortest possible period and ensure that wildlife is not deliberately harmed or hunted.
- Open excavations shall be checked daily and animals safely released where practicable.
- Small escape ramps or sloped sides shall be provided where appropriate.
- Excavations shall be covered or protected when work stops.
- Excavations shall be backfilled as soon as the work is completed.
- Hunting, trapping, capturing or killing wildlife by workers shall be strictly prohibited.
- Workers shall receive a site induction on wildlife protection, particularly at Lower Zambezi National Park, Mana Pools National Park, Sapi and Chewore Safari Areas.
- Any wildlife incident shall be reported to the site supervisor and relevant wildlife authority.

Aquatic and riparian habitat disturbance near AWLR/flow-monitoring sites

AWLR and flow-monitoring installations will necessarily be located close to the Zambezi River or associated channels and therefore require particular attention to aquatic and riparian habitats. The downstream Zambezi contains extensive riverine and floodplain habitats. At Mana Pools, the river supports pools, sandbanks, floodplains and associated vegetation, with hippopotamus, crocodile and numerous other aquatic and terrestrial species. The objective of the EWS is to monitor the river and provide an early warning function, therefore, some physical access to the riverbank is unavoidable. However, the installation should not result in unnecessary modification of the riverbank or aquatic environment.

Mitigation measures

- AWLR and flow-monitoring works shall follow a minimum-disturbance river-access approach.
- Existing river access points and previously disturbed areas (bridges, station etc.) shall be used wherever practicable.
- The exact monitoring point shall be selected to avoid unnecessary removal of riparian vegetation.
- The smallest practical foundation and support arrangement shall be used.
- Machinery shall not enter the river unless specifically required by the approved installation method.
- Riverbank vegetation shall be retained wherever possible.
- Excavated soil and construction materials shall be stored away from the river.
- Concrete washout, fuel storage and equipment maintenance shall be prohibited close to the water's edge.
- Work shall be suspended during unsafe river conditions or extreme flows.
- Any temporarily disturbed riverbank area shall be stabilised and restored immediately after completion.

Introduction or spread of invasive alien plant species

Because EWS sites are distributed along the downstream Zambezi and may include both protected natural areas and developed tourism facilities, vehicles and equipment will move between ecologically different locations. This creates a potential pathway for movement of invasive plant seeds and contaminated soil.

Mitigation measures

The Contractor shall control vehicle and soil movement between sites.

- Vehicles and machinery shall be inspected and cleaned where necessary before moving between sites.
- Particular attention shall be given to equipment moving from disturbed areas into Lower Zambezi National Park, Mana Pools National Park and other protected sites.
- Soil and plant material shall not be transported unnecessarily between EWS locations.
- Fill, gravel and other imported materials shall be obtained from approved sources.
- Workers shall be instructed not to transport seeds, plant cuttings or contaminated soil between sites.
- Disturbed areas shall be restored promptly after construction.
- Any invasive plant species observed within the work area shall be reported and managed in consultation with the relevant authority.

Accidental veld/forest fire affecting vegetation and habitat

Construction activities involving welding, cutting, generators and other ignition sources may cause an accidental fire. The potential consequence is greater at downstream sites surrounded by dry woodland, grassland or other combustible vegetation. A fire at a site within or adjacent to Lower Zambezi National Park, Mana Pools National Park or other conservation areas could spread beyond the immediate work area and affect natural habitat.

Mitigation measures

- Fire prevention shall be treated as a site-specific environmental control, particularly during hot and dry periods.
- Hot works shall be undertaken only in controlled locations away from dry vegetation.
- Fire extinguishers shall be available during welding, cutting and other hot works.
- Open burning of vegetation, waste or packaging shall not be permitted.
- Construction vehicles shall be checked for fuel leaks and overheating.
- Only the minimum vegetation necessary for safe work shall be managed.
- Workers shall receive fire-awareness training.
- At protected-area sites, the Contractor shall follow the fire-management requirements of the relevant park authority.
- Hot works shall be suspended when extreme fire conditions make safe control impracticable.

Operation Stage

Permanent loss of small areas of vegetation beneath installations

Permanent vegetation loss will occur beneath siren foundations, tower/pole bases, equipment cabinets and other fixed infrastructure. The affected area will be small, and the impact will be substantially reduced where the installation is placed in an existing developed area. The project will therefore seek to avoid placing permanent infrastructure in undisturbed natural habitat where a suitable developed alternative exists.

Mitigation measures

- Permanent habitat loss shall be minimised through careful site selection.
- Existing developed areas, clearings, lodge/resort premises and previously disturbed sites shall be preferred.
- The smallest practical permanent footprint shall be used.
- Mature trees and significant riverine vegetation shall be retained wherever possible.
- Natural vegetation surrounding the equipment shall be retained where it does not create a fire, safety or operational problem.
- Within protected areas, any permanent vegetation clearance shall be undertaken only with the approval of the relevant authority.
- Disturbed margins shall be allowed to regenerate naturally where practicable.

Wildlife disturbance from siren testing and emergency activation

Siren testing is one of the more specific biological concerns associated with the EWS because the sirens are designed to produce a loud audible warning. However, the sirens will not operate continuously. Under normal conditions they will remain silent and will only be activated for necessary testing or during an actual emergency. The potential disturbance is more relevant at sites within or near Lower Zambezi National Park, Mana Pools National Park, Sapi and Chewore Safari Areas, and at downstream lodges and resorts where wildlife may occur close to developed areas.

At lodge and resort locations, the surrounding environment is already influenced by tourism activities, but unnecessary or unexplained siren activation could still disturb wildlife and visitors.

Mitigation measures

- The project should adopt a planned and low-disturbance siren-testing protocol, with advance communication and use of silent testing wherever technically possible.
- Routine system checks of power, communication, control systems and equipment status shall use silent testing wherever technically feasible.
- Audible siren activation shall be limited to tests that are actually necessary to verify the acoustic warning function.
- Routine audible tests shall be scheduled in advance and shall not be undertaken without prior information to affected facilities and relevant authorities.
- For sites within or close to protected areas, testing arrangements shall be discussed and agreed with the relevant park authority.

- At downstream lodges and resorts, the timing of audible testing shall be agreed with facility management.
- Where a drill involves community participation, the timing, duration, purpose and expected response shall be communicated in advance and consensus on the drill arrangements shall be sought.
- Test activations shall preferably be undertaken during agreed daytime periods and kept as short as technically possible.
- The public shall be informed clearly that the activity is a planned test and not an emergency warning.
- Repeated unnecessary audible activation shall not be permitted.
- During a genuine flood emergency, the siren shall be activated as required because protection of human life takes precedence over temporary wildlife disturbance.

Visual and landscape mismatch of EWS installations with surrounding

Some EWS installations, particularly those located within or near lodges, resorts and tourism facilities, even in protected areas may appear visually different from the surrounding landscape because of poles, sirens, solar panels, batteries and protective fencing. This may be more noticeable in tourism areas where maintaining the natural appearance of the surroundings is important.

Mitigation measures

- The installations/fence shall be designed and maintained to blend as far as practicable with the existing surroundings, while maintaining safety and equipment performance. The fence and associated equipment shall be kept to the minimum footprint required.
- At lodges and resorts, the final location and appearance shall be discussed with facility management.
- Where practicable, locally appropriate vegetation shall be planted around the outside of the fence to screen the installation and help it blend with the surrounding landscape.
- Vegetation selected for screening shall be locally appropriate and non-invasive, and where sites are exposed to elephants, species that are less attractive to elephants may be considered in consultation with DNPW/ZimParks.
- Vegetation shall not be planted where it could interfere with the electric fence, solar panels, access or equipment maintenance.
- Existing vegetation shall be retained wherever practicable to provide natural screening.
- At protected-area sites, landscaping and screening shall be agreed with the relevant wildlife authority.

Wildlife disturbance from maintenance activities

Maintenance will involve occasional visits to sirens, towers, solar panels, rain gauges, communication equipment and AWLR stations. These visits will generally be short, but vehicle movement and human presence can temporarily disturb wildlife.

Mitigation measures

Maintenance shall be undertaken using a low-disturbance approach similar to that used during construction.

- Existing Park, lodge and maintenance roads shall be used wherever practicable.
- Vehicles shall remain on established tracks.
- Maintenance personnel shall remain within the existing EWS work area.
- Maintenance will generally be undertaken during daylight hours.
- Workers will not feed, chase, approach or otherwise disturb wildlife.
- Maintenance activities shall be completed efficiently to minimise the duration of disturbance.
- Where wildlife is present immediately around the equipment, work shall be paused where necessary.

Disturbance from maintenance and lighting

Some downstream EWS locations, particularly those within resorts, lodges or managed facilities, may have security or maintenance lighting. Artificial lighting can attract insects and influence nocturnal wildlife behaviour.

Mitigation measures

- Lighting shall be kept to the minimum necessary for safety and security.
- Continuous floodlighting shall be avoided unless required.
- Lights shall be directed towards the EWS equipment rather than surrounding vegetation or the river.
- Shielded, low-intensity lighting shall be preferred.
- Lights shall be switched off when not required.
- At protected-area sites, permanent lighting shall be avoided unless specifically justified and agreed with the relevant authority.
- At lodges and resorts, EWS lighting shall be integrated with existing security lighting rather than creating unnecessary additional illumination.

Bird collision with communication towers, masts or wires

The proposed communication structure is a single-pole tower of approximately 15 m height, rather than a tall lattice or guyed communication tower. Therefore, the potential for bird collision is expected to be relatively low. However, the risk may still occur at sites within or close to the Zambezi River corridor and protected areas, where bird activity can be high.

Mitigation measures

- The simple pole design and careful siting shall be used to minimise any potential bird-collision risk.
- The 15 m single-pole structure shall be preferred, with guy wires avoided.
- The pole shall be located away from known bird nesting, roosting or concentration areas where practicable.
- No unnecessary lighting or other features that could attract birds at night shall be installed.
- Where any associated cable or support component creates a visible collision risk, appropriate bird diverters/visibility markers shall be considered.

- Any observed bird collision shall be recorded and reviewed.
- If repeated collisions are identified, additional bird-visibility measures or minor site adjustments shall be considered in consultation with DNPW or ZimParks, as applicable.

Electric fencing and potential wildlife injury, electrocution or disturbance

At some EWS locations within or close to wildlife areas, a solar-powered electric fence may be installed to deter elephants and other animals from damaging EWS infrastructure. Poor design or maintenance could cause injury or electrocution to wildlife, including birds, or interfere with normal animal movement.

Mitigation measures

- The solar fence shall be designed as a non-lethal wildlife deterrent and shall minimise risks to wildlife.
- A solar-powered, battery-backed pulsed energiser with controlled output shall be used.
- Fence height and wire spacing shall be suitable for the wildlife present, particularly elephants, and minimise entanglement or injury.
- The fence shall enclose only the minimum area required and shall not unnecessarily obstruct wildlife movement or access to water.
- DNPW and ZimParks shall be consulted on design and placement at protected-area sites.
- Proper earthing, insulation and protection against accidental contact by birds and other wildlife shall be provided.
- Barbed or razor wire shall not be used.
- The fence shall be regularly inspected and safely isolated during maintenance.
- Any wildlife injury or electrocution shall be recorded, reported and the fence arrangement reviewed.

Maintenance

Disturbance to protected areas and sensitive habitat during maintenance access

The repeated movement of maintenance vehicles into natural areas could cause gradual disturbance if informal access routes develop or vegetation is repeatedly cleared. This is particularly relevant to installations associated with Lower Zambezi National Park, Mana Pools National Park and other Safari Areas.

Mitigation measures

- Maintenance access shall be controlled throughout the operating life of the EWS.
- Existing Park roads and tracks shall be used wherever practicable.
- No informal tracks shall be created to reach EWS equipment.
- Entry into protected areas shall follow the requirements of the relevant protected-area authority.
- Maintenance crews shall carry only the equipment necessary for the planned task.
- Vegetation clearance for access shall be avoided wherever possible.
- Any accidental disturbance to vegetation shall be restored where practicable.

- Maintenance waste shall be removed from the site after every visit.
- If repeated maintenance access is causing visible ecological disturbance, the access arrangement shall be reviewed.

Wildlife disturbance from maintenance vehicles and personnel

Maintenance vehicles and personnel may temporarily disturb wildlife, particularly in remote protected areas. However, because maintenance visits will be periodic and relatively short, the overall impact is expected to remain low.

Mitigation measures

- Maintenance personnel shall apply wildlife-sensitive working practices.
- Vehicle speeds shall be kept low within protected areas.
- Drivers shall follow instructions issued by park authorities.
- Vehicles shall remain on established tracks.
- Workers shall not approach or feed wildlife.
- Unnecessary horns and noise shall be avoided.
- Maintenance shall be completed as efficiently as possible.
- If significant wildlife activity is observed at the site, work shall be paused or rescheduled where practicable.

<u>Decommissioning Phase</u>

Disturbance of vegetation and wildlife during removal of equipment

Removal of EWS infrastructure will require workers, vehicles and lifting equipment to access the installation. By the time of decommissioning, vegetation may have regenerated around the installation and wildlife may have become accustomed to the area.

Mitigation measures

Decommissioning shall be planned so that removal does not create a larger footprint than the original construction.

- Existing access roads and tracks shall be used.
- The removal area shall be clearly defined before dismantling begins.
- Vegetation shall not be cleared unnecessarily.
- Naturally regenerated vegetation shall be retained wherever it does not compromise safe dismantling.
- Towers and poles shall be dismantled in a controlled manner.
- Excavations created by removal shall be backfilled promptly.
- Disturbed ground shall be stabilised and restored.
- At protected-area sites, decommissioning shall be coordinated with the relevant park authority.

6.6 Cumulative Impact Assessment

The cumulative impacts of the EWS have been considered in relation to the number and location of installations, the scale of construction works and the operation of the siren system. More than 100 locations were initially considered for the EWS. Following further review and optimisation of the network, the number was reduced to 87 locations, including 50 siren locations. The optimisation was undertaken to avoid unnecessary installations, reduce disturbance and limit the potential for overlapping siren noise while maintaining the required warning coverage.

