LEBANON MINISTRY OF TOURISM

JIITA SHOWCAVE

INSPECTION & CORRECTIVE ACTIONS

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TABLE OF CONTENTS

Acronyms iv
Abbreviations & Units v
Glossary v
Executive Summary vi
Purpose vi
Key Findings vi
Strategic Upgrades for Tender Integration (CAPEX Items) vii
1. Scope of Work 1
2. Site Inspection Findings 1
2.1 Cave Microclimate 1
2.1.1 Measurements 1
2.1.2 Interpretation of Measurements 9
2.2 Speleothem Conditions 13
2.3 Infrastructure Conditions and Systems 18
2.3.1 Concrete Structures 18
2.3.2 Metal Structures 20
2.3.3 Electrical System 21
2.3.4 Lighting 22
2.4 Operational Gaps 23
2.4.1 Tourist Access and Management 23
2.4.2 Internal Communication Protocols 23
2.4.3 Emergency Procedures and Equipment 23
2.4.4 Microclimate Stability and Air Quality Risks 24
2.4.5 Waste Management and Visitor Conduct 24
2.4.6 Cave Concretion Fragments in Souvenir Shop 25
2.4.7 Speleothem Cleaning 25
3. Recommended Corrective Actions 26
3.1 Corrective Actions for Re-Opening of Jiita Showcave 26
3.2 Micro-Climate & Radon Monitoring Specifications 28
Alarm & Response Logic 31
3.3 Technical Specifications for Electrical Systems 32
3.3.1 General Technical Requirements 32
3.3.2 Lighting Specifications 32
3.3.3 Junction Boxes 33

3.3.4 Sound System 33
3.3.5 Control System 33
3.4 Visitor Walkway Cleaning and Disinfection Mats 36
3.4.1 Walkway Cleaning 36
3.4.2 Shoe Disinfection Mats 37
3.5 Electric boat charging stations for Lower Gallery: 38
3.5.1 Scope of Work 38
3.5.2 Applicable Standards 39
3.5.3 Site and Environmental Conditions 39
3.5.4 Technical Requirements 40
3.5.4.1 Electrical Input 40
3.5.4.2 DC Output 40
3.5.4.3 Protection Features 41
3.5.4.4 Mechanical and Environmental 41
3.5.4.5 Indicators and Controls 41
3.5.5 Installation and Cabling 42
3.5.6 Testing and Commissioning 42
3.5.7 Documentation and Deliverables 42
3.5.8 Quality and Warranty 42
3.5.9 Quantities 43
3.6 Recommended Visitor Management and CO_2 Control 43
3.6.1 Upper Gallery 43
3.6.1.1 Goal 43
3.6.1.2 Operating Concept 43
3.6.1.3 CO_2 Control 44
3.6.2 Lower Gallery 45
3.6.2.1 Goal 45
3.6.2.2 Operating Concept 46
3.6.2.3 CO_2 Control 46
Appendix A: Inspection Team & Minimum Qualifications 48

ACRONYMS

Acronym	Meaning
AED	Automated External Defibrillator
BLE	Bluetooth Low Energy (short-range wireless download)
CAN	Controller Area Network (field-bus protocol)
CO_2	Carbon Dioxide
CCTV	Closed-Circuit Television
CRI	Color Rendering Index
DC-UPS	Direct-Current Uninterruptible Power Supply
DMX	Digital Multiplex Lighting-Control Protocol
ELV	Extra-Low Voltage (≤ 50 V AC / 120 V DC)
EMP	Emergency Management Plan
ERP	Emergency Response Procedure (caretaker phase)
GFCI	Ground-Fault Circuit Interrupter
HID	High-Intensity Discharge (lighting)
IK	Impact-Protection Rating (mechanical strength)
IP-65 / IP-68	Ingress-Protection ratings for dust- and water-tight enclosures
LED	Light-Emitting Diode
LoRa	Long-Range, low-power radio mesh protocol
NDIR	Non-Dispersive Infra-Red (gas-sensing technology)
PA	Public Address (sound system)
PoE	Power over Ethernet (IEEE 802.3af)
RJ-45	Standard 8-pin Ethernet connector
Rn	Radon-222
RS-232 / RS-485	Serial communication standards
SS 316 L	Stainless Steel grade 316, low-carbon
T	Air Temperature
RH	Relative Humidity
UPS	Uninterruptible Power Supply

ABBREVIATIONS & UNITS

- ppm: parts per million (gas concentration)
- Bq·m^{-3}: becquerels per cubic meter (radon concentration)
- °C: degrees Celsius
- K: Kelvin (color temperature for lighting)
- vph: visitor per hour
- vpd: visitor per day
- wk / mo: week / month

GLOSSARY

Term	Definition
Apex Dissolution	Localized chemical erosion at the tip of a stalagmite due to undersaturated or acidic drip water.
Automatic Ticketing Throttle	Software link that slows or suspends ticket sales whenever live CO_2 readings exceed preset thresholds, preventing further visitor entry until conditions return to safe levels.
Ingress Protection (IP) Rating	IEC code that classifies the degree of protection provided by enclosures against dust and water (e.g., IP-65 is dust-tight and protected against water jets; IP-68 is dust-tight and suitable for continuous immersion).
Impact-Protection (IK) Rating	IEC measure of mechanical impact resistance for enclosures; IK10 withstands a 5 kg hammer dropped from 40 cm.
Lampenflora	Algae, mosses, and other photosynthetic organisms that grow under artificial cave lighting, often causing green biofilms on speleothems.
Speleothem	Secondary cave mineral deposit (e.g., stalactite, stalagmite, flowstone) formed mainly from calcium carbonate.
Extra-Low Voltage (ELV)	Electrical systems operating at voltages low enough (≤ 50 V AC or 120 V DC) to reduce shock risk, specified for cave lighting and control circuits.

EXECUTIVE SUMMARY

PURPOSE

This inspection-based report evaluates the current micro-climate, speleothem condition, infrastructure, and operations of the Jiita Show-Cave (upper & lower galleries) after 6 months of closure. It identifies capital and specialist upgrades to be embedded in the upcoming operator tender, ensuring long-term conservation and visitor safety.

All operational figures and thresholds presented (capacities, headways, dispatch rates, CO_2 response levels, and pulse-ventilation frequencies) are initial design values and shall be validated and, where needed, readjusted based on actual operational data, calibrated continuous cave microclimate monitoring, and cave-health observations, while maintaining the adopted conservation and safety targets.

KEY FINDINGS

i. Micro-climate

a. Initial SCL baseline spot measurements indicate CO_2 levels generally around 2,600 ppm in deeper internal zones, with peaks exceeding 3,000 ppm; subsequent operational monitoring confirmed that higher CO_2 levels can occur with visitors inside.

b. Relative humidity drops near open doors when both entrances are propped open.

c. Result: elevated visitor discomfort risk and accelerated calcite dissolution near entrances.

ii. Speleothems

a. Dust deposition, lampenflora growth, bleaching from cleaning, microbial black staining, and apex dissolution observed.

b. Visitor contact has caused abrasion, scratching, and coin-littered rimstone pools.

c. Result: ongoing aesthetic and structural degradation of cave formations.

iii. Infrastructure

a. Corroded handrails, exposed or obsolete cabling, non-waterproof junction boxes, and outdated HID fixtures remain in service.

b. Dead UPS batteries eliminate backup power for lighting.

c. Result: immediate electrical and physical safety hazards plus non-compliance with modern show cave standards.

iv. Operations & Safety

a. No visitor cap; free-flow entry without guides; inadequate emergency signage and radio dead zones.

b. First-aid kits stored outside; unclear access to AEDs; no regular drills.
c. Souvenir shop displays real speleothem fragments - encouraging vandalism.
d. Result: heightened liability and mixed conservation messaging to tourists.

STRATEGIC UPGRADES FOR TENDER INTEGRATION (CAPEX ITEMS)

i. Safety & Risk Management

a. Draft a full Emergency Management Plan within 3 months of contract start and gain approval by month 6.
b. Install permanent CO_2 and radon telemetry (one-minute logging, cloud dashboard, SMS alarms) within 6 months as follows:
    i. Lower Gallery: 5 stations for temperature and relative humidity (4 of which including CO_2).
    ii. Upper Gallery: 10 stations for temperature and relative humidity (5 of which including CO_2).
    iii. Radon: 2 continuous loggers per gallery - one at the highest-radon point, one just inside the entrance.
    iv. Sensors log T, RH, CO_2, Rn every minute.
    v. Data transfer backbone: Install shielded Cat-6 PoE cabling or a LoRa mesh with gateway at the tunnel mouth so sensors can ultimately push data to the cloud every ≤ 5 min.
    vi. Cloud dashboard with SMS/e-mail alarms using a staged CO_2 response framework: 2,800 ppm as a conservation watch/trend level, 3,200 ppm as the Amber throttling level, and 3,600 ppm as the provisional permitted ceiling / Red action level, with automatic ticketing throttle linked to live CO_2 readings.

ii. Environmental Controls

a. Build engineered double-door airlocks at the upper tunnel and lower river exit (if feasible for Lower Gallery) within 9 months.

iii. Electrical & Lighting

a. Electrical backbone and low-voltage re-wire (refer to Section 3.3):
    i. Install the 12–48 V DC distribution network in shielded conduit with IP-65/68 junction boxes and PoE capability within 9 months of contract start.
    ii. Complete removal of all legacy wiring and HID fixtures, and final commissioning of the new system, within 12 months.
b. High-CRI LED lighting retrofit (refer to Section 3.3.2) within 12 months of contract start:
    i. ≤ 50 W luminaires (2 700–3 000 K, CRI ≥ 90 %) rated IP-67 for dry zones and IP-68 for submersible points.

ii. each fixture with constant-current driver, polarity-reversal protection, and scene control via a central wired/radio controller.

c. Integrated systems (refer to Section 3.3) within 9 months of contract start: maintained twin-feed emergency-exit lighting, cave-grade PA/background-music loudspeakers, and a wired intercom linked to the management office - all housings in 316 L stainless, coated aluminum, or UV-stable polycarbonate with insulated mixed-metal interfaces.

iv. Visitor Infrastructure

a. Replace corroded handrails with 316 L stainless or marine-grade anodized aluminum (or competent authority[1] - approved epoxy coating) within 9 months.

b. Implement controlled visitor-flow systems (Upper & Lower Galleries) within 6 months:

i. Upper Gallery (walk-through): Implement a guided-group visitor-flow system (groups of 20 released every 3 minutes; operational cap ≤180 persons inside; dynamic capacity tied to continuous CO_2 monitoring, with throttling at 3,200 ppm and a provisional permitted ceiling of 3,600 ppm).

ii. Lower Gallery (boat route): Implement discrete guided boat departures (no free flow) with dispatch throttling tied to live CO_2 telemetry at the mid-route control sensor (Station S3), using the same staged CO_2 response framework adopted for the Upper Gallery (2,800 ppm conservation watch/trend level; 3,200 ppm Amber throttling level; 3,600 ppm provisional permitted ceiling / Red action level) and using dispatch throttling as the first-line control to avoid crowding at the docks and repeated ventilation pulses.

c. Walkway hygiene measures:

i. Shoe-disinfection mats (1 % Virkon S or equivalent) installed at the main entrance within 3 months.

ii. Wet-vac path-cleaning unit(s) procured and in service within 6 months; wastewater to be removed from cave.

v. Conservation

a. Submit a speleothem conservation plan within 6 months, including dry-ice / CO_2 snow cleaning protocol, pilot testing, fixed-point photography, condition mapping, and annual specialist survey; complete the first condition survey within 12 months.

b. Establish an on-site first-aid treatment room (AED, oxygen, trauma supplies) within 3 months.

[1] Ministry of Environment (MoE): Protects natural features and regulates any intervention that may affect geology, biodiversity, or water quality.

Directorate-General of Antiquities (DGA) – Ministry of Culture: Has jurisdiction over "natural monuments and sites of scientific, historical, or aesthetic value" under the 1933 Law on Antiquities. Jiita cave is on Lebanon's UNESCO Tentative List, so DGA reviews any modification that might impact its heritage attributes.

c. Deliver non-slip paths, tactile edging, CCTV, and full accessibility upgrades within 9 months.

d. Publish an annual sustainability report (energy, water, visitor load, conservation metrics) starting 15 months after contract award.

vi. Visitor Management & CO_2 Control (Upper Gallery)

a. Operating concept: Route 450 m each way (~900 m total). Guided groups of 20 (one trained guide per group; relief guides on standby). Dwell ≈ 30 min; headway 3 min.

b. Capacity & caps: ≤ 9 concurrent groups (≤ 180 persons); throughput 300-400 visitors/h (approximately 2,400-3,200 visitors/day). Increase only if monitoring confirms compliance during peak hours.