Construction Phase

The cumulative impacts during construction are expected to be low and temporary. The EWS installations are spread over a large area and the sites are generally not close to each other. The works at each location are also small in scale and require relatively limited quantities of construction materials and other resources. Therefore, the combined effects of construction activities are not expected to be significant. The main temporary impacts may include dust, noise, vehicle movement, small-scale soil disturbance, limited vegetation clearance and construction waste. These impacts will generally be restricted to individual sites and will reduce once the installation works are completed.

Mitigation Measures

The Contractor will:

- use only the approved EWS locations and keep activities within the defined site footprint;
- use existing roads and access tracks wherever practicable;
- obtain construction materials from approved sources and avoid unnecessary transport of materials;
- cover cement, sand and other fine materials during storage and transport and control dust during construction;
- maintain vehicles and equipment and avoid unnecessary engine idling;
- carry out noisy activities during appropriate working hours;
- minimise vegetation clearance, particularly at environmentally sensitive locations;
- prevent soil, cement, fuel, oil and other construction materials from entering rivers or drainage channels;
- properly collect, store and dispose of construction waste; and
- reinstate disturbed areas after completion of the works.

Where EWS works take place at the same time as other construction or maintenance activities in the area, the Contractor and Supervision Consultant will coordinate the works to avoid unnecessary overlap and additional disturbance.

Operational Phase

During operation, the main potential cumulative impact is noise from the sirens, particularly during routine testing. The sirens are, however, an essential part of the EWS and need to provide sufficient sound coverage for the warning system to work effectively. At the same time, unnecessary or repeated noise should be avoided, particularly close to communities, tourism facilities, schools, health facilities, protected areas and other sensitive receptors. The final network of 50 sirens has been selected after optimisation of the initially identified locations. Reducing the overall number of locations from more has helped reduce the number of potential noise sources and unnecessary overlap between siren coverage areas.

Operational Mitigation Measures

ZRA will:

- undertake a cumulative noise impact assessment for the operational siren network;
- review the findings of the assessment and introduce additional measures where required;
- maintain the optimised network and avoid installing additional sirens where the required warning coverage can be achieved through the existing system;
- carry out routine siren testing according to an approved testing schedule;
- keep routine testing to the minimum frequency and duration necessary to confirm system performance;
- inform communities and relevant facilities about planned tests, where practicable;
- avoid unnecessary simultaneous testing of multiple sirens;
- give particular attention to sensitive receptors, including communities, tourism facilities and wildlife-sensitive areas;
- maintain sirens and associated equipment properly to ensure that they operate as designed; and
- record and address complaints relating to siren noise through the GRM.

During an actual emergency, siren activation will take priority because the primary purpose of the system is to provide timely warning to potentially affected communities.

7 ENVIRONMENTAL AND SOCIAL MANAGEMENT PLAN

7.1 Introduction

The Environmental and Social Management Plan provides the framework for managing the potential environmental and social impacts of the proposed EWS in Zambia and Zimbabwe. It is based on the impacts assessed and provides corresponding mitigation, monitoring and implementation responsibilities. The EWS is a small-footprint, low-intensity intervention, with most potential impacts limited to short-duration installation activities such as minor excavation, foundation works, equipment installation, fencing and testing. Wastewater generation at individual sites is expected to be minimal. However, the distributed EWS network includes sites near communities, villages, schools, hospitals, markets, lodges, resorts, the Zambezi River and protected areas. Site-specific management will therefore be applied to address local environmental and social sensitivities.

The ESMP will follow an avoid-minimise-restore approach and will ensure compliance with applicable regulatory requirements, including those of ZEMA under Zambia's environmental management legislation and EMA under Zimbabwe's Environmental Management Act, as well as relevant requirements of DNPW, ZimParks and other competent authorities. ZRA will obtain the required regulatory permission, land-use rights and site-access permissions, while the Contractor will comply with applicable construction permits and implement ESMP under the guidance of ZRA's environment and social consultant.

7.2 Objectives of the ESMP

The main objectives of the ESMP are to:

- ensure that all mitigation measures identified in the impact assessment are implemented,
- ensure compliance with applicable environmental, social, health and safety requirements in Zambia and Zimbabwe
- define clear responsibilities for implementation, supervision and monitoring
- ensure that construction activities remain within approved site boundaries and footprints
- minimise disturbance to communities, tourism facilities, protected areas and natural habitats
- prevent pollution of soil and water resources
- protect workers, communities, visitors and wildlife from avoidable risks
- ensure that EWS operation and maintenance do not create unnecessary environmental or social disturbance,
- provide a mechanism for monitoring performance and taking corrective action, and
- maintain records demonstrating environmental and social compliance throughout the project life.

7.3 ESMP Implementation Principles

The following principles will guide implementation:

1. Site-specific management

Because the EWS sites have different surroundings and access conditions, the Contractor will utilise this ESMP to prepare a site-specific Construction Environmental and Social Management Plan (C-

ESMP) for each group of works or individual location, as appropriate. The C-ESMP will reflect the actual terrain, access, land use, nearby receptors, material requirements, wildlife sensitivity and construction method.

2. Minimum footprint

The permanent and temporary working areas will be kept to the minimum required for safe installation and operation. For example, the approximate 4 m × 4 m siren installation footprint will not be unnecessarily expanded.

3. Use of existing access

Existing roads, tracks and already modified areas will be used wherever practicable, particularly within protected and environmentally sensitive areas. Remote river-side sites may use boat access wherever safe and practical.

4. Contractor good construction practice

Most routine construction control including PPE, dust control, waste management, spill prevention, traffic management, excavation safety, fire prevention and site reinstatement will be incorporated into the Contractor's construction cost/C-ESMP.

5. Protection of sensitive receptors

Additional controls will apply at sites close to villages and community areas, schools and hospitals, markets, lodges and resorts, the Zambezi River and riverbanks, Lower Zambezi National Park, Mana Pools National Park & other safari, game and sensitive areas.

6. Stakeholder engagement

ZRA will continue consultation with landowners, institutions, Chiefs, Headmen, community leaders, regulatory agencies, protected-area authorities, tourism operators and other relevant stakeholders before site mobilisation.

7.4 Environmental and Social Management Measures

The detailed ESMP matrix presented below provides the environmental and social management schedule for the project and will form part of the requirements to be incorporated into the relevant project and construction contracts. The Contractor will be required to incorporate applicable measures into its site-specific C-ESMP and implement them throughout construction. ZRA and the supervising team will monitor compliance and ensure that corrective actions are implemented where required. The mitigation measures presented in this ESMP should be read in conjunction with the detailed mitigation measures provided for each potential impact in the preceding impact-assessment chapters. The preceding chapters provide the impact-specific context and rationale, while this ESMP translates those measures into practical requirements for implementation, monitoring and supervision.

Part A. Socio-economic Environment

Table 33: Environment and Social Management Plan Matrix (Socio-economic, Physical and Biological Environment)

Environmental Aspect / Project Activity	Potential Impact	Mitigation Measures	Performance Indicator	Monitoring / Frequency	Responsibility	Cost
Regulatory approvals and land-use arrangements	Failure/delay in obtaining required Consents, Permits, Clearances and NOCs	ZRA will obtain land-use rights and site-access permissions from relevant institutions, landowners, lodges/resorts and community representatives before site handover. - Contractor will obtain construction-related permits/NOCs required for its activities.	Required approvals available before mobilisation, no work without approval	Before each site mobilisation	ZRA / Contractor	ZRA/project cost, Contractor's cost for construction permits
Construction planning and logistics	Inadequate site-specific Construction Plan covering material sources, labour, machinery/equipment, access and transportation logistics	Contractor will prepare a site-specific construction arrangement covering material sources, equipment, labour, access and transport. Existing roads/tracks will be used where practicable, boat access may be used for suitable remote river sites. -Site Specific ESMP	Site-specific plan approved before mobilisation, approved material sources identified	Before construction at each site	Contractor	Contractor's cost
Temporary occupation/access	Temporary land access and use of installation sites	Working and access areas will be agreed in advance and kept to the minimum. The approximately 4 m × 4 m siren footprint will not be unnecessarily expanded. Disturbed areas will be restored.	Approved access arrangements, no unnecessary land disturbance, restoration completed	Before/during/after works	Contractor / ZRA	Contractor's cost
Site selection and consultation	Community concerns regarding installation locations and land ownership	Communities, Chiefs, Headmen and affected land users will be consulted. Schools, hospitals, markets, lodges and resorts will be consulted on site-specific arrangements.	Consultation records, grievances recorded and resolved	Before site finalisation	ZRA / Contractor	ZRA/project cost
Community consultation	Exclusion of vulnerable groups from consultation and warning-system planning	Women, elderly persons, persons with disabilities and representatives of schools, hospitals and markets will be included. Alternative warning channels will be considered where sirens alone are insufficient.	Vulnerable groups represented in consultations, alternative arrangements identified where needed	During consultation and drills	ZRA / Local authorities	ZRA/project cost
Site verification and excavation	Disturbance of cultural, archaeological, burial or sacred resources through inappropriate siting	Known sensitive locations will be avoided. Chance-find procedures will be followed if archaeological material, graves or other cultural resources are encountered.	No known cultural sites disturbed, chance-find records maintained	Before/during excavation	Contractor / ZRA	Contractor's cost
Construction traffic	Construction traffic and road-safety risks	Speed limits, competent drivers, vehicle safety checks and safe loading will be required. Access to villages, schools, hospitals, markets, lodges and resorts will be maintained.	No traffic incidents attributable to project, speed/control measures implemented	Daily during construction	Contractor	Contractor's cost
Occupational, Health & safety	Occupational accidents, work at height and electrical hazards	Trained workers, PPE, fall-arrest systems, exclusion zones and competent electrical personnel will be used. Public access to work areas will be prevented.	100% workers using required PPE, no uncontrolled access, work-at-height controls in place	Daily	Contractor	Contractor's cost
Occupational, Health & safety	Drowning and wildlife encounters during river-based work	Approved boats, competent boat operators, life jackets and communication arrangements will be used. Work will stop during unsafe river or weather conditions.	Life jackets available/used, competent boat operator, no uncontrolled river activity	Each river-based activity	Contractor	Contractor's cost
Occupational, Health & safety	Worker exposure to dust, noise, heat and adverse weather	PPE, drinking water, rest periods and suitable working hours will be provided. Work will be suspended during unsafe weather conditions.	PPE and drinking water available, rest arrangements implemented	Daily	Contractor	Contractor's cost

Environmental Aspect / Project Activity	Potential Impact	Mitigation Measures	Performance Indicator	Monitoring / Frequency	Responsibility	Cost
Community Health & safety	Community health and safety risks from open excavations, vehicles and equipment	Excavations will be barricaded or covered, equipment secured and exclusion zones maintained. Additional controls will apply near schools, hospitals, markets and tourism facilities.	All open excavations protected, warning signs/barriers installed	Daily	Contractor	Contractor's cost
Recruitment/procurement/site selection	Social conflict arising from employment, procurement or site selection	Local employment and procurement will be transparent. Technical site-selection criteria will be explained and grievances managed through the GRM.	Recruitment/procurement records, grievances recorded and resolved	Monthly / as required	Contractor / ZRA	Contractor/project cost
Worker-community interaction	GBV, SEA/SH and inappropriate worker behaviour	Workers will sign a Code of Conduct and receive GBV/SEA/SH induction. Confidential reporting arrangements will be provided and unnecessary interaction with communities avoided.	100% workers sign Code of Conduct and receive training, complaints addressed	At induction and periodically	Contractor	Contractor's cost
Hot works/electrical systems	Fire affecting communities or facilities from hot works, electrical systems or equipment	Hot works will be controlled, fire extinguishers provided, electrical/battery systems installed correctly, dry vegetation controlled around equipment.	Fire extinguishers available, hot-work controls implemented, no uncontrolled fire	Daily during works / periodic operation	Contractor / ZRA	Contractor's cost
EWS operation	Warning-system failure or malfunction during an emergency	Sirens, AWLRs, communication systems, solar panels and batteries will be inspected and maintained. Faults will be logged and prioritised.	Scheduled maintenance completed, faults logged and rectified	As per O&M schedule	ZRA / EWS Operator	O&M budget
Warning activation	False or inconsistent warnings	Standard warning protocols will define authorised activation. Testing/drills will be clearly distinguished from emergency activation through prior notification and agreed procedures.	No unauthorised activation, tests notified in advance	Each test/drill	ZRA / EWS Operator	O&M/project cost
Warning coverage	Unequal access to warnings	Sirens will be supplemented, where necessary, by SMS, radio, VHF, public-address systems, local leaders and community networks. Particular attention will be given to remote communities and the Luangwa area affected by potential Zambezi backflow.	Warning coverage reviewed, gaps identified and addressed	Periodic / during drills	ZRA / Local authorities	O&M/project cost
Equipment security	Theft, vandalism or deliberate damage to EWS equipment	Equipment will be secured and, where appropriate, located within managed premises. Local communities and facility managers will be informed of its safety purpose.	Security arrangements in place, incidents recorded	Periodic	ZRA / Facility/Park management	O&M budget
Siren testing/drills	Siren testing and emergency activation noise affecting communities	Silent testing will be used where technically practicable. Audible tests and drills will be notified in advance and coordinated with communities, schools, hospitals, lodges, resorts and park authorities.	Test/drill notification completed, complaints recorded and addressed	Each test/drill	ZRA / EWS Operator	O&M/project cost
Maintenance activities	Temporary noise, traffic and access disturbance	Maintenance will be planned in advance and scheduled to avoid peak activities at lodges, resorts, schools, hospitals and markets. Existing access will be used.	Maintenance visits coordinated, no unresolved access complaints	Each visit	Contractor / ZRA	Contractor's cost
Electrical/battery maintenance	Work-at-height, electrical and battery-replacement risks	PPE, fall protection and electrical isolation will be used. Batteries will be safely removed, transported and sent to approved recycling/disposal facilities.	Maintenance records, electrical isolation/PPE used, batteries properly managed	Each maintenance activity	Maintenance Contractor / ZRA	O&M cost

B. Physical Environment

Environmental Aspect / Project Activity	Potential Impact	Mitigation Measures	Performance Indicator	Monitoring / Frequency	Responsibility	Cost
Land & Soil Environment	Soil disturbance and compaction	Keep the working area to the minimum, use existing disturbed areas and access routes, restrict machinery to designated areas and restore disturbed ground.	Minimum footprint maintained, disturbed areas restored	Daily / after completion	Contractor	Routine duty of contractor as construction best practices/ Contractor's cost
Land & Soil Environment	Soil erosion on slopes, riverbanks and access routes	Avoid unstable areas where practicable, control runoff, stabilise exposed soil and reinstate disturbed areas.	No significant erosion, exposed areas stabilised	Weekly/after heavy rain	Contractor	Routine duty of contractor as construction best practices/ Contractor's cost
Land & Soil Environment	Fuel, oil and chemical spills and soil contamination	Use sealed containers and secondary containment, refuel in controlled areas away from water, maintain spill kits and clean spills immediately.	No uncontrolled spills, spill kits available, incidents recorded	Daily	Contractor	Routine duty of contractor as construction best practices/ Contractor's cost
Water Environment	Surface-water and groundwater contamination	Keep fuel, cement, soil and waste away from watercourses, prevent direct discharge, manage limited wastewater through appropriate sanitation arrangements.	No visible contamination, no direct discharge	Daily	Contractor	Routine duty of contractor as construction best practices/ Contractor's cost
Ambient Air & Noise	Dust emissions from excavation, roads and material handling	Control vehicle speeds, cover fine materials, minimise exposed soil and use water suppression where necessary.	No persistent visible dust nuisance	Daily in dry weather	Contractor	Routine duty of contractor as construction best practices/ Contractor's cost
Ambient Air & Noise	Vehicle and equipment exhaust emissions	Maintain equipment, avoid unnecessary idling and optimise deliveries. Use solar-powered systems where practicable for permanent EWS equipment.	Equipment maintained, no excessive idling	Weekly	Contractor	Routine duty of contractor as construction best practices/ Contractor's cost
Ambient Air & Noise	Construction noise and vibration	Restrict noisy work to daytime, maintain machinery and coordinate activities near communities, schools, hospitals, lodges and resorts.	No unresolved noise complaints, noisy work within approved hours	Daily	Contractor	Routine duty of contractor as construction best practices/ Contractor's cost
Construction & Domestic Waste	Construction and domestic waste generation	Segregate waste, reuse/recycle where possible, prohibit burning/burying and remove waste to approved facilities. Food waste will not be left where it can attract wildlife.	Waste segregated, no littering/burning, waste removed	Daily	Contractor	Routine duty of contractor as construction best practices/ Contractor's cost
Construction/storage areas	Temporary visual disturbance from construction activities	Keep materials within approved areas, avoid unnecessary stockpiling and restore temporary areas after completion.	Work areas clean, temporary areas restored	Weekly / completion	Contractor	Routine duty of contractor as construction best practices/ Contractor's cost
Hot works/electrical installation	Accidental fire from construction activities, hot works or equipment	Control hot works, provide fire extinguishers and prevent accumulation of dry vegetation around equipment.	Fire equipment available, no uncontrolled burning	Daily	Contractor	Routine duty of contractor as construction best practices/ Contractor's cost
Battery/electronic replacement	Used batteries, electronic waste and damaged solar/electrical components	Collect, label and securely store used batteries/e-waste and transfer them to approved recycling/disposal facilities.	100% used batteries/e-waste accounted for and removed	Each replacement	ZRA / Maintenance Contractor	O&M cost
Extreme rainfall/flood/high-flow events	Flood/extreme-weather damage to EWS infrastructure	Design and locate equipment considering flood levels, wind, drainage and local conditions, inspect equipment after major events.	Post-event inspections completed, damaged equipment repaired	After major events	ZRA / Maintenance Contractor	O&M budget
Decommissioning/removal	Scrap metal, batteries, cables, concrete and electronic waste	Remove all redundant equipment, segregate recyclable/electronic waste and restore disturbed areas.	All equipment/waste removed, sites restored	At decommissioning	Contractor / ZRA	Decommissioning cost

C. Biological Environment

Table 34: Biological Environment

Environmental Aspect / Project Activity	Potential Impact	Mitigation Measures	Performance Indicator	Monitoring / Frequency	Responsibility	Cost
Site clearance/foundation works	Vegetation clearance and habitat disturbance	Use existing developed/disturbed areas, keep clearance to the minimum and retain mature trees/vegetation wherever practicable. Restore temporary disturbance.	Minimum vegetation clearance, restoration completed	Before/during construction	Contractor	Routine duty of contractor as construction best practices/ Contractor's cost
Access routes/construction footprint	Fragmentation or disturbance of sensitive habitats	Use existing roads and tracks, avoid new access routes and sensitive habitats/wildlife movement areas.	No unnecessary new tracks, sensitive areas avoided	Daily	Contractor / Park authority	Routine duty of contractor as construction best practices/ Contractor's cost
Vehicles/workers/noise	Wildlife disturbance from vehicles, workers and construction noise	Restrict vehicle speeds, prohibit feeding/chasing/approaching wildlife and minimise noise and duration of works.	No wildlife harassment incidents	Daily	Contractor	Routine duty of contractor as construction best practices/ Contractor's cost
Excavations/trenches/pits	Injury or mortality of small animals in open excavations	Keep excavations open for the shortest period, inspect daily, provide escape ramps where practicable and backfill promptly.	Excavations inspected, no trapped animals	Daily	Contractor	Routine duty of contractor as construction best practices/ Contractor's cost
Worker activities	Hunting or harm to wildlife	Hunting, trapping, capturing or killing wildlife will be prohibited and included in worker induction and Code of Conduct requirements.	Zero hunting/wildlife-killing incidents	Daily / incident-based	Contractor / Park authority	Routine duty of contractor as construction best practices/ Contractor's cost
AWLR/flow monitoring works	Aquatic and riparian habitat disturbance near AWLR/flow-monitoring sites	Use existing river access, minimise bank disturbance, retain riparian vegetation and keep machinery/materials away from the river.	No unnecessary riparian clearance, disturbed areas restored	Each activity	Contractor / ZRA	Routine duty of contractor as construction best practices/ Contractor's cost
Movement between sites	Introduction or spread of invasive alien plant species	Use approved material sources and clean equipment where required before movement between sites, avoid transferring contaminated soil/plant material.	Equipment/vehicles checked, no new invasive species attributable to project	Before movement	Contractor	Routine duty of contractor as construction best practices/ Contractor's cost
Hot works/dry vegetation	Accidental veld/forest fire affecting vegetation and habitat	Control hot works, provide firefighting equipment and comply with applicable DNPW/ZimParks requirements.	No project-related vegetation fires	Daily during works	Contractor / Park authority	Routine duty of contractor as construction best practices/ Contractor's cost
Permanent EWS installations	Permanent loss of small areas of vegetation beneath installations	Locate installations in existing developed/modified areas wherever practicable and maintain the minimum permanent footprint.	Permanent footprint within approved boundary	During installation/inspection	Contractor / ZRA	Routine duty of contractor as construction best practices/ Contractor's cost
Siren testing/emergency activation	Wildlife disturbance from siren testing and emergency activation	Use silent testing where practicable, notify park/lodge management before audible tests and coordinate drills to minimise unnecessary disturbance.	Tests notified, no repeated wildlife disturbance complaints	Each test/drill	ZRA / Park authority	O&M/project cost
Lodge/resort/protected-area fencing and installations	Visual/landscape mismatch of EWS installations with surrounding habitat	Keep the installation/fence footprint small, agree location with lodge/resort management, retain surrounding vegetation and use compatible screening vegetation where appropriate and acceptable to wildlife authorities.	Installation visually integrated, vegetation retained/established	During installation and periodic inspection	Contractor / ZRA / Facility management	Contractor's cost
Security/maintenance lighting	Disturbance from security and maintenance lighting	Use only necessary lighting, directed towards equipment and avoid unnecessary continuous illumination, particularly in protected areas.	Lighting limited to required areas	Periodic	ZRA / Facility management	O&M cost
Safety of Avi-Fauna	Bird collision with communication towers, masts or guy wires	Use the proposed 15-m single-pole structure and avoid guy wires. Avoid important nesting/roosting locations and install visibility markers if a collision risk is identified.	No recurring bird-collision incidents	Periodic/incident-based	ZRA / Contractor / DNPW/ZimParks	Contractor's cost
Safety of Wildlife Animals	Electric fencing and potential wildlife injury, electrocution or disturbance	Use a controlled pulsed solar energiser, minimum fence footprint and wildlife-appropriate wire spacing. No barbed/razor wire. Design to be agreed with DNPW/ZimParks at protected-area sites.	Fence inspected, no wildlife injury attributable to fencing	Monthly/after incident	ZRA / Contractor / DNPW/ZimParks	Contractor/O&M cost

Environmental Aspect / Project Activity	Potential Impact	Mitigation Measures	Performance Indicator	Monitoring / Frequency	Responsibility	Cost
Maintenance access in protected areas	Disturbance to protected areas and sensitive habitat during maintenance access	Use existing park/lodge roads and tracks, obtain access permission, avoid unnecessary vegetation clearance and remove all maintenance waste.	Approved access used, no unnecessary clearance	Each maintenance visit	Maintenance Contractor / Park authority	Contractor's cost
Maintenance vehicles/personnel	Wildlife disturbance from maintenance vehicles and personnel	Maintain low vehicle speeds, remain on established tracks, avoid approaching wildlife and minimise duration of visits.	No wildlife disturbance incidents	Each visit	Maintenance Contractor	Contractor's cost
Equipment removal	Disturbance of vegetation and wildlife during removal of equipment	Use existing access, minimise removal footprint and restore disturbed ground following removal.	Site restored, no unnecessary vegetation clearance	During decommissioning	Contractor	Decommissioning cost
Battery/electronic waste	Generation of electronic, battery and other waste with potential ecological effects	Remove all batteries, electronic components, solar panels and cables from the site, no abandonment or disposal within protected areas or riverine locations.	100% waste removed and transferred to approved facilities	Each replacement/decommissioning	Contractor / ZRA	Contractor/O&M cost

7.5 Environmental Monitoring Plan

The Environmental Monitoring Plan is intended to verify that the mitigation measures are actually working and that any unforeseen impacts are identified early and corrected. The monitoring programme will be risk-based rather than based on extensive laboratory monitoring, because the EWS has a small physical footprint and limited construction activities. Monitoring will focus on site inspections, compliance records, community feedback, wildlife observations, waste/spill records and EWS operational performance.

Table 35: Environmental Monitoring Plan

Project Phase / Monitoring Programme	Monitoring Location	Parameters / Issues to be Monitored	Frequency	Time Frame	Performance Indicator	Responsible Person / Authority	Supervision	Indicative Cost (Ref. ESMP Budget Section)
Pre-construction - Site-selection compliance & NOCs, regulatory compliance	All proposed EWS sites	Approved coordinates, site footprint, land ownership/access, proximity to communities, water bodies, protected areas, lodges/resorts and sensitive receptors Regulatory permits & NOCs before construction	Once before construction and after any site relocation	Pre-construction	Sites approved, access arrangements completed, sensitive areas avoided	Design consultant, Environmental and Social focal officers of ZRA	ZRA	Covered under Design and ZRA Contingency/ fund
Pre-construction - Stakeholder and access arrangements	Villages, communities, schools, health facilities, markets, lodges, resorts and protected areas	Consultation, access arrangements, concerns raised and commitments made	Before mobilisation	Pre-construction	Required consultations completed, access arrangements documented, concerns addressed	Design consultant, Environmental and Social focal officers of ZRA	ZRA	Covered under Design and ZRA Contingency/ fund
Pre-construction - Cultural heritage	Installation footprints and excavation areas	Heritage sensitivity, graves, sacred places and chance-find requirements	Before construction	Pre-construction	Required clearances obtained, sensitive sites avoided	Environmental and Social focal officers of ZRA	ZRA	Covered under Design and ZRA Contingency/ fund
Pre-construction- Baseline air quality and noise	Selected representative EWS sites near sensitive receptors and locations where construction activities may generate dust/noise	Air: PM_{10}, $PM_{2.5}$; Noise: Leq, Lmax where appropriate; meteorological conditions where relevant (by using handheld calibrated equipments)	Once before construction	Pre-construction	Baseline values established and monitoring locations recorded	Contractor EHS Focal Person / Environmental Specialist	Supervision Consultant	Contractor monitoring cost
Construction - Air quality and dust	Construction sites, access roads and nearby sensitive receptors	Visible dust, vehicle emissions, complaints and road condition	Daily visual inspection, instrumental monitoring if complaints arise	Construction	No persistent dust nuisance, complaints addressed	Contractor	Supervision Consultant/ ZRA	Covered under Contractor Costs / Construction and Engineering Good Practices
Construction- air quality and noise Monitoring	Active construction sites, particularly near communities, lodges, schools, health facilities and other sensitive receptors	Air: PM_{10}, $PM_{2.5}$; Noise: Leq, Lmax where appropriate; meteorological conditions where relevant (by using handheld calibrated equipments)	Weekly during active construction and as necessary, using calibrated handheld monitoring equipments	Pre-construction	Baseline values established and monitoring locations recorded	Contractor EHS Focal Person / Environmental Specialist	Supervision Consultant	Contractor monitoring cost
Construction - Soil disturbance and erosion	Foundations, access routes, slopes, riverbanks and temporary work areas	Soil disturbance, erosion, drainage, exposed soil and slope stability	Weekly and after heavy rainfall	Construction	No uncontrolled erosion, disturbed areas stabilised	Contractor	Supervision Consultant/ ZRA	Covered under Contractor Costs / Construction and Engineering Good Practices
Construction - Soil contamination and spills	Fuel/oil storage, equipment areas and installation sites	Oil/fuel leakage, chemical spills, containers, bunds and spill kits	Daily visual check, monthly documented inspection	Construction	No uncontrolled contamination, spills contained and remediated	Contractor	Supervision Consultant/ ZRA	Covered under Contractor Costs / Construction and Engineering Good Practices
Construction - Surface-water protection	Zambezi River, tributaries, wetlands and drainage channels near works	Turbidity, visible sediment, oil sheen, waste and direct discharge	Weekly and after heavy rainfall, laboratory testing following incidents	Construction	No visible pollution or uncontrolled discharge	Contractor	Supervision Consultant/ ZRA	Covered under Contractor Costs / Construction and Engineering Good Practices