c. Pulse-ventilation protocol:

i. Conservation watch/trend level: CO_2 ≥2,800 ppm.

ii. Amber throttling level: CO_2 ≥3,200 ppm; automatically slow or pause group releases and manage crowding.

iii. Provisional permitted ceiling / Red action level: CO_2 ≥3,600 ppm; halt new entries and initiate a Single-Entrance Pulse.

iv. Primary action: Single-Entrance Pulse – open the Upper Gallery entrance door for up to 15 min while tours already inside continue toward the exit; close when CO_2 falls to ≤3,200 ppm or after 15 min, whichever occurs first.

v. Escalation: If, post-pulse, CO_2 remains >3,200 ppm, initiate a short Dual-Entrance Pulse by opening the Upper and Lower Gallery doors simultaneously for up to 10 min, where feasible and only as an escalation measure.

vi. Pulse frequency cap: No more than 1 pulse per 2 hours on average (i.e., ≤4 pulses over an 8-hour day); otherwise, visitor capacity and ventilation practice shall be reassessed.

vii. Ticketing throttle: Alarms automatically throttle group releases at 3,200 ppm and pause new entries at 3,600 ppm until recovery conditions are met.

d. Micro-climate safeguards: Doors remain closed during opening hours except for pulses; monthly RH trend check near the entrance.

vii. Visitor Management & CO_2 Control (Lower Gallery)

a. Operating concept: Discrete, guided boat departures (no free flow). 4 boats × 15 pax. Cycle time 8-10 min (8 min return trip + 30 s embark/disembark). Initial headway 2.5 min (10 min cycle ÷ 4), dynamically adjusted using live CO_2 at

Station S3. Visitors released in groups of 15; 45 s walk to docks; manage dock flow so the arriving group typically waits ≤2 min before departure.

b. Capacity & caps: ≤60 passengers inside the visited river section at any one time (excluding staff). Manage dock crowding: keep dock queue to ≤2 boatloads (≤30 passengers). Increase dispatch only if monitoring confirms compliance during peak hours.

c. Pulse-ventilation protocol (control point: Station S3; same staged framework as Upper Gallery):

   i. Conservation watch/trend level: S3 CO_2 ≥2,800 ppm.

   ii. Amber throttling level: S3 CO_2 ≥3,200 ppm; increase dispatch headway, pause discretionary departures, and prevent dock crowding.

   iii. Provisional permitted ceiling / Red action level: S3 CO_2 ≥3,600 ppm; halt new entries and boat departures, allow boats already inside to complete the normal exit cycle, and initiate pulse ventilation.

   iv. Primary action: Single-Entrance Pulse – open the Lower Gallery entrance door for up to 15 min; no additional boats launched during the pulse; close when CO_2 falls to ≤3,200 ppm or after 15 min, whichever occurs first.

   v. Escalation: If post-pulse S3 CO_2 remains >3,200 ppm, apply a short Dual-Entrance Pulse by opening both relevant gallery doors for up to 10 min, where feasible and only as an escalation measure.

   vi. Pulse frequency cap: ≤1 pulse / 2 h on average (≤4 per 8-h day); otherwise, dispatch rate, dock crowding, and ventilation practice shall be reassessed.

   vii. Ticketing/dispatch throttle: Use S3 alarms to throttle dispatch at 3,200 ppm and stop new departures/entries at 3,600 ppm until recovery conditions are met.

d. Micro-climate safeguards: Doors remain closed during opening hours except for short CO_2-triggered pulses, to limit humidity disturbance and avoid routine "always-open" ventilation.

The 3,600 ppm CO_2 value is adopted as a provisional permitted ceiling for adaptive operations and shall be reduced if continuous monitoring, humidity trends, drip-water chemistry, or speleothem condition surveys indicate unacceptable cave-health impacts.

1. SCOPE OF WORK

This brief study consists of a site inspection of the Jiita Showcave in Kesrwan, Lebanon on 13 June 2025 (upper and lower galleries) and subsequent assessment of the microclimatic, speleothem, and infrastructure conditions inside the cave. Two additional SCL monitoring visits were later conducted on 27 July and 17 August of the same year, and their microclimatic measurements were accounted for in the assessment. A further set of measurements dated 22 November 2025, collected by Dar Al-Handasah using a separate Kaiterra Sensedge indoor air quality monitor, is also presented in the measurement tables for indicative comparison only; however, SCL did not verify the calibration or sensor-module status of that device. Prioritized corrective actions for reopening after six months of closure are also provided.

2. SITE INSPECTION FINDINGS

2.1 CAVE MICROCLIMATE

2.1.1 Measurements

Temperature, relative humidity, and carbon dioxide (CO_2) measurements conducted by SCL on 13 June, 27 July, and 17 August 2025 were collected using the Fluke 975 AirMeter™[2], a handheld multi-parameter indoor air quality instrument capable of simultaneously logging and displaying T, RH, and CO_2.

Additional measurements were collected by Dar Al-Handasah on 22 November 2025 using a separate Kaiterra Sensedge indoor air quality monitor; however, SCL did not verify the calibration, field-check, or sensor-module status of that device. The Kaiterra Sensedge is an indoor air-quality monitor and it is not considered a cave-grade monitoring instrument unless its calibration/sensor-module status is documented and the unit is protected against high humidity, condensation, dripping water, and dust through an appropriate ventilated enclosure. The 22 November 2025 readings collected using this device should therefore be treated as indicative and verified through the permanent calibrated monitoring system specified in Section 3.2.

Measurements are provided in Table 2-1 to Table 2-6 below with the locations of stations inside the cave shown in Figure 2-1 and Figure 2-2. The 22 November 2025 values are shown for

[2] Fluke 975 AirMeter™:

- Specifications: Temperature range -20 °C to 50 °C (accuracy ±0.5 °C within 5 °C to 40 °C); relative humidity range 10–90% RH (accuracy ±2% RH); CO_2 range 0–5000 ppm (accuracy ±2.75% of reading + 75 ppm).
- Calibration: Valid until 23 Sep 2025.
- This instrument was used for the SCL measurements collected on 13 June, 27 July, and 17 August 2025.

indicative comparison only because they were collected using a separate non-SCL device whose calibration and sensor-module status were not verified by SCL.