Project Phase / Monitoring Programme	Monitoring Location	Parameters / Issues to be Monitored	Frequency	Time Frame	Performance Indicator	Responsible Person / Authority	Supervision	Indicative Cost (Ref. ESMP Budget Section)
Construction - Groundwater protection	Boreholes, wells and springs near work areas, sanitation and hazardous-material storage	Leakage, sanitation condition and contamination indicators where relevant	Monthly inspection, sampling where risk is identified	Construction	No evidence of contamination, corrective action completed	Contractor	Supervision Consultant/ ZRA	Covered under Contractor Costs / Construction and Engineering Good Practices
Construction - Water uses/abstraction	Project water sources/community sources	Quantity abstracted, permit limits and community complaints	Monthly where abstraction occurs	Construction	Abstraction within permitted limits, no disruption to community supply	Contractor	Supervision Consultant/ ZRA	Covered under Contractor Costs / Construction and Engineering Good Practices
Construction - Construction noise	Villages, schools, hospitals, lodges, resorts and protected areas near works	Working hours, equipment condition, complaints and sound levels where required	Checks noise levels (dB) measurement where warranted	Construction	Approved working hours maintained, complaints addressed	Contractor	Supervision Consultant/ ZRA	Covered under Contractor Costs / Construction and Engineering Good Practices
Construction - Waste management	Construction sites, storage areas and temporary facilities	Waste segregation, storage, litter, disposal records and illegal burning/burying	Weekly	Construction	Clean sites, waste properly removed, no illegal disposal	Contractor	Supervision Consultant/ ZRA	Covered under Contractor Costs / Construction and Engineering Good Practices
Construction - Vegetation clearance	Construction footprints and access routes	Area cleared, mature trees, riparian vegetation and compliance with approved footprint	Before clearing and weekly during construction	Construction	No unauthorised clearance, sensitive vegetation retained	Contractor	Supervision Consultant/ ZRA	Covered under Contractor Costs / Construction and Engineering Good Practices
Construction - Wildlife and habitat	Lower Zambezi National Park, Mana Pools, Sapi, Chewore and other wildlife-sensitive sites	Wildlife disturbance, mortality, trapped animals, hunting, worker conduct and wildlife incidents	Daily during works	Construction	No unauthorised wildlife disturbance, hunting or project-related mortality	Contractor	Supervision Consultant/ ZRA /Park Authorities	Covered under Contractor Costs / Construction and Engineering Good Practices
Construction - Aquatic/riparian habitat	AWLR and flow-monitoring sites	Riverbank disturbance, riparian vegetation, sediment movement and waste entering water	During each river-side activity	Construction	No unnecessary aquatic/riparian disturbance	Contractor	Supervision Consultant/ ZRA /Park Authorities	Covered under Contractor Costs / Construction and Engineering Good Practices
Construction - Invasive species	Construction sites and access routes	Introduction/spread of invasive plants through vehicles, machinery and materials	Before movement between sensitive sites and during construction	Construction	No observed project-related spread, equipment/material controls implemented	Contractor	Supervision Consultant/ ZRA /Park Authorities	Covered under Contractor Costs / Construction and Engineering Good Practices
Construction - Fire prevention	Construction sites, dry vegetation and protected areas	Hot works, fire extinguishers, combustible waste, smoking and fire risk	Daily during hot works, periodic inspection	Construction	Fire controls available, no uncontrolled project-related fire	Contractor	Supervision Consultant/ ZRA /Park Authorities	Covered under Contractor Costs / Construction and Engineering Good Practices
Construction - Traffic safety	Access roads, villages, schools, markets and tourism facilities	Vehicle speed, signage, driver competence, vehicle condition, accidents and complaints	Daily during active works	Construction	Speed controls and signs maintained, incidents investigated	Contractor	Supervision Consultant/ ZRA /Park Authorities	Covered under Contractor Costs / Construction and Engineering Good Practices
Construction - Community health and safety	Communities and public facilities near installations	Public access to excavations/equipment, barriers, signs and complaints	Daily	Construction	Hazardous, excavated areas secured, no public-access incidents	Contractor	Supervision Consultant/ ZRA /Park Authorities	Covered under Contractor Costs / Construction and Engineering Good Practices
Construction - OHS and work at height	All construction sites, towers/poles and elevated equipment	PPE, inductions, toolbox talks, permits, fall-arrest systems, first aid, near misses and injuries	Daily, monthly reporting	Construction	PPE compliance, trained workers, corrective actions closed	Contractor	Supervision Consultant/ ZRA /Park Authorities	Covered under Contractor Costs / Construction and Engineering Good Practices
Construction - River/boat safety	River-monitoring sites	Life jackets, boat condition, operator competence, weather/river conditions and rescue equipment	Before every river-based activity	Construction	Safety checks completed, no drowning incidents	Contractor	Supervision Consultant/ ZRA /Park Authorities	Covered under Contractor Costs / Construction and Engineering Good Practices

Project Phase / Monitoring Programme	Monitoring Location	Parameters / Issues to be Monitored	Frequency	Time Frame	Performance Indicator	Responsible Person / Authority	Supervision	Indicative Cost (Ref. ESMP Budget Section)
Construction - Worker conduct and GBV	Worker camps, construction sites and host communities	Code of Conduct, training, complaints and referral arrangements	At induction	Construction	All workers trained and signed Code of Conduct, cases managed	Contractor	Supervision Consultant/ ZRA /Park Authorities	Covered under Contractor Costs / Construction and Engineering Good Practices
Construction - Employment and procurement	Project-affected communities in Zambia and Zimbabwe	Local employment, recruitment, supplier participation and labour grievances	Monthly	Construction	Transparent recruitment, local participation, grievances addressed	Contractor	Supervision Consultant/ ZRA /Park Authorities	Covered under Contractor Costs / Construction and Engineering Good Practices
Construction - Cultural heritage/chance finds	Excavation and installation areas	Graves, artefacts, fossils, sacred places and compliance with chance-find procedure	Continuous during excavation	Construction	No unauthorised disturbance, finds reported	Contractor	Supervision Consultant/ ZRA /Park Authorities	Covered under Contractor Costs / Construction and Engineering Good Practices
Construction - Stakeholder engagement and grievance management	Communities, villages, lodges, schools, health facilities and protected areas	Meetings, notifications, complaints, response time and resolution status	Continuous, monthly review	Construction	Grievance register maintained, issues resolved within agreed periods	Contractor	Supervision Consultant/ ZRA /Park Authorities	Covered under Contractor Costs / Construction and Engineering Good Practices
Operation - EWS reliability	Sirens, sensors, telemetry, control centres, solar systems and backup power	System uptime, communication failures, power availability, faults and maintenance response	Continuous remote monitoring, monthly functional checks, annual comprehensive test	Operation	Required system availability achieved, faults promptly rectified	Contractor till AMC period & later ZRA Operations Team	ZRA	O&M budget
Operation - Warning coverage and accessibility	Communities, villages, lodges, resorts, schools, health facilities and other warning receptors	Warning coverage, audible reach, alternative communication channels, language and disability accessibility	Noise/audibility coverage At commissioning, annually, after major changes	Operation	At-risk communities covered by appropriate warning channels, gaps corrected	Contractor till AMC period & later ZRA Operations Team, Disaster Authorities, Local Authorities	ZRA	Contractors cost/O&M budget
Operation - Siren testing and disturbance	Communities, schools, hospitals, lodges, resorts and protected areas	Advance notification, complaints, wildlife response and public understanding of test signals	Every scheduled test/drill, Noise level monitoring at representative sites	Operation	Tests notified in advance, tests distinguished from emergencies	Contractor till AMC period & later ZRA Operations Team	ZRA	O&M budget
Operation - Warning activation and false alarms	Control centres and warning network	Authorisation, message consistency, false alarms, delayed warnings and feedback	After every activation, drill or false alarm	Operation	Every activation reviewed, corrective action implemented	ZRA EWS Operational team/Disaster Authorities	ZRA	O&M budget/Administrative
Operation - Equipment security	All EWS installations	Theft, vandalism, deliberate damage and security condition	Quarterly/ after incidents	Operation	Security incidents recorded, damaged equipment promptly restored	ZRA EWS Operational team	ZRA	O&M budget/Administrative
Operation - Wildlife and habitat	Lower Zambezi National Park, Mana Pools, Sapi, Chewore and other sensitive sites	Wildlife disturbance, electric-fence incidents, vegetation condition and wildlife interactions	Annually and after incidents	Operation	No recurring wildlife injury/disturbance attributable to EWS	ZRA EWS Operational team DNPW, ZimParks	ZRA	O&M budget/Administrative
Operation - Bird collision/electrical safety	15-m communication poles and electrical installations	Bird collision evidence, exposed electrical components and protective measures	Annually and after incidents	Operation	No exposed energised components, incidents investigated	ZRA EWS Operational team/Wildlife Authorities, Equipment Supplier	ZRA	O&M budget/Administrative
Operation - Solar fencing	EWS sites where solar fencing is installed	Fence condition, energiser, wildlife interaction/injury, vegetation contact and movement obstruction	Annually and after incidents	Operation	Fence functional and safe, no recurring wildlife injury	ZRA EWS operation Team/, Maintenance Team, DNPW/Zim-Parks	ZRA	O&M budget/Administrative
Operation - Visual/landscape integration	EWS sites at/near lodges, resorts and sensitive landscapes	Condition of fencing, retained vegetation, visual compatibility and unnecessary vegetation removal	Annually	Operation	Installation maintained in visually compatible condition	ZRA EWS operation team, Facility Management	ZRA	O&M budget/Administrative

Project Phase / Monitoring Programme	Monitoring Location	Parameters / Issues to be Monitored	Frequency	Time Frame	Performance Indicator	Responsible Person / Authority	Supervision	Indicative Cost (Ref. ESMP Budget Section)
Operation - Fire safety	Solar systems, batteries and EWS installations	Electrical condition, fire extinguishers, dry vegetation and combustible materials	Quarterly and before dry season	Operation	Fire equipment functional, no uncontrolled fire	ZRA, Maintenance Team, Park Authorities	ZRA	O&M budget/Administrative
Operation - Flood/extreme-weather damage	River-side, flood-prone and exposed EWS installations	Damage to poles, foundations, sensors, solar systems, batteries and communication equipment following extreme events	After major flood/extreme-weather events	Operation	Damaged equipment identified and restored, no unsafe installations	ZRA Operations /Maintenance Team	ZRA	O&M budget/Administrative
Maintenance - Access and environmental disturbance	Maintenance routes and EWS sites	Temporary access restrictions, vegetation disturbance, traffic, noise and wildlife disturbance	Every maintenance visit	Maintenance	Existing access used, unnecessary disturbance avoided	Contractor till AMC period/ ZRA	ZRA	O&M/Contractor cost
Maintenance - Protected-area access	Lower Zambezi, Mana Pools, Sapi, Chewore and other sensitive areas	Access permissions, vehicle routes, vegetation disturbance and wildlife interaction	Every maintenance visit	Maintenance	Approved routes and access arrangements followed	Contractor till AMC period/ ZRA DNPW/ZimParks	ZRA	O&M cost
Maintenance - Work at height/electrical safety	Poles, towers, elevated equipment and electrical systems	PPE, fall protection, electrical isolation, worker competence and weather conditions	Before every activity	Maintenance	Safe work procedures followed, no unauthorised climbing	Maintenance Contractor	ZRA	O&M cost
Maintenance - Batteries and e-waste	EWS sites, storage and maintenance facilities	Used batteries, solar panels, sensors, cables and electronic equipment, storage and disposal records	During every replacement	Maintenance	All waste removed and transferred to approved facilities	Maintenance Contractor/ Authorised Waste Handler/ZRA SHE team	ZRA	O&M cost
Decommissioning - Site restoration	Retired EWS sites and access areas	Equipment/foundation removal, soil condition, erosion and vegetation restoration	During decommissioning and after restoration	Decommissioning	Sites restored, stable, clean and safe	Decommissioning Contractor	ZRA	Closure budget
Decommissioning - Electronic and hazardous waste	Decommissioned sites and waste storage facilities	Batteries, solar panels, cables, electrical/electronic components and scrap metal	Throughout decommissioning	Decommissioning	All waste removed, disposal/recycling records available	Decommissioning Contractor, Authorised Waste Handler	ZRA	Closure budget
All phases - Environmental and social compliance audit	Representative EWS installations in Zambia and Zimbabwe	Compliance with ESMP, permits, monitoring commitments, incidents and corrective actions	Annual audit	All applicable phases	Audit completed, non-conformities closed within agreed periods	Contractor, Independent Auditor	ZRA/ Regulators	As budgeted

7.6 ESMP Budget

The ESMP budget provides for the additional environmental and social resources required for implementation of the project. Most routine environmental, social and OHS measures will remain part of the Contractor's normal construction and O&M responsibilities, while specific provisions are included for environmental monitoring, training and GRM, cumulative siren noise assessment, and environmental and social contingency. The detailed budget is provided below

Table 36: ESMP Budget

No.	Phase	ESMP activity/budget item	No. of sites	Cost/unit (USD)	Total (USD)	Responsibility/remarks
Construction phase						
1	Construction	Site-specific ESMP implementation, including dust control, barricading and warning signs, PPE and OHS measures, waste management, spill prevention, material storage, traffic and access management, vegetation and wildlife protection, soil and water protection, community safety, GRM and site restoration	87	500/site	**43,500**	Contractor. This allocation supplements, but does not replace, the Contractor's normal obligations for good engineering, housekeeping, PPE, safe material handling and OHS compliance.
2	Construction	Environmental monitoring, including particulate matter, noise and other site-specific parameters using calibrated equipment	Project-wide	Lump sum	**20,000**	Contractor, under the oversight of the Supervision Consultant and ZRA
3	Construction	Worker and staff induction, toolbox talks, community consultation and GRM implementation	Project-wide	Lump sum	**10,000**	Contractor and EHS Focal Person
4	Construction	Environmental and social supervision and reporting, including site inspections, checklist reviews, monthly ESMP reports, incident reporting and photographic records	Project-wide	Lump sum	**15,000**	Supervision Consultant and ZRA
		Construction-phase subtotal			**88,500**	
Operation and maintenance phase						
5	Operation	Operational ESMP implementation, including routine inspections, waste and e-waste management, battery management, wildlife protection, occupational and community safety, corrective measures and GRM	87	200/site	**17,400**	ZRA and O&M Contractor
6	Operation	Cumulative siren-noise assessment, commissioning measurements and periodic monitoring at sensitive receptors	All siren sites	Lump sum	**25,000**	ZRA
7	Operation	Community EPP & EWS awareness, GRM and emergency preparedness, including advance communication of siren tests and community emergency-response activities	Project-wide	Lump sum	**35,000**	ZRA, local authorities and disaster-management institutions
8	Operation	Periodic environmental, social, OHS and emergency-response training and capacity building	Project-wide	Lump sum	**5,000**	ZRA and O&M Contractor
		Operation and maintenance subtotal			**82,400**	
Contingency						
9	Construction and operation	Environmental and social contingency for unforeseen mitigation, emergency response and corrective measures	Project-wide	Lump sum	**5,100**	ZRA, subject to approval and documented use

7.7 Environmental Monitoring and Reporting

The ESMP reporting system will be implemented to ensure regular monitoring, documentation and timely corrective action across all EWS installation sites and project activities. The Contractor will undertake daily environmental, social and OHS inspections and maintain site records, which will be consolidated into a Weekly Site Inspection Record. The Supervision Consultant will review these records and, with supporting information from the Contractor's EHS Focal Person, prepare the Monthly ESMP Compliance and Progress Report covering the status of all active sites, ESMP implementation, monitoring results, incidents, grievances, OHS performance, wildlife and protected-area issues, stakeholder engagement, non-compliances and corrective actions. Significant environmental, social, health and safety incidents will be reported immediately by the Contractor, while the Supervision Consultant will prepare and submit the formal incident report to ZRA and relevant authorities, as applicable. An annual ESMP compliance audit will provide an overall assessment of ESMP implementation and regulatory

Table 37: Environmental Reporting Requirement

Report / Record	Reporting Requirement / Contents	Frequency	Responsibility	Submission / Review
Weekly Site Inspection Record (Refe. Appendix 4 for Templet)	Consolidated record of daily site inspections covering all active EWS installation sites, environmental, social and OHS observations, compliance with ESMP mitigation measures, waste, dust, noise, erosion, vegetation, wildlife, traffic, community safety and worker safety, photographs, non-compliances and corrective actions	Weekly, based on daily site inspections	Contractor EHS Focal Person / Site Supervisor	Reviewed by Supervision Consultant and submitted to ZRA
Monthly ESMP Compliance & Progress Report (Refe. Appendix 5 for Templet)	Overall progress of all EWS active construction sites, site-wise construction/installation progress, ESMP implementation and monitoring results, summary of weekly inspections, environmental and social performance, OHS, stakeholder engagement and grievances,	Monthly	Supervision Consultant, with support/data from Contractor EHS Focal Person	Submitted to ZRA

Report / Record	Reporting Requirement / Contents	Frequency	Responsibility	Submission / Review
	wildlife/protected-area issues, incidents, permits/NOCs, non-compliances, corrective-action status, photographs and key issues requiring ZRA action			
Incident / Accident Report	Immediate notification by Contractor of significant environmental, social, OHS, community or wildlife incidents. Supervision Consultant investigates/assesses the incident and prepares the formal incident report, including cause, response, corrective and preventive actions and closure status	Immediately after significant incident	Initial notification: Contractor, formal report: Supervision Consultant with Contractor support	ZRA and relevant authorities, as applicable
Annual ESMP Compliance Audit Report	Overall ESMP implementation and regulatory compliance across the project, performance trends, monitoring results, incidents and grievances, corrective actions, site inspections, outstanding issues and recommendations	Annually	Supervision Consultant / Independent Auditor, as applicable	ZRA / relevant authorities / financing institution, as applicable

7.8 Institutional Arrangement and Environmental Responsibilities

The ESMP will be implemented through a coordinated arrangement involving the Contractor, Supervision Consultant and ZRA SHE Team, with clear responsibilities for environmental, social, OHS and engineering aspects of the EWS works, as summarized below:

- **Contractor Project/Site Manager:** The Project Manager will have overall responsibility for implementing the EWS installation and ESMP, ensuring adequate resources, manpower and equipment, and compliance with contractual environmental, social and OHS requirements.

- **Contractor- EHS Focal Person:** The EHS Focal Person will oversee day-to-day E&S and OHS implementation, conduct daily inspections, maintain records, coordinate monitoring, support worker training, and report incidents and non-compliances.
- **Supervision Consultant-Engineers:** The Engineers will supervise the engineering and construction aspects of the EWS, including installation of towers/poles, sensors, sirens, communication systems, power supply and associated infrastructure, while coordinating with the Environmental and Social Specialists to ensure ESMP requirements are incorporated into site works.
- **Supervision Consultant-Environmental Specialist:** The Environmental Specialist will monitor ESMP implementation, undertake site inspections, verify environmental monitoring and corrective actions, and support preparation of the monthly ESMP report and investigation of significant incidents.
- **Supervision Consultant-Social Specialist:** The Social Specialist will monitor stakeholder engagement, GRM, gender, community health and safety, labour and other social requirements, and support reporting and incident investigations.
- **ZRA-SHE Team:** The ZRA SHE Team will provide overall E&S oversight, review ESMP reports, monitor compliance with applicable requirements, coordinate with relevant authorities, and ensure that significant non-compliances and corrective actions are appropriately addressed.

7.9 Training and Capacity Building

ZRA and its Supervision Consultant will ensure that the Contractor and relevant project personnel receive site induction before construction and refresher training every six months. Training will cover ESMP requirements, environmental and social mitigation measures, OHS and PPE, work at height, electrical and battery safety, spill and fire response, waste management, wildlife protection, cultural heritage, GBV/SEA/SH, community interaction, traffic and river safety, and incident reporting. During operation, training will be conducted by ZRA focusing on EWS operation, battery/e-waste management, wildlife-safe maintenance, electric-fence safety, and emergency response.

8 DECOMMISSIONING AND CLOSURE PLAN

The Early Warning System is intended to remain operational for as long as communities downstream of Kariba Dam and along the Zambezi River are exposed to flood and dam-related emergencies. Decommissioning will therefore only be undertaken when equipment reaches the end of its operational life, is replaced by improved technology, becomes redundant following redesign of the warning network or when the entire system is formally closed by the responsible authorities.

Unlike an ordinary commercial facility, the EWS cannot be discontinued abruptly because an interruption in warning coverage could expose communities in Zambia and Zimbabwe to serious risk. Decommissioning must therefore be carefully planned and coordinated to ensure that monitoring, communication and warning functions remain operational until replacement systems are fully installed, tested and commissioned.

The Decommissioning and Closure Plan will apply to:

- sirens and public-address equipment;
- communication towers, antennas and associated structures;
- hydrological and meteorological sensors;
- telemetry and radio communication equipment;
- solar panels, batteries and backup power systems;
- control-room equipment and computer systems;
- electrical cables, fencing and equipment cabinets;
- concrete foundations and equipment platforms;
- temporary and permanent access infrastructure; and
- waste, hazardous materials and contaminated soil associated with the installations.

8.1 Decommissioning Objectives

The principal objectives of the Decommissioning and Closure Plan will be to:

- maintain public-warning coverage throughout the transition period;
- safely isolate, dismantle and remove obsolete equipment;
- prevent injury to workers and members of the public;
- recover equipment and materials suitable for reuse or recycling;
- manage batteries and electronic waste through authorized facilities;
- remove contamination and rehabilitate disturbed land;
- protect archaeological, cultural and natural heritage resources;
- restore drainage, vegetation and landscape conditions;
- communicate closure or equipment replacement to affected communities;
- transfer functional assets to an approved successor operator where appropriate; and
- confirm that closed sites do not present continuing environmental or public-safety risks.

8.2 Progressive Decommissioning and Rehabilitation

Decommissioning will be implemented progressively. Individual sensors, sirens, batteries, solar panels and communication components will be replaced or removed as they become obsolete or unserviceable. Disturbed areas that are no longer required will be rehabilitated immediately instead of being left until closure of the entire project.

Before removing any operational warning component, ZRA shall confirm that:

- the component is no longer required or has reached the end of its serviceable life;
- an alternative warning or monitoring system is available;
- replacement equipment has been installed and successfully tested;
- affected communities and emergency-response institutions have been notified;
- critical data and maintenance records have been archived; and
- all applicable environmental, land-access and heritage approvals have been obtained.

Where equipment remains functional, preference should be given to refurbishment, relocation or transfer to an approved government institution, local authority, emergency-response agency or successor operator. Transfer shall only occur after confirming that the receiving institution has the technical and financial capacity to operate and maintain the equipment safely.

8.3 Institutional and Stakeholder Coordination

Decommissioning will be undertaken in consultation with relevant authorities and stakeholders in Zambia and Zimbabwe. These may include:

- the Zambezi River Authority;
- national disaster-management authorities;
- environmental regulatory agencies;
- water-resource management institutions;
- local and provincial authorities;
- wildlife and protected-area authorities;
- the National Heritage Conservation Commission in Zambia;
- the National Museums and Monuments of Zimbabwe;
- traditional authorities and community committees;
- landowners and facility operators;
- tourism establishments; and
- licensed waste, recycling and electronic-waste handlers.

Communities must be informed before sirens or other warning facilities are removed, replaced or temporarily taken out of service. Notifications must explain the reason for the change, the period of reduced service and the alternative warning arrangements available during the transition.

8.4 Decommissioning Activities

The principal activities will include:

- preparation of a detailed decommissioning method statement;
- environmental, social and occupational safety risk assessment;
- notification of affected communities and institutions;
- establishment of temporary warning arrangements;
- electrical isolation and removal of batteries and solar-power systems;
- dismantling of sirens, towers, antennas and communication equipment;
- removal of sensors, cables, equipment cabinets and fencing;
- removal or making safe of concrete foundations;
- segregation of reusable, recyclable, general and hazardous waste;
- transportation of waste to authorized facilities;
- investigation and remediation of contaminated soil;
- reinstatement of natural drainage;
- backfilling and stabilization of excavations;
- replacement of topsoil and revegetation using indigenous species;
- inspection for archaeological or cultural heritage discoveries; and
- post-closure monitoring and certification.

8.5 Hazardous Materials and Electronic Waste

Used batteries, solar panels, circuit boards, sensors, cables, oils and other electronic components shall not be disposed of with domestic waste. These materials will be securely stored, recorded and transferred to suppliers, recycling facilities or licensed hazardous-waste handlers. Storage and transportation arrangements must prevent leakage, breakage and unauthorized access. Documentation should include the type and quantity of waste, date of removal, transporter, receiving facility and final treatment or disposal method. Any soil contaminated by fuel, oil, battery chemicals or other hazardous substances must be investigated and remediated. Contaminated material shall be transported to an authorized treatment or disposal facility.

8.6 Site Rehabilitation

After equipment removal, disturbed sites will be restored to a stable and safe condition. Rehabilitation measures will include:

- removal of construction and demolition waste;
- backfilling and compacting open excavations;
- removal or reduction of foundations below ground level where appropriate;
- reinstatement of natural drainage;
- stabilization of erosion-prone slopes;
- replacement of stored topsoil;
- revegetation using locally appropriate indigenous species;
- control of invasive alien plants; and
- removal of unnecessary warning signs, fencing and access restrictions.

Within protected areas, rehabilitation methods must be approved by the responsible wildlife or park authority. Access tracks that are no longer required should be closed and rehabilitated unless communities or authorities request their retention for an agreed beneficial use.

8.7 Cultural Heritage Protection

Excavation and foundation removal may expose archaeological artefacts, fossils, graves or other heritage resources. The approved chance-find procedure will remain applicable throughout decommissioning. If suspected heritage material or human remains are discovered, work must stop in the immediate area. The location shall be secured and reported to the National Heritage Conservation Commission in Zambia or the National Museums and Monuments of Zimbabwe. Work shall only resume after authorization from the responsible authority.

8.8 Post-Closure Monitoring

Post-closure inspections will be undertaken to confirm that:

- no hazardous equipment or waste remains onsite;
- excavations and foundations have been made safe;
- drainage systems are stable;
- no soil or water contamination remains;
- revegetation is successfully established;
- erosion is controlled;
- public access does not present a safety risk; and
- alternative warning arrangements remain operational.

Monitoring should continue for at least 12 months after rehabilitation, or longer where erosion, contamination or poor vegetation establishment is identified. Corrective measures shall be implemented where closure objectives have not been achieved.

8.9 Review and Updating of the Closure Plan

The Decommissioning and Closure Plan shall be reviewed periodically and updated when:

- new EWS installations are added;
- equipment is replaced or relocated;
- technology or operational arrangements change;
- environmental or social conditions change;
- ownership or institutional responsibilities change; or
- revised cost estimates become available.

ZRA shall maintain an updated asset register showing the location, condition, expected service life and estimated decommissioning cost of every installation. Closure-cost estimates should be reviewed annually to account for inflation, changes in waste-disposal costs and the actual number of installations requiring removal.

9 DECLARATION OF AUTHENTICITY

The Zambezi River Authority, as the proponent of the proposed Early Warning System Project, affirms its commitment to planning, implementing, operating and maintaining the Project in accordance with the applicable environmental and social legislation of Zambia and Zimbabwe, relevant bilateral obligations and recognized international environmental and social safeguard standards. In recognition of the Project's importance to the safety and preparedness of communities along the Zambezi River, the Authority engaged Jomiso Consulting of India to undertake the Environmental and Social Impact Assessment. The assessment covers the Project's potential effects on communities, land, water resources, biodiversity, protected areas, cultural heritage, public health, occupational safety and other relevant environmental and socioeconomic receptors in both countries.