Table 2-1. Lower Gallery | Underground River Temperature (°C) Measurements

Station	Distance from Entrance	Distance from Entrance (m)	13 Jun 2025	27 Jul 2025	17 Aug 2025 Morning	22 Nov 2025 Morning[3]
1	Right outside lower gallery entrance	0	26.1	27		22.1
2	Docks of the small tourist boats	65	18.3	19.5	23.2	18.8
3	Pisa Tower location (~100 m from the dock)	270	18			
4	Pillar of "Sète" (downstream of Maxwell Pillar)	350	17.3			17.8
5	Maxwell Pillar	430	18.3			
6	Opening leading to the upper gallery	500	17.5			

Table 2-2. Lower Gallery | Underground River Relative Humidity (%) Measurements

Station	Distance from Entrance	Distance from Entrance (m)	13 Jun 2025	27 Jul 2025	17 Aug 2025 Morning	22 Nov 2025 Morning[3]
1	Right outside lower gallery entrance	0	71	78		46
2	Docks of the small tourist boats	65	84	79.8	67	72
3	Pisa Tower location (~100m from the dock)	270	83			
4	Pillar of "Sète" (downstream of Maxwell Pillar)	350	88.4			77
5	Maxwell Pillar	430	83.1			
6	Opening leading to the upper gallery	500	87.1			

[3] The 22 November 2025 measurements were collected by Dar Al-Handasah using a separate Kaiterra Sensedge indoor air quality monitor, as indicated by the field photograph. SCL did not verify the calibration, field-check, or sensor-module status of this device. These values are therefore indicative and should be interpreted cautiously until verified by the permanent calibrated monitoring system specified in Section 3.2.

Table 2-3. Lower Gallery | Underground River CO_2 (ppm) Measurements

Station	Distance from Entrance	Distance from Entrance (m)	13 Jun 2025	27 Jul 2025	17 Aug 2025 Morning	22 Nov 2025 Morning[3]
1	Right outside lower gallery entrance	0	490	1,120		461
2	Docks of the small tourist boats	65	1,940	2,038	1,900	6,473
3	Pisa Tower location (~100m from the dock)	270	2,435			
4	Pillar of "Sète" (downstream of Maxwell Pillar)	350	2,625			6,703
5	Maxwell Pillar	430	2,580			
6	Opening leading to the upper gallery	500	2,661			

Table 2-4. Upper Gallery Temperature (°C) Measurements (Station 3 did not include measurements)

Station	Location Description	Distance from Entrance (m)	13 Jun 2025	27 Jul 2025	17 Aug 2025 Morning	17 Aug 2025 Evening	22 Nov 2025 Morning[3]
1	Right outside the tunnel	0	26.2	27.0	29.0	30.7	23.3
2	Inside, end of tunnel at cave start	125	21.3	20.8	22.9	23.0	21.5
4	Stalagmite on display (paleoclimate study)	200	20.3	20.5	21.3	21.7	20.3
5a	Artificial passage (first point)	275	19.9		20.9	21.0	19.9
5b	Artificial passage (second point)	291	19.8	20.4			
6	Start of Bridge	328	19.6	20.6	20.3	20.8	19.3

Station	Location Description	Distance from Entrance (m)	13 Jun 2025	27 Jul 2025	17 Aug 2025 Morning	17 Aug 2025 Evening	22 Nov 2025 Morning[3]
7	Bottom of Long Stairway	410	19.5	20.9	20.9	20.9	19.1
8	Top of Long Stairway	460	19.5	21.6	20.1	20.4	18.8
9	End of tourist-accessible part and walkway, farther inside	510	19.5	22.9	20.0	20.4	
10	Top of last stairway (Amphitheater)	565	19.5		19.9	19.9	18.3

Table 2-5. Upper Gallery Relative Humidity (%) Measurements (Station 3 did not include measurements)

Station	Location Description	Distance from Entrance (m)	13 Jun 2025	27 Jul 2025	17 Aug 2025 Morning	17 Aug 2025 Evening	22 Nov 2025 Morning[3]
1	Right outside the tunnel	0	73.0	77.0	50.0	60.8	37
2	Inside, end of tunnel at cave start	125	85.2	91.6	80.0	81.9	75
4	Stalagmite on display (paleoclimate study)	200	88.9	90.4	85.8	85.8	80
5a	Artificial passage (first point)	275	90.6		86.7	88.1	81
5b	Artificial passage (second point)	291	90.9	91.0			
6	Start of Bridge	328	91.3	88.5	88.6	87.9	83

Station	Location Description	Distance from Entrance (m)	13 Jun 2025	27 Jul 2025	17 Aug 2025 Morning	17 Aug 2025 Evening	22 Nov 2025 Morning[3]
7	Bottom of Long Stairway	410	91.7	87.5	87.5	90.2	84
8	Top of Long Stairway	460	93.1	84.8	89.9	90.5	87
9	End of tourist-accessible part and walkway, farther inside	510	93.2	80.0	91.6	90.6	
10	Top of last stairway (Amphitheater)	565	93.3		91.8	92.2	90

Table 2-6. Upper Gallery CO_2 (ppm) Measurements (Station 3 did not include measurements)

Station	Location Description	Distance from Entrance (m)	13 Jun 2025	27 Jul 2025	17 Aug 2025 Morning	17 Aug 2025 Evening	22 Nov 2025 Morning[3]
1	Right outside the tunnel	0	880	1,250	490	675	431
2	Inside, end of tunnel at cave start	125	1,801	3,510	3,155	3,233	3,600
4	Stalagmite on display (paleoclimate study)	200	2,304	3,560	3,860	3,515	3,810
5a	Artificial passage (first point)	275	2,444		3,879	3,560	3,711
5b	Artificial passage (second point)	291	2,534	3,650			

Station	Location Description	Distance from Entrance (m)	13 Jun 2025	27 Jul 2025	17 Aug 2025 Morning	17 Aug 2025 Evening	22 Nov 2025 Morning[3]
6	Start of Bridge	328	2,579	3,634	3,933	3,690	4,095
7	Bottom of Long Stairway	410	2,641	3,625	3,625	4,108	4,150
8	Top of Long Stairway	460	2,669	3,480	4,133	4,247	4,072
9	End of tourist-accessible part and walkway, farther inside	510	2,596	3,420	4,407	4,311	
10	Top of last stairway (Amphitheater)	565	3,101		4,641	4,596	5,530

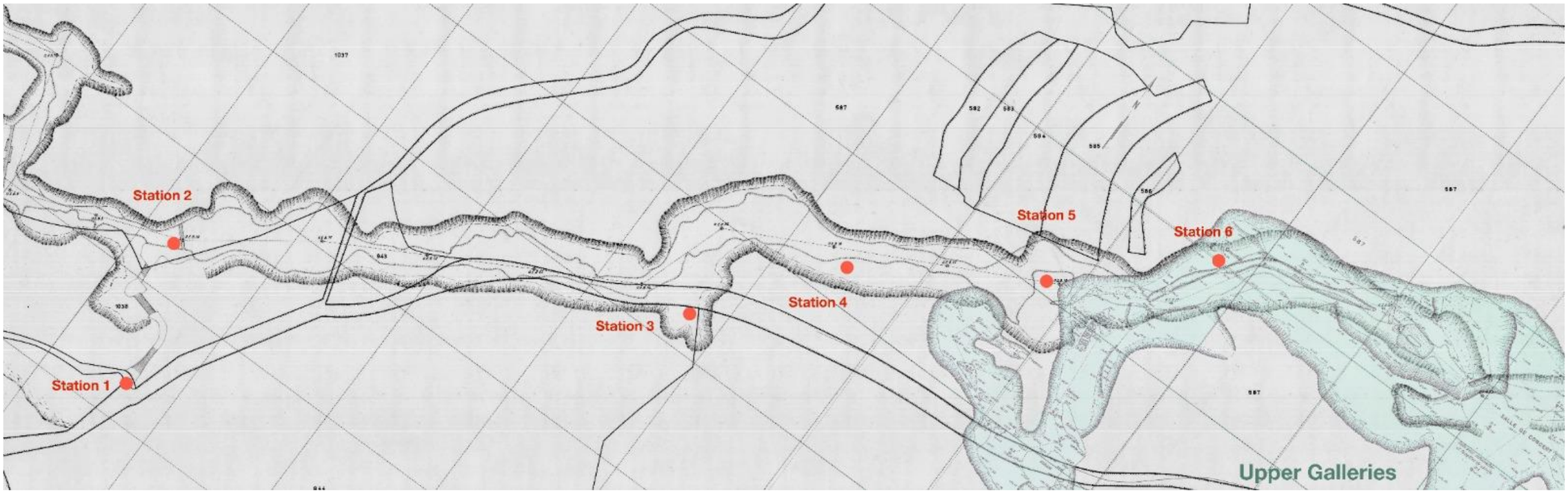


Figure 2-1. Microclimate Measurement Stations inside Lower Gallery (Scale: 50 m Grid Spacing)

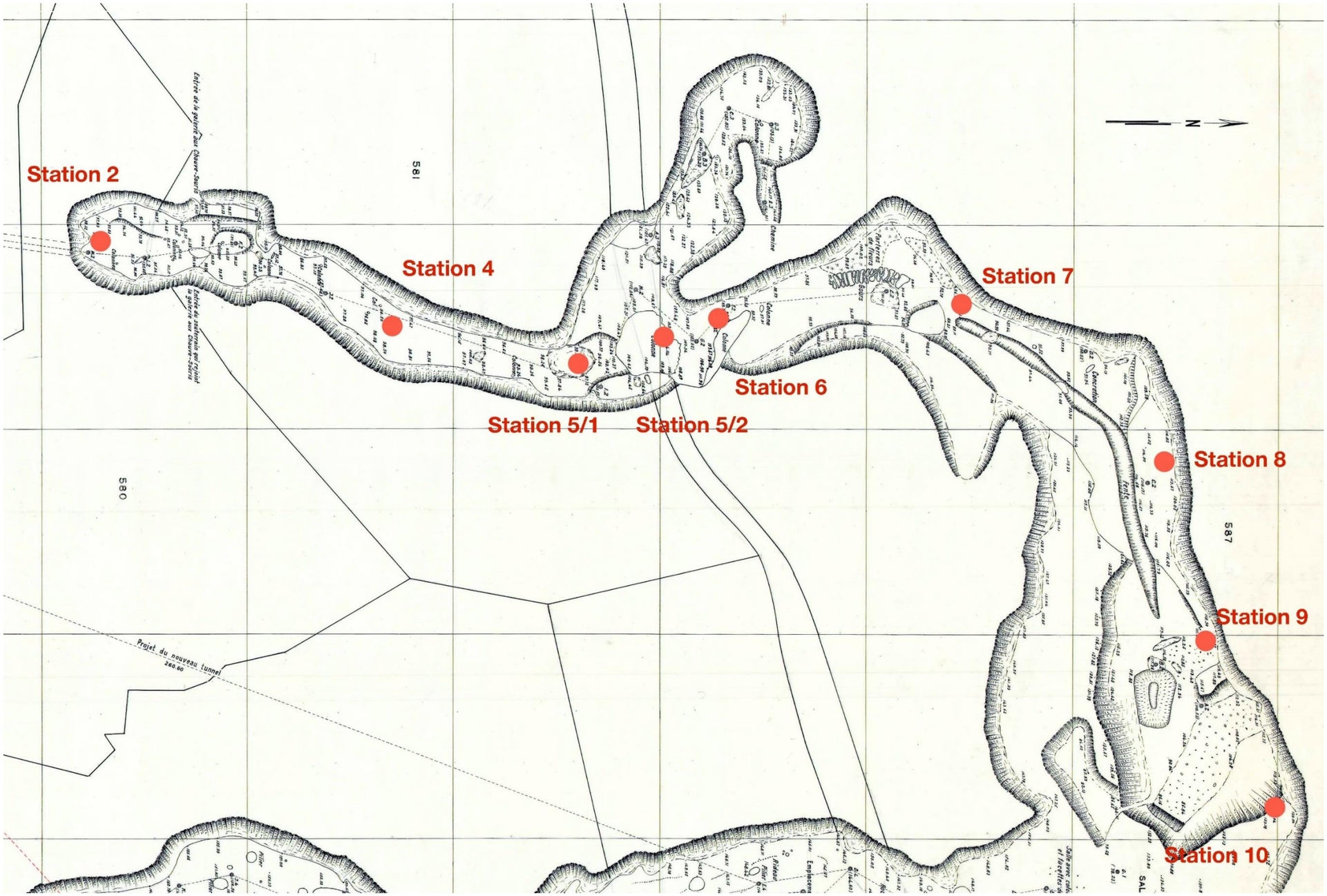


Figure 2-2. Microclimate Measurement Stations inside Upper Gallery (Scale: 50 m Grid Spacing)

2.1.2 Interpretation of Measurements

During the visits, which took place in summer, temperature values were observed to generally decrease with increasing distance from the entrance before stabilizing deeper inside the cave. Conversely, relative humidity and CO_2 values were observed to generally increase with increasing distance from the entrance before stabilizing deeper inside the cave.