The consultants engaged for the assignment possess relevant experience in environmental, social and cultural heritage assessments within Zambia, Zimbabwe and the wider region. The Consultant was required to work with local experts, and this requirement was complied to. Appropriate mitigation, enhancement, monitoring and management measures have consequently been recommended to avoid or minimize adverse impacts and strengthen the Project's positive contribution to disaster-risk reduction and community safety. Through its consultants and Project representatives, the Authority engaged relevant stakeholders and their representatives in Zambia and Zimbabwe. The consultation process included engagement with national and local government institutions, environmental and disaster-management authorities, traditional leaders, affected communities, tourism operators, protected-area managers and other interested and affected parties. These engagements supported Project disclosure, awareness raising, baseline-information collection and documentation of stakeholder concerns and recommendations.

The Zambezi River Authority commits to implementing the measures contained in the Environmental and Social Management Plan, Environmental and Social Monitoring Plan and associated emergency-preparedness procedures. The Authority will also ensure that contractors, service providers and other parties involved in the Project comply with the applicable environmental, social, health, safety and cultural heritage requirements. The Authority hereby declares that, to the best of its knowledge, the information presented in this report is accurate and authentic and that the assessment has been undertaken in good faith using the information available at the time of preparation.

For and on behalf of the Zambezi River Authority

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11 APPENDICES

11.1 Appendix 1: ZRA ACT of Parliamnt (Zambia, in part)

The Laws of Zambia

REPUBLIC OF ZAMBIA

THE ZAMBEZI RIVER AUTHORITY ACT

CHAPTER 467 OF THE LAWS OF ZAMBIA

CHAPTER 467 THE ZAMBEZI RIVER AUTHORITY ACT

THE ZAMBEZI RIVER AUTHORITY ACT

ARRANGEMENT OF SECTIONS

CHAPTER 467

ZAMBEZI RIVER AUTHORITY

Act No.
17 of 1987

The Laws of Zambia

An Act to give effect to certain provisions of an interstate agreement relating to the utilisation of the Zambezi River concluded between the governments of the Republics of Zambia and Zimbabwe; to repeal Part III of the Federation of Rhodesia and Nyasaland (Dissolution) Order in Council, 1963; to repeal the Central African Power Act; and to provide for matters connected with or incidental to the foregoing.

[24*th September*, 1987]

1. (1) This Act may be cited as the Zambezi River Authority Act. Short title

2. In this Act unless the context otherwise requires- Interpretation

"Agreement" means the agreement between the Republic of Zambia and the Republic of Zimbabwe relating to the utilisation of the Zambezi River, which agreement is set out in the Schedule;

"appointed date" means the date appointed by the Minister under section *one* as the date of commencement of this Act;

"assets" includes rights of any description;

"Authority" means the Zambezi River Authority continued in existence by section *four*;

"Corporation" means the Central African Power Corporation constituted by section *thirty-six* of the Order in Council.

"Council" means the Council of Ministers continued in existence by section *three*;

"Higher Authority for Power" means the Higher Authority for Power constituted by section *thirty-three* of the Order in Council;

"National Electricity Undertakings" means the Zambia Electricity Supply Corporation and the Zimbabwe Electricity Supply Authority and includes any successor organisation and references to a National Electricity Undertaking shall be construed accordingly;

"obligations" includes obligations of any description, whether statutory, contractual, delictual or otherwise;

"Order in Council" means the Federation of Rhodesia and Nyasaland (Dissolution) Order in Council, 1963, of the United Kingdom;

11.2 ZRA ACT of Parliament (Zimbabwe, in part)

TITLE 20

Chapter 20:23

PREVIOUS CHAPTER

ZAMBEZI RIVER AUTHORITY ACT

Acts 19/1987, 18/1989 (s. 41), 12/1999.

ARRANGEMENT OF SECTIONS

Section

AN ACT to enable effect to be given to certain provisions of an inter-State agreement relating to the utilization of the Zambezi River concluded between the governments of the Republics of Zimbabwe and Zambia; and to provide for matters incidental to or connected with the foregoing.

[Date of commencement: 1st October, 1987.]

1 Short title

This Act may be cited as the Zambezi River Authority Act [Chapter 20:23].

2 Interpretation

In this Act—

"Agreement" means the agreement between the Republic of Zimbabwe and the Republic of Zambia relating to the utilization of the Zambezi River, which agreement is set out in the Schedule;

"assets" includes rights of any description;

"Authority" means the Zambezi River Authority referred to in section four;

"Corporation" means the Central African Power Corporation constituted under section 36 of the Order in Council;

"Council" means the Council of Ministers referred to in section three;

"fixed date" means the1st October, 1987;

"Higher Authority for Power" means the Higher Authority for Power constituted under section 33 of the Order in Council;

"Minister" means the Minister of Transport and Energy or any other Minister to whom the President may, from time to time, assign the administration of this Act;

"National Electricity Undertakings" means the Zimbabwe Electricity Supply Authority and the Zambia Electricity Supply Corporation, or any successor organizations thereto, and references to a National Electricity Undertaking shall be construed accordingly;

"obligations" includes obligations of any description, whether statutory, contractual, delictual or otherwise;

"Order in Council" means the Federation of Rhodesia and Nyasaland (Dissolution)

Order in Council, 1963, of the United Kingdom;
"the two States" means the Republics of Zimbabwe and Zambia, and references to a State shall be construed accordingly.

3 Council of Ministers

(1) Notwithstanding section ten, the Higher Authority for Power, which shall henceforth be known as the Council of Ministers, shall continue in existence.

(2) The composition, functions and procedure of the Council shall be as set out in Articles 4, 5 and 6 of the Agreement.

4 Zambezi River Authority

(1) Notwithstanding section ten, the Corporation, which shall henceforth be known as the Zambezi River Authority, shall continue in existence as a body corporate capable of suing and being sued in its corporate name and of doing all such things and performing all such acts as are necessary for or incidental to the carrying out of its functions under this Act as read with the Agreement.

(2) The composition, functions, administration, financing. procedure, privileges and immunities of the Authority shall be as set out in Articles 7, 8, 9, 10, 11, 12, 13, 14, 15 and 17 of the Agreement.

5 Transfer of employees

The Authority shall transfer or take such steps as are appropriate to effect the transfer of its employees in accordance with, employees. and to such extent as will be necessary to give effect to, Article 29 of the Agreement and any directions given thereunder by the Council.

6 Transfer of assets, liabilities and obligations

(1) The Authority shall transfer or take such steps as are appropriate to effect the transfer of its assets, liabilities and obligations in accordance with, and to such extent as will be necessary to give effect to, Article 30 of the Agreement and any agreement relating to the distribution of the assets, liabilities and obligations reached thereunder.

(2) For the purposes of any transfer under this section—

(a) all agreements, instruments and working arrangements giving rise or otherwise related to any asset, liability or obligation which subsisted immediately before the date of transfer shall, on and after that date, have effect and be enforceable as if references therein to the Corporation or the Authority, as the case may be, were references to the State or National Electricity Undertaking to which the asset, liability or obligation is transferred and, where the Authority, whether under its old or new name, was a party thereto, as if the State or National Electricity Under taking concerned had been a party thereto instead of the Authority;

(b) any legal proceeding or cause of action connected with any transferred asset, liability or obligation which was pending or existing by or against the Authority, whether under its old or new name, immediately before the date of transfer shall be continued by or against the State or National Electricity Undertaking, as the case may be, to which the asset, liability or obligation is transferred as though the State or National Electricity Undertaking concerned were the Authority.

(3) Where title to any immovable property or any right or obligation relating to such property is transferred to a State or National Electricity Undertaking in terms of this section, it shall not be necessary for the Registrar of Deeds to make any alterations or endorsements on title deeds or other documents in his registers in respect of such immovable property or any right or obligation relating to such property:

Provided that whenever he is requested in writing to do so by the State or National Electricity Undertaking concerned, or by any other person having an interest in such property, or in a right or obligation relating thereto, he shall make the necessary alterations or endorsement at no cost to the State, National Electricity Undertaking or

11.3 Appendix 2: Stakeholder Consultation

Stakeholder consultation and public participation form an integral part of the environmental and social assessment of the proposed Early Warning System (EWS). The effectiveness of the EWS depends not only on the installation and operation of monitoring and warning infrastructure, but also on the awareness, acceptance, preparedness and participation of downstream communities, traditional leadership, district authorities, disaster-management institutions, conservation agencies, tourism establishments and other Interested and Affected Parties (I&APs). Engagement has therefore been treated as a continuous process extending from Phase I baseline assessment through public-safety awareness activities to Phase II site verification and implementation preparation.

The Project Phase I: environmental and social baseline consultations were undertaken principally in September 2024 and documented in the Environmental and Social Baseline Assessment Report issued in January 2025. These engagements used community meetings, Focus Group Discussions (FGDs), Key Informant Interviews (KIIs) and institutional consultations. Subsequent ZRA engagements during 2025 focused on public safety, dam safety, climate risk and EWS preparedness. Phase II: consultations in July-August 2026 focused on site suitability, sensitive receptors, wildlife, access, permissions and implementation arrangements.

Regulatory Basis for Consultation

The stakeholder consultation process has been prepared with reference to the Environmental Management Act No. 12 of 2011, as amended, and the Environmental Management (Environmental Impact Assessment) Regulations, Statutory Instrument No. 3 of 2026. Regulation 9(4) requires an ESPB to include the information set out in the Third Schedule and to be accompanied by proof of consultation with relevant stakeholders interested in, or likely to be affected by, the proposed project. The Third Schedule specifically requires proof of consultation with Interested and Affected Parties, including contact address/details. Accordingly, consultation records, attendance registers, meeting notes, photographs and relevant institutional correspondence should be appended or cross-referenced as supporting evidence in the ZEMA submission.

Objectives of Stakeholder Consultation

i. Inform stakeholders about the purpose, components and implementation arrangements of the EWS.
ii. Obtain environmental and socio-economic information and local knowledge relevant to project design and site selection.
iii. Understand previous flood experience, warning arrangements, evacuation practices and communication preferences.
iv. Identify vulnerable groups and sensitive receptors requiring specific consideration.
v. Clarify land ownership, access, institutional permissions, wildlife and protected-area considerations.
vi. Identify concerns associated with construction, siren testing, operation and maintenance.

vii. Incorporate stakeholder recommendations into site selection, mitigation measures, emergency preparedness and the ESMP.

viii. Promote community and institutional ownership and long-term sustainability of the EWS.

Stakeholders Identified and Consulted

Stakeholder category	Principal stakeholders	Main relevance to the EWS
Project proponent	Zambezi River Authority (ZRA)	Project planning, implementation, EWS operation, dam safety and warning dissemination.
Environmental regulator	Zambia Environmental Management Agency (ZEMA)	Environmental assessment review, approval, compliance and monitoring.
Wildlife/conservation authorities	Department of National Parks and Wildlife (DNPW), ZimParks and protected-area managers	Biodiversity, protected areas, wildlife movement and permissions for works.
District/local administration	District Commissioners, local authorities and district structures	Local coordination, permissions, public administration and emergency preparedness.
Disaster-management institutions	DMMU/DDMMC/DCPU and related structures	Warning dissemination, preparedness, evacuation and emergency response.
Traditional authorities	Chiefs, Headmen and Headwomen	Community mobilisation, customary/local knowledge and local land matters.
Downstream communities	Villages and settlements within the EWS corridor	Direct beneficiaries/receptors of warnings and key participants in preparedness.
Sensitive community facilities	Schools, health facilities and police facilities	Sensitive receptors, public safety, siting and operational coordination.
Tourism establishments	Lodges, resorts and tourism operators	Visitor safety, visual impact, wildlife interaction, access and warning procedures.
Technical institutions	Meteorological, water-resource and telecommunications agencies	Monitoring, hydrological data, communication and warning dissemination.
Vulnerable groups	Children, older persons, persons with disabilities and persons with limited access to communication	Accessible warnings and assisted evacuation.

Consultation Approach and Methodology

Consultation methods were selected according to stakeholder type and the purpose of engagement. The process included community meetings, FGDs, KIIs, institutional consultations, courtesy calls and meetings with traditional leaders, public-safety sensitisation sessions, site-specific discussions with facility managers, field observations and consultations with wildlife and conservation authorities. During Phase I, village clusters were mapped and meetings coordinated with local leadership. Questionnaires, maps, attendance registers and field notes were used to document the engagement. Where necessary, locally understood languages and community representatives supported communication.

Chronology of Stakeholder Consultation and Engagement Activities

The detailed consultation engagement was carried different period of project phases is presented below Table.

Period	Consultation / engagement	Locations / coverage	Stakeholders	Key outcome / relevance to ESPB
September 2024	Phase I environmental and social baseline consultation	Namoomba/Namomba, Chalokwa, Mugurameno, Kabwadu, Chidada, Amoro and other downstream locations	Communities, traditional leaders, government institutions, schools, tourism operators and other key informants	Established the environmental and socio-economic baseline; identified flood experience, warning preferences, vulnerable groups, evacuation constraints, wildlife concerns and mitigation needs.
January 2025	Revised Baseline Assessment Report issued	Zambia-Zimbabwe EWS corridor	Project team/ZRA	Formally documented the Phase I baseline consultation findings and their implications for EWS planning.
May 2025	Public Safety Awareness and EWS stakeholder engagement	Kariba, Siavonga, Chirundu and associated communities	District Commissioners, disaster-management committees, traditional authorities and communities including Namoomba, Chalokwa, Pambazana, Kabwadu and Chitende	Reinforced awareness of dam safety, EWS purpose and emergency roles; confirmed need for continuous sensitisation and preparedness.
July 2025	Public Safety and Climate-Risk Awareness engagement	Kafue and Luangwa Districts	District Commissioners, DDMMCs, Chief Mburuma, Chief Mphuka and communities including Kavhalamanja, Amoro, Chalokwa and Chidada	Highlighted multi-level communication, institutional coordination, community ownership, visual awareness tools and local participation.
August 2025	EWS preparedness monitoring	Luangwa District, including Chidada, Amoro and Kavalamanja	ZRA, World Bank representative, District Commissioner, DDMMC,	Confirmed strong interest but identified continuing gaps in EWS understanding and need for structured

Period	Consultation / engagement	Locations / coverage	Stakeholders	Key outcome / relevance to ESPB
			communities and lodge operators	sensitisation and coordination.
November 2025	Public Safety and EWS awareness engagement	Chirundu, Chiawa and Kanyemba areas	Traditional leaders, local authorities, community members and local institutions	Strengthened awareness and trust; reinforced training, inclusion of schools/vulnerable groups and protection of EWS infrastructure.
July 2026	Phase II site verification and implementation consultation	Proposed EWS installation sites in Zambia and Zimbabwe	ZRA, consultants, local authorities, facility managers, traditional leaders, conservation authorities and tourism establishments	Shifted engagement to implementation readiness, site suitability, access, land, sensitive receptors, wildlife and permissions.
30th July 2026	Site-specific consultation	Musokwe Health Clinic, Manyepa School and related locations	Village headmen, clinic/school representatives, ZRA and consultants	Alternative, safer and more secure siren locations considered; site-specific mitigation identified for sensitive facilities.
31st July 2026	Site-specific consultation	Chirundu Transport Area and related sites	Local operators, ZRA and consultants	Need to maintain vehicle/pedestrian access and avoid obstruction during installation.
1st August 2026	Formal community consultation	Chimusambo Village, Chiawa Area, Kafue District	Headman Nyakamiza, Headwoman Chimusambo, community members, ZRA and consultants	Community recommended moving the proposed siren away from the roadside; alternative site accepted for further assessment.
1st August 2026	Facility consultation	Chiawa Community Police Station	Deputy Officer-in-Charge, ZRA and consultants	Rear open area preferred, subject to formal permission and safe clearance from overhead power lines.
2nd August 2026	Tourism/wildlife site consultation	Mana Pools, Royal Zambezi Lodge and other tourism/wildlife locations	Lodge management, conservation stakeholders, ZRA and consultants	Recommendations included relocation near existing infrastructure, reduced visual impact and wildlife-compatible protection.