In the Lower Gallery (see Figure 2-3), temperature decreased from 18.3 °C at the dock area (Station 2) to 17.5 °C at Station 6 during the first visit. Conversely, relative humidity increased from 84% to 87.1% and CO_2 from 1,940 ppm to 2,661 ppm between the 2 stations. Some level of stabilization is suggested from the measurements starting Station 4 and beyond, except for Station 5, where measurement levels are the reverse of what is expected; the explanation requires additional measurements but it may be due to localized air circulation. Further observations and measurements during cave operations indicated a rise in temperature, a decrease in humidity, and minimal change in CO_2 levels between June and August. The 22 November 2025 measurements indicate potentially very high CO_2 conditions in parts of the Lower Gallery; however, these values were collected using a separate non-SCL device whose calibration and sensor-module status were not verified by SCL. More continuous measurements are therefore needed to confirm the magnitude of these values and establish reliable trends.

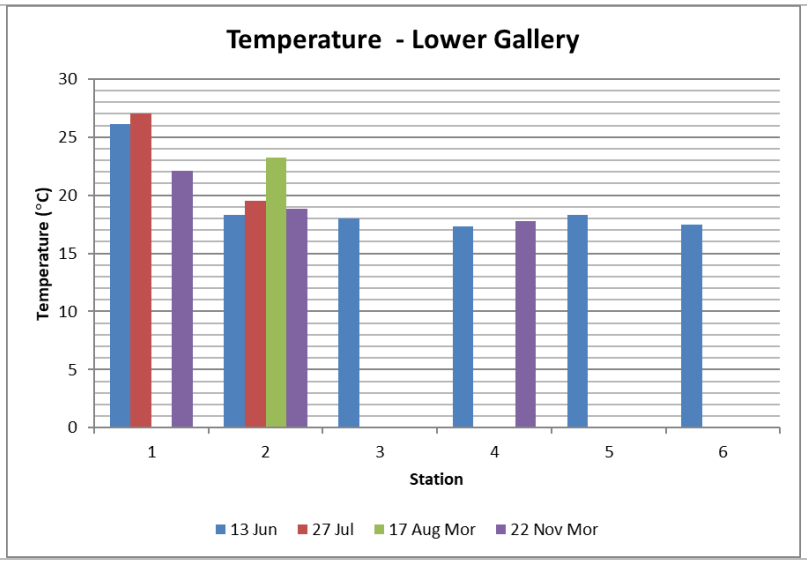
In the Upper Gallery (see Figure 2-4), temperature decreased from 21.3 °C at the end of the artificial tunnel inside the cave to 19.5 °C at Station 10 during the first visit. Conversely, relative humidity increased from 85.2% to 93.3% and CO_2 from 1,801 ppm to 3,101 ppm between the 2 stations. Some level of stabilization is suggested from Station 6 onward, except for CO_2 at Station 10, where values increase more markedly. More measurements deeper in this gallery are needed to understand whether CO_2 levels become higher farther inside where air circulation and communication with the outside are naturally lower. Subsequent visits and measurements during operation of the cave showed an increase in temperature, a drop in humidity, and an important increase in CO_2 values attributed to visitors inside the cave. The 22 November 2025 values suggest further elevated CO_2 conditions in the Upper Gallery, but these results should be treated as indicative because they were collected using a separate non-SCL device whose calibration and sensor-module status were not verified by SCL.

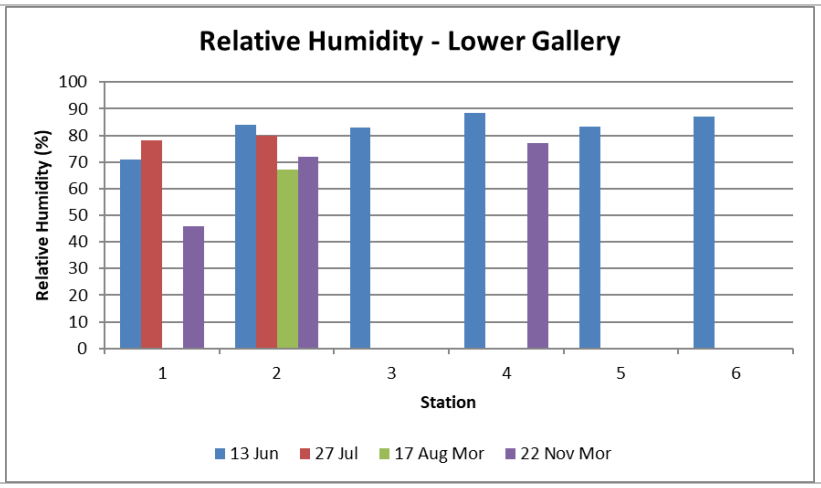
Variation with distance from the entrance can be explained by the influence of outside air closer to the entrance. It is worth noting that measurements were conducted when the doors to both galleries were closed with reduced interference from outside air; however, such interference can be amplified when the doors of both galleries are open. This was reported by the operation and maintenance staff to have been intentionally performed whenever there was a large number of visitors. By opening the doors of both galleries during summer when both galleries are accessible[4], a flow of warmer air from the outside into the upper gallery

[4] The Lower Gallery is not typically accessible during winter and spring seasons.

and down toward the cooler lower gallery and out would be induced, thereby improving the quality of air inside the cave and preventing CO_2 build-up. It cannot be confirmed at this stage if this air flow changes directions with outdoor changes in weather conditions. The show cave operator was aware that opening all doors would reduce humidity leading to dryer conditions that would adversely affect the integrity of speleothems (concretions); accordingly, this was performed during daytime only in the high summer season.

CO_2 measurements conducted during operation of the cave on the same day in August did not reveal a notable increase in values at the end of the day relative to the morning; in fact, values actually dropped in the afternoon until station 6. More monitoring is obviously needed to assess with more confidence the reasons behind such unexpected results; however, fluctuations in visitor numbers inside the upper gallery may have a significant effect on CO2 levels during shorter timeframes. This supports capping visitor numbers inside the cave at any one time, although visitor caps alone may not prevent elevated CO_2 conditions without additional operational controls such as staged entry throttling and short, controlled pulse ventilation, as discussed in Section 3.6.





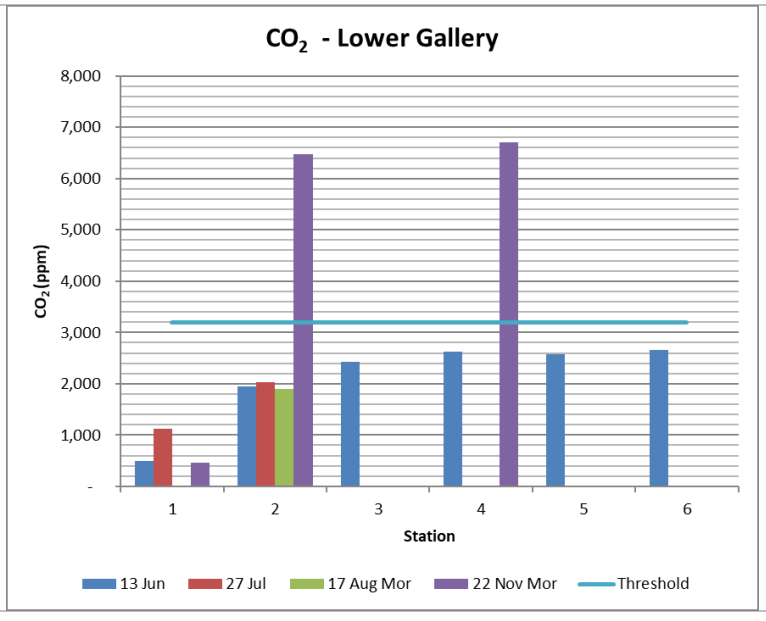
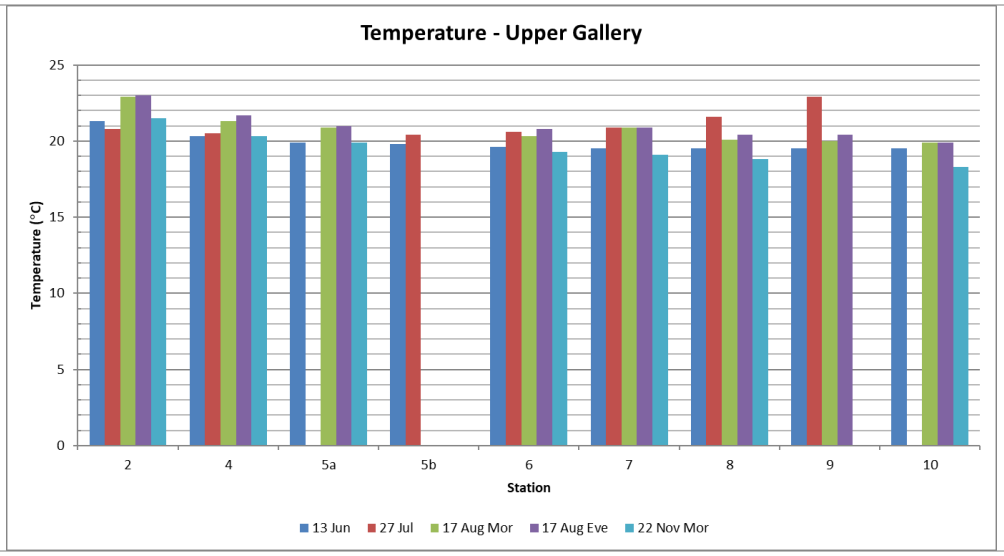
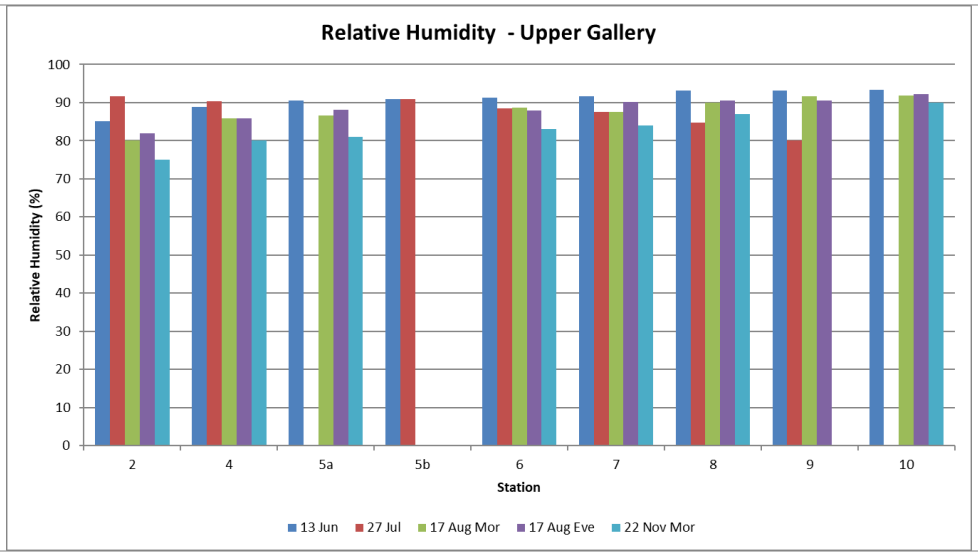


Figure 2-3. Climate Measurements in Lower Wet Gallery





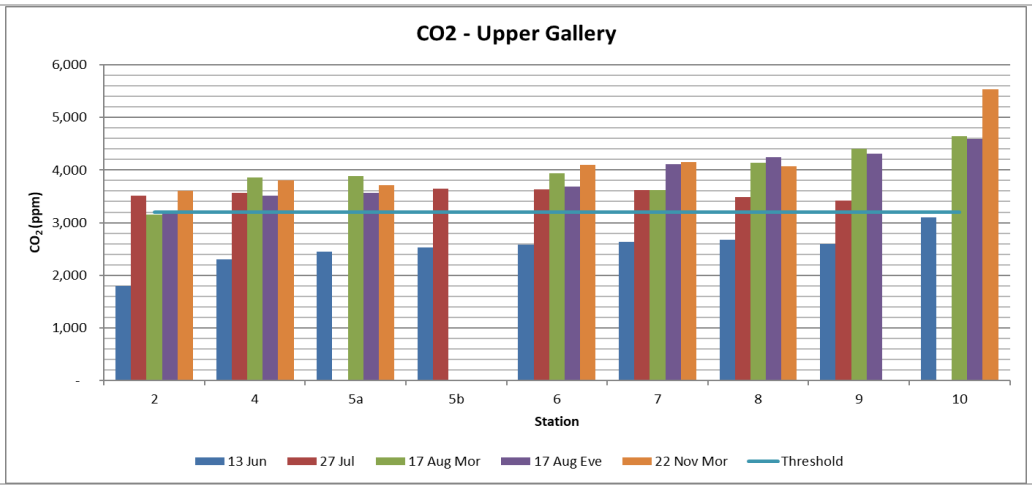


Figure 2-4. Climate Measurements in Upper Gallery[5]

[5] Station 1, located outside the cave, was excluded from the upper gallery measurements to avoid skewing the values and making the chart difficult to read.