Period	Consultation / engagement	Locations / coverage	Stakeholders	Key outcome / relevance to ESPB
3rd August 2026	Institutional consultation	DNPW, Chirundu Office	DNPW officials, ZRA and consultants	DNPW advised avoidance of sensitive habitat and wildlife routes and requested GPS coordinates for review; permission required for works in protected areas.
5th August 2026	District-level consultation	Luangwa District	District Commissioner, ZRA and consultants	Strong support expressed; timely implementation and completion of environmental/regulatory approvals emphasised.

The consultation sequence demonstrates an evolution from baseline assessment and risk identification, through public awareness and preparedness, to site-specific implementation consultation. This provides a continuous engagement record rather than a single consultation event.

Key Issues Raised and Project Response

Issue	Stakeholder concern / expectation	Project response / ESPB commitment
Timely warning	Previous warnings may be delayed or inadequate.	EWS to strengthen monitoring, forecasting and timely warning dissemination.
Warning channels	A single channel may exclude households with weak mobile/radio access.	Use sirens together with complementary communication and community dissemination mechanisms.
Local language and clarity	Warnings must be easily understood.	Use locally appropriate language and accessible awareness materials.
Vulnerable groups	Some persons require additional warning or evacuation assistance.	Integrate vulnerable groups into preparedness, communication and evacuation planning.
Siren siting	Some preliminary locations presented road, land, access or safety concerns.	Refine locations through micro-siting and consultation before construction.
Siren testing/noise	Testing may disturb residents, patients, pupils, tourists or wildlife.	Notify stakeholders in advance and schedule tests to minimise disturbance.
Schools and health facilities	Construction and testing can disrupt sensitive facilities.	Coordinate with facility management, secure work areas and avoid sensitive periods where practicable.

Issue	Stakeholder concern / expectation	Project response / ESPB commitment
Wildlife and protected areas	Towers/fencing may affect wildlife movement or sensitive habitat.	Consult DNPW, avoid sensitive habitats/corridors and apply wildlife-compatible protection.
Tourism/visual impact	Towers may affect lodge settings and visitor experience.	Locate near existing infrastructure and minimise vegetation clearance/visual intrusion where practicable.
Land/access and permissions	Installation requires clear site authority and access.	Confirm ownership/tenure and obtain written permission/authorisation before works.
Equipment security	Risk of vandalism and wildlife damage.	Use site-specific protection and community awareness/ownership measures.
Local participation	Communities expressed interest in project opportunities.	Consider local labour where technically feasible and consistent with procurement requirements.
Emergency preparedness	Infrastructure alone will not ensure effective response.	Continue sensitisation, evacuation training, mock drills and institutional coordination.

Vulnerable Groups and Sensitive Receptors

The engagement process identified groups that may face barriers in receiving or acting on warning information, including children, older persons, persons with disabilities, pregnant women, persons with medical conditions, households without reliable mobile-phone or radio access, persons with limited literacy, fishers and farmers working away from settlements, tourists unfamiliar with local emergency procedures, and remote households. Schools, clinics, tourism establishments and wildlife-sensitive locations are also treated as sensitive receptors. The EWS communication strategy should therefore use complementary warning mechanisms and preparedness arrangements rather than rely on a single electronic channel.

Incorporation of Consultation Findings into Project Design

i. Relocation/refinement of preliminary siren sites where stakeholders identified safety, access, land, visual or wildlife concerns.
ii. Preference for secure sites within existing public/institutional compounds where appropriate.
iii. Advance notification and coordination for audible siren testing and mock drills.
iv. Protection of schools, health facilities, tourism establishments and other sensitive receptors.
v. DNPW review of locations in or near protected and wildlife-sensitive areas and avoidance of migration routes/sensitive habitats.

vi. Use of multi-channel, locally understandable warning communication and inclusion of vulnerable groups.
vii. Continued community sensitisation, preparedness exercises and institutional coordination during implementation and operation.

Stakeholder Engagement During Construction, Commissioning and Operation

Before construction at each site, ZRA and/or the Contractor will confirm land and access arrangements, obtain required permissions, notify relevant local authorities/traditional leadership and facility managers, confirm environmental and wildlife restrictions, communicate the work programme and provide contact arrangements for concerns. During construction, engagement will address access, noise, community health and safety, worker-community interaction, sensitive facilities, wildlife, waste and grievances. Before audible testing or mock drills, affected communities and responsible authorities will be notified and the meaning of warning signals and evacuation arrangements will be explained. During operation, ZRA will maintain periodic awareness, preparedness exercises and feedback mechanisms to reinforce community ownership and system effectiveness.

Grievance and Feedback Mechanism

A project-level grievance and feedback mechanism will be maintained for construction, commissioning and operation. Potential grievances may include temporary access restrictions, construction disturbance, property damage, worker conduct, land/access concerns, siren testing, safety, impacts on sensitive facilities, wildlife-related concerns or EWS operational issues. Grievances will be recorded, acknowledged, assessed, assigned for action, responded to within an appropriate timeframe and closed following documented resolution. The mechanism will be accessible without cost and will not restrict any stakeholder from using other administrative or legal remedies available under Zambian law.

Disclosure and Evidence of Consultation

For ZEMA submission, the ESPB should be accompanied by proof of consultation. The supporting annexures should include, as available, signed attendance registers with stakeholder contact details, meeting minutes, consultation photographs, FGD/KII records, institutional consultation notes, questions and responses, site-specific consultation records, written comments, permissions and correspondence, and records showing how material stakeholder recommendations were incorporated into project design or mitigation measures.

Overall Stakeholder Perception and Conclusion

The consultation records demonstrate broad stakeholder support for the proposed EWS. Communities recognise its potential to reduce risks to life, property, crops and livelihoods, while institutions recognise its importance for downstream emergency preparedness. Stakeholder support is accompanied by expectations that warning information will be timely and understandable, sensitive receptors and wildlife will be protected, necessary permissions will be secured, equipment will be maintained and consultation, training and preparedness exercises will continue. No material community opposition is recorded in the consultation documentation reviewed for this ESPB. Stakeholder engagement will therefore remain an integral part of detailed design, construction, commissioning, testing and operation of the EWS.

Second phase Public Consultation and Stakeholder Engagement

Public consultation and stakeholder engagement were undertaken as part of the environmental and social assessment of the proposed Early Warning System (EWS) Project. The consultations covered selected downstream communities, traditional leaders, government institutions, protected-area authorities, schools, commercial establishments, tourism operators and other potentially affected or interested stakeholders in Zambia and Zimbabwe.

The engagement process was intended to:

- Explain the purpose, components and operational arrangements of the EWS Project;
- Assess stakeholder awareness of flood and dam-related risks;
- document experiences of previous flooding events;
- Identify appropriate warning and communication channels;
- Obtain local knowledge on proposed equipment locations;
- Identify environmental, wildlife, public-safety and access concerns;
- Establish institutional roles in emergency preparedness and response;
- Determine community training and evacuation-support needs; and
- Incorporate stakeholder recommendations into the final siting, design, construction and operation of the system.

Consultations included community meetings, key informant interviews, discussions with government authorities, meetings with landholders and facility managers, and joint inspections of proposed siren locations. The principal engagements were undertaken between 1 and 5 August 2026.

Stakeholders Consulted

The principal stakeholders engaged during the assessment included:

Date	Stakeholder/location	Country	Main subject
1 August 2026	Chimusambo Village, Chiawa Area	Zambia	Community sensitisation and selection of an alternative siren location
2 August 2026	Royal Zambezi Lodge management	Zambia	Siren siting, visual effects, wildlife safety and land access
3 August 2026	Department of National Parks and Wildlife, Chirundu Office	Zambia	Protected-area authorisation, wildlife corridors and ecological sensitivity
5 August 2026	Luangwa District Commissioner	Zambia	District flood vulnerability, coordination and implementation support

Date	Stakeholder/location	Country	Main subject
5 August 2026	Kanyemba Meteorological Station	Zimbabwe	Siren siting, security, utilities and protection of monitoring equipment
5 August 2026	Kanyemba Lodge area	Zimbabwe	Siren siting, lodge access, wildlife habitat and further consultation
5 August 2026	Proposed large-siren site near Luangwa CBD	Zambia	Public safety, vendors, utilities, noise and access
5 August 2026	Kamoba Village	Zambia	Mini-siren siting, seasonal access and community safety
Field consultation period	Senior Headwoman Godfridah Kabwadu, Muguram eno Village	Zambia	Flood history, preparedness and warning preferences
Field consultation period	Ireen Kapesa, Ward Development Committee, Muguram eno	Zambia	Communication barriers and community warning channels
Field consultation period	Chakanaka Banana Farm representatives	Zambia	Flood experience, farm vulnerability and communication networks
Field consultation period	ZimParks, Mana Pools National Park	Zimbabwe	Flood response, wildlife conservation and institutional coordination
Field consultation period	Mr. Mwanamonga, Headteacher, Chilombwe Primary School	Zambia	Schools' role in information dissemination and preparedness
Field consultation period	Mr. Moses Phiri, Ward Development Committee, Kavalamanja	Zambia	Community vulnerability, evacuation and warning channels

Community Consultation at Chimusambo Village

A public consultation meeting was held at Chimusambo Village in the Chiawa area of Kafue District on 1 August 2026, from 12:00 to 12:55 hours. The meeting was attended by representatives of the Zambezi River Authority, project consultants, traditional leaders and members of the local community.

Traditional leadership was represented by Headman Nyakamiza and Headwoman Chimusambo. The ZRA delegation included Ms. Constance Lyambai and Ms. Georgina Chomba. The consultant team comprised Dr. Rahul, Environmental Consultant; Mr. Prasanta, Socio-Economic Consultant; and Mr. Geofrey Mwanza, Local Environmental Consultant.

Headwoman Chimusambo welcomed the participants and encouraged the community to contribute actively to the discussion. Following an opening prayer and introductions, Ms. Lyambai explained that the engagement was the second sensitisation meeting undertaken in the village concerning the EWS Project.

During the discussion, it became apparent that some community members were not familiar with the institutional mandate of ZRA, with one participant initially interpreting "ZRA" as the Zambia Revenue Authority. The project team clarified that ZRA refers to the Zambezi River

Authority, a binational institution jointly established by Zambia and Zimbabwe to manage the relevant section of the Zambezi River and the Kariba Dam.

The community was informed that the EWS would provide timely warnings in the event of severe flooding or the unlikely occurrence of a dam-related emergency. The system is intended to give downstream populations sufficient time to evacuate to safer areas. ZRA further explained that additional awareness programmes, evacuation training and mock drills would be undertaken before the system becomes operational.

Selection of the Siren Location

The project team sought clarification regarding the ownership and availability of land initially identified for the siren installation. Traditional leaders confirmed that community land could be made available because the installation would provide a direct public-safety benefit. However, Headman Nyakamiza and community representatives advised that the preliminary site near a baobab tree was too close to the main road and could present safety and access concerns. The community consequently proposed an alternative site at:

15°49'27.8"S, 29°07'10.3"E

The proposed alternative was accepted for detailed technical and environmental assessment. Several hamlets occur within approximately 100 metres of the location. Final site confirmation must therefore consider audible coverage, operational noise, community safety, tower security and the need to announce siren tests and mock drills in advance.

Questions Raised

Community members asked who would operate the siren after installation. ZRA explained that the siren would be operated and monitored remotely from the ZRA Control Room in Kariba. The installation would also incorporate a CCTV security system; therefore, no local person would be employed solely to operate or guard the equipment. A further question concerned the level and frequency of noise. ZRA clarified that the siren would comply with applicable technical standards for emergency warning systems. It would not sound daily and would only be activated during an emergency or an authorised test or drill. Advance notice would be provided for scheduled tests to minimise alarm and disturbance.

The community expressed support for the project, and no objections were raised. The meeting concluded at 12:55 hours with a closing prayer.

Key Informant Interviews

Senior Headwoman Godfridah Kabwadu – Mugurameno Village

Senior Headwoman Godfridah Kabwadu explained that Mugurameno Village experienced serious flooding in 2000 and again in 2010. The floods destroyed household gardens, reduced food availability and affected local livelihoods. She expressed concern that many community members had not received basic disaster-preparedness or evacuation training.

Nyanja was identified as the most widely understood local language and should therefore be used for community warnings, awareness materials and evacuation instructions. Because some residents have limited literacy, audible warnings, public-address systems and sirens were considered particularly important.

The Headwoman recommended that communities receive approximately one week's advance notice, where operational circumstances allow, before the opening of the Kariba Dam sluice gates. She stated that delays and gaps in communication during previous flood events had contributed to losses of livelihoods and, according to local recollection, loss of life.

Ward Development Committee – Mugurameno Village

Ms. Ireen Kapesa, representing the Ward Development Committee, recalled the 2000 floods, during which crops were destroyed and households experienced food shortages. The respondent was aware of the proposed EWS from an earlier community meeting.

Nyanja was recommended as the principal warning language. FM radio, social media and sirens were identified as useful communication channels, although limited access to technology and uneven network coverage could restrict the effectiveness of phone- and internet-based communication. The respondent recommended approximately one week's advance warning before planned sluice-gate opening, where practicable.

The interview demonstrated the importance of combining sirens with radio announcements, local leadership structures and direct community mobilisation rather than relying exclusively on digital communication.

Chakanaka Banana Farm

The project team interviewed the Chakanaka Banana Farm manager, Ms. Ruth Mfune, together with a long-serving farm employee. The respondents recalled unusually high water levels in 2000, when floodwaters carried away crops and threatened agricultural production. The long-serving employee also recalled a similar high-water event in 1978.

The respondents indicated that MTN provides the most reliable mobile network in the area. Communication and technological limitations were identified as major reasons why people had previously received delayed information regarding changes in river levels and sluice-gate operations. Traditional and community leaders were recognised as important intermediaries in spreading warnings. The respondents supported the installation of sirens as part of the wider communication system.

ZimParks – Mana Pools National Park

Representatives of ZimParks explained that Mana Pools National Park has approximately 250 permanent residents. Cellular network and radio reception are poor in parts of the park, although Wi-Fi is available at some facilities. Social media and institutional communication networks are used to provide information concerning impending hazards. Several lodges and tourism establishments close during the rainy season because of flood risks and limited accessibility. ZimParks has previously used boats to evacuate staff, residents and affected persons during flooding. Flood events in 2012 and 2020 reinforced the need to maintain preparedness and respond promptly to official warnings.

The respondents identified the protection of human life as the primary emergency-management priority, alongside the authority's core wildlife-conservation responsibilities. They requested improved communication systems, targeted warning arrangements, greater operational resources and stronger institutional support. ZimParks welcomed the EWS and stressed that the final siting and protection of infrastructure must be compatible with wildlife movement and protected-area management.

Chilombwe Primary School

Mr. Mwanamonga, Headteacher of Chilombwe Primary School, explained that schools can play an important role in disseminating warning information through pupils, parents and meetings held on school premises. The school also has a broader role in promoting public awareness and disaster preparedness.

Poor mobile-network coverage was identified as a major obstacle to timely communication. The school lacks sufficient disaster-management training and emergency-response resources. The Headteacher requested training for teachers and pupils, together with clear guidance on warning signals, evacuation routes, assembly points and the actions expected during an emergency.

Kavalamanja Ward Development Committee

Mr. Moses Phiri explained that the Kavalamanja Ward Development Committee comprises the councillor, civil servants, traditional leadership and church representatives. The committee reportedly has 13 male and two female members. Kavalamanja Village has an estimated population of approximately 1,526 people.

The respondent recalled very high-water levels in 1978. At that time, many gardens were located close to the river, although there were fewer houses in flood-prone areas. The community of Kadembwele was reportedly compelled to relocate to Kavalamanja after flooding damaged its former settlement.

The principal challenges during flood emergencies were identified as inadequate shelter and insufficient food for displaced households. In previous events, messengers from the traditional leadership moved through the area to announce the anticipated opening of sluice gates. Churches, door-to-door communication, community leadership and SMS messages were identified as appropriate supplementary warning channels. Zamtel was reported to provide useful coverage in parts of the area.

Nyanja was recommended as the principal community communication language. The respondent also requested approximately one week's notice, where technically possible, to allow households to prepare and evacuate safely.

Consultation with Institutional Stakeholders

Department of National Parks and Wildlife – Chirundu Office

DNPW officials were consulted on 3 August 2026. The project objectives, proposed infrastructure and preliminary tower locations were presented to the department. DNPW advised that final sites must avoid sensitive wildlife habitats, recognised animal-movement routes and other ecologically important areas. The department requested exact GPS coordinates for proposed installations within or near protected areas so that the locations could be reviewed and adjustments recommended where necessary.

DNPW explained that ZEMA would ordinarily refer the environmental assessment report to the department for technical comments. A separate environmental no-objection certificate may not generally be required; however, ZRA and its contractors must obtain the necessary authorisation before entering or undertaking works within protected areas.

Luangwa District Commissioner

The Luangwa District Commissioner was consulted on 5 August 2026. The project team presented the objectives of the EWS, the proposed infrastructure and the purpose of the environmental and social field assessments.

The District Commissioner welcomed the project and observed that an operational warning system is particularly important to Luangwa District because of its exposure to flooding from the Zambezi River and backflow from tributaries. The District Commissioner emphasised timely implementation, compliance with environmental and other regulatory requirements, and continued coordination with the district administration. The office committed to cooperate during site confirmation and implementation.

Consultation and Findings at Proposed Installation Sites

Royal Zambezi Lodge, Zambia

Lodge management was consulted on 2 August 2026 regarding the proposed siren installation. The project team explained the purpose and technical characteristics of the siren and discussed its preliminary position near the lodge entrance. Management recommended relocating the siren slightly behind the existing buildings, near other communication towers. This would reduce visual intrusion and integrate the installation with existing infrastructure.

Because elephants frequently move through the area, management recommended wildlife-compatible protection around the tower. The appropriate protection measure should be agreed with DNPW and lodge management to ensure that it does not obstruct wildlife movement, entrap animals or introduce new safety risks.

The lodge expressed support for the project, subject to internal consultation with its General Manager and owner and receipt of formal communication from ZRA. Environmental and receptor sensitivity at the site were classified as high because of the wildlife habitat and presence of lodge guests, while social sensitivity was considered low.

Kanyemba Meteorological Station, Zimbabwe

The proposed siren location was assessed on 5 August 2026. Following discussions at the station, the preliminary position was shifted approximately 30 metres to a location at the rear of the meteorological station compound. The fenced and secured compound would reduce the risk of wildlife interference, vandalism and unauthorised access. However, shallow rock may be encountered during excavation. Ground conditions should therefore be confirmed before construction so that appropriate excavation equipment and foundation methods can be selected.

An overhead electricity line is situated near the proposed location, and the nearest building is approximately 20 metres away. Construction must maintain the required utility clearances and protect the station's meteorological instruments and Automatic Weather Station equipment during the movement of personnel, machinery and materials. Environmental, social and receptor sensitivities were classified as low, subject to maintaining electrical clearances and protecting the existing monitoring infrastructure.

Kanyemba Lodge Area, Zimbabwe

The proposed location near Kanyemba Lodge was inspected externally on 5 August 2026 because lodge representatives were unavailable. The preliminary site was adjacent to, but outside, the lodge boundary. Relocating the tower to the opposite side of the existing dirt road could reduce interference with lodge access and routine operations. The area contains scattered bushes, natural forest and wildlife habitat, although only limited vegetation clearance would be necessary for the approximately 4 m × 4 m tower footprint. The nearest building and the Zambezi River are each approximately 100 metres from the proposed site.

Local information indicated frequent movement of large mammals in the surrounding landscape. Wildlife-protection measures and the final tower location must therefore be agreed with ZimParks. Formal consultation with lodge management is also required before the location is confirmed.

Environmental sensitivity was classified as moderate to high, social sensitivity as low and receptor sensitivity as high because of the wildlife habitat, natural vegetation and lodge visitors.

Large Siren Site near Luangwa Central Business District

The proposed large-siren site was assessed on 5 August 2026. It is located on elevated roadside ground within the built-up area of Luangwa, near the Office of the President. The site has adequate space for the proposed 4 m × 4 m foundation and associated equipment, although limited vegetation clearance would be required. Three roadside vending structures are situated adjacent to the site. Markets, shops and residential buildings occur within approximately 100 metres, and the Luangwa River is approximately 500 metres behind the proposed location. A communication tower and an overhead electricity line are also present nearby.

Construction must maintain access to businesses and residences, protect vendors and road users, and comply with utility-clearance requirements. Temporary barriers, warning signs and controlled material-storage areas will be required. Siren tests and mock drills must be announced in advance because of the site's position within a busy commercial and residential area.

Environmental sensitivity was classified as low, while social and receptor sensitivities were classified as moderate.

Kamoba Village

The proposed mini-siren location at Kamoba Village was assessed on 5 August 2026. The site is in an open area on the riverward side of the village, adjacent to a community football ground. It provides adequate space for the installation and would require minimal vegetation clearance. Only a small number of scattered houses occur nearby. Although the site is readily accessible during the dry season, flooding and poor road conditions may restrict access during the rainy season. Installation should therefore be prioritised before the onset of the rains. The construction area must be securely barricaded to protect children and other users of the adjoining playground.

Environmental, social and receptor sensitivities were classified as low.

Consolidated Consultation Findings

The consultations showed broad support for the EWS Project. Stakeholders recognised that downstream settlements, farms, schools, tourism establishments and protected areas remain vulnerable to flooding and require more reliable and timely warnings.

The principal issues raised across Zambia and Zimbabwe were:

Consultation theme	Consolidated finding	Required project response
Flood experience	Communities recalled damaging floods and unusually high-water levels in 1978, 2000, 2010, 2012 and 2020.	Incorporate local flood experience into awareness, evacuation and drill programmes.
Advance warning	Several respondents requested approximately one week's notice before planned sluice-gate opening.	Provide the earliest technically reliable notice possible and clearly distinguish planned releases from sudden emergencies.
Warning language	Nyanja is the most widely understood language in several consulted Zambian communities.	Issue warnings and training information in Nyanja and other locally appropriate languages, supported by clear audible signals.
Communication channels	Sirens were strongly supported, but stakeholders also identified radio, SMS, social media, churches, schools, traditional leaders and door-to-door communication.	Adopt a redundant, multi-channel warning system rather than relying on a single communication method.
Network limitations	Poor cellular and radio coverage occurs in several remote communities and protected areas.	Use sirens and locally managed communication chains as primary backups where network coverage is unreliable.
Community preparedness	Several communities, schools and local institutions lack training and disaster-response resources.	Conduct evacuation training, public awareness campaigns and periodic mock drills before commissioning.

Consultation theme	Consolidated finding	Required project response
Siren testing	Communities and businesses could mistake tests for genuine emergencies.	Announce tests and drills in advance through local leaders, radio, SMS and other available channels.
Local siting knowledge	Communities and facility managers proposed safer alternative locations at Chimusambo, Royal Zambezi Lodge, Kanyemba and other sites.	Complete technical, acoustic, environmental and land-access verification before finalising locations.
Wildlife	Elephants and other large mammals occur near several lodge and protected-area sites.	Consult DNPW and ZimParks and use wildlife-compatible designs that do not obstruct established movement routes.
Protected areas	Work within protected areas requires prior authorisation.	Obtain access and work authorisations from the relevant wildlife authority before mobilisation.
Public safety	Some proposed sites are near roads, vendors, markets, houses and playgrounds.	Use barriers, signs, traffic controls, safe work zones and community notification during construction.
Existing infrastructure	Electricity lines, communication towers and monitoring instruments are present at some sites.	Maintain prescribed clearances and protect existing infrastructure during construction.
Seasonal access	Rainfall and flooding could restrict access to remote sites such as Kamoba.	Prioritise difficult-to-access sites for installation during the dry season.
Livelihood vulnerability	Flooding has previously affected crops, gardens, tourism operations, food security and shelter.	Include livelihood protection, temporary shelter and vulnerable-person support in emergency planning.
Institutional coordination	District authorities, wildlife agencies, schools, traditional leaders and tourism operators have complementary roles.	Establish clear communication protocols and contact lists for warning dissemination and emergency response.

Conclusion

The stakeholder-engagement process established that the proposed EWS is generally supported by communities, traditional leaders, government authorities, schools, agricultural enterprises, tourism operators and protected-area institutions. Stakeholders consistently recognised the need for timely, reliable and understandable flood warnings.

The consultations also demonstrated that the effectiveness of the EWS will depend on more than the installation of sirens. It will require accurate site selection, reliable communication protocols, locally appropriate languages, community training, announced testing, evacuation planning and continued coordination between ZRA, district authorities, traditional leadership, schools, wildlife agencies and local businesses.

No fundamental objection to the project was identified. Nevertheless, several locations require further consultation, land confirmation, wildlife-authority review or technical assessment before they can be approved for installation. These outstanding requirements should be incorporated into the Environmental and Social Management Plan and completed before construction begins at the respective sites.

11.4 Consultation photos

Figure 21: Namonga FGD

Figure 22: Chalokwa village FGD

Figure 23: Kabwadu village FGD

Figure 24: Amora FGD

Figure 25: Kavalanja WDC

Figure 26: Chidada village FGD

Figure 27: Socio and environmental expert with Kabwadu ward Councilor

Figure 28: Research team holding a consultative meeting with manager for Elephant Hills Resort, Zimbabwe.

Figure 29: Research team holding a consultative meeting with ZIMPARKS, Kariba, Zimbabwe.

Figure 30: Consultative meeting with the Sister in charge at Musokwe health clinic, Siavonga District, Zambia.

Figure 31: Consultative meeting at Manyepa School compound, Siavonga district, Zambia.

Figure 32: Consultative meeting with the owner of the land were one of the sirens will be installed in Chirundu CBD

Figure 33: Consultative meeting with acting sister in charge at Chipepo health post in Chirundu

Figure 34: Consultative meeting at Muguramero village

Figure 35: Consultative meeting at Chiyaba Police station

Figure 36: Research team holding a consultative meeting with manager for Mana Pools Safari Lodge, Mana Pools, National Park, Zimbabwe.

Figure 37: Research team holding a consultative meeting with manager for Zambezi Royal Lodge, Lower Zambezi

Figure 38: Consultative meeting with DPNW Chirundu office

Figure 39: Consultative meeting and courtesy call on Luangwa District Commissioner

Figure 40: Propose location of the siren at Kenyemba Met station, Zimbabwe.

Figure 41: Proposed location of a large siren in Luangwa CBD near the OP offices

Figure 42: Consultative discussion with headwoman Godfridah - Kabwadu Village

Figure 43: KII meeting with Mana Pools National Park

...THE END...