2.2 SPELEOTHEM CONDITIONS

While the cave still comprises considerable beauty and "healthy" concretions also referred to as speleothems, the following observations focus on degradation observed in the cave for the purpose of future conservation:

- Dust accumulation near the Upper Gallery entrance due to wind draft (Figure 2-5)
- Black microbial staining due to hand-contact, lampenflora and/or dust-laden cleaning runoff (Figure 2-6)
- Decalcification of speleothems due to microclimate changes (Figure 2-7)
- Bleaching of speleothems due to lampenflora cleaning (Figure 2-7)
- Lampenflora near light fixtures (Figure 2-8)
- Abrasion, staining, and scratching of speleothems within hand reach along the visitor walkway in the Upper Gallery (Figure 2-9)
- Rimstone pools littered with coins tossed by visitors
- Corrosion of light fixtures (Figure 2-11)
- Stalagmite apex dissolution suggesting potential anthropogenic changes in microclimatic conditions and/or changes in water chemistry (more acidic and undersaturation of calcium carbonate) (Figure 2-12)



Figure 2-5. Dust Accumulation on Concretions



Figure 2-6. Black Staining of Speleothems Likely Due to Cleaning Runoff



Figure 2-7. Decalcification of Speleothems and Bleaching due to Lampenflora Cleaning



Figure 2-8. Lampenflora Growth on Speleothems



Figure 2-9. Abrasion, Staining, and Scratching of Speleothems within Hand Reach along the Visitor Walkway

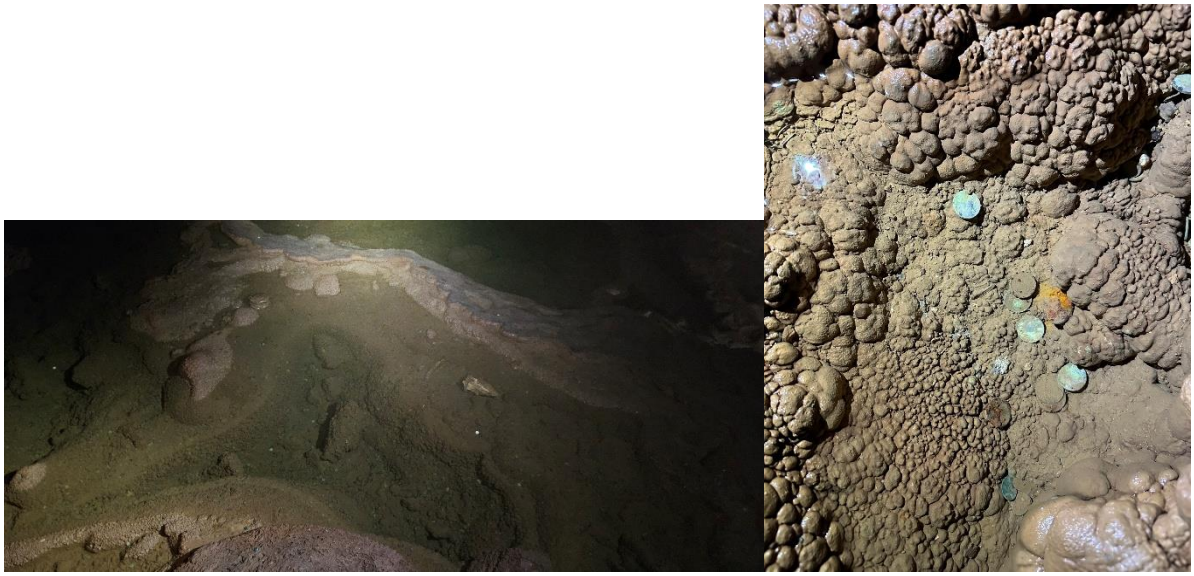


Figure 2-10. Rimstone Pool with Coins Tossed by Visitors



Figure 2-11. Corroded Light Fixtures



Figure 2-12. Pitted Stalagmite Tips Suggesting Apex Dissolution due to Changes in Drip-Water Chemistry

2.3 INFRASTRUCTURE CONDITIONS AND SYSTEMS

2.3.1 Concrete Structures

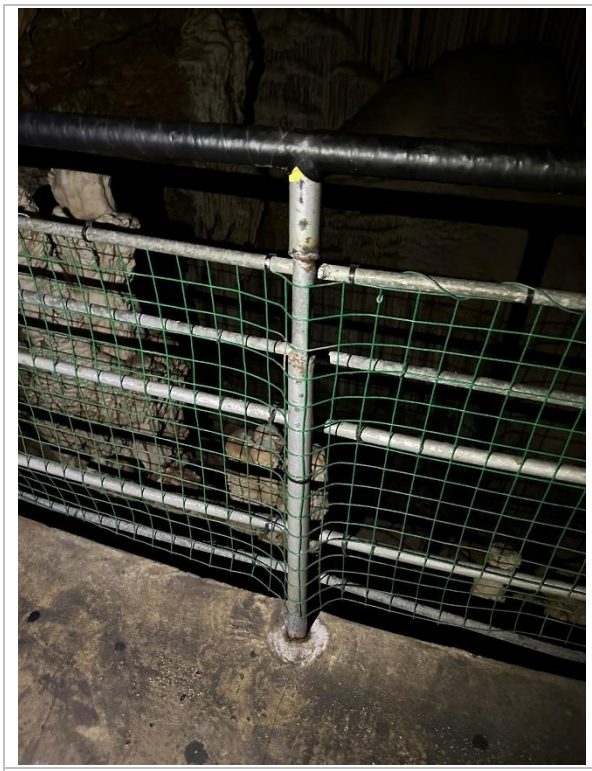
No priority damage to concrete structures inside the cave was observed during the visit; concrete structures seem to be in acceptable condition as shown in Figure 2-13 (the bridge). Some rebars are shown in rusty condition that needs brush cleaning and anti-corrosion paint. In general concrete needs anti-carbonation coatings to protect concrete structures from the harmful effects of carbonation and leading to corrosion of the reinforcing steel. Anti-carbonation coatings act as a barrier, preventing the ingress of carbon dioxide, water, and chlorides, thereby extending the lifespan of the concrete.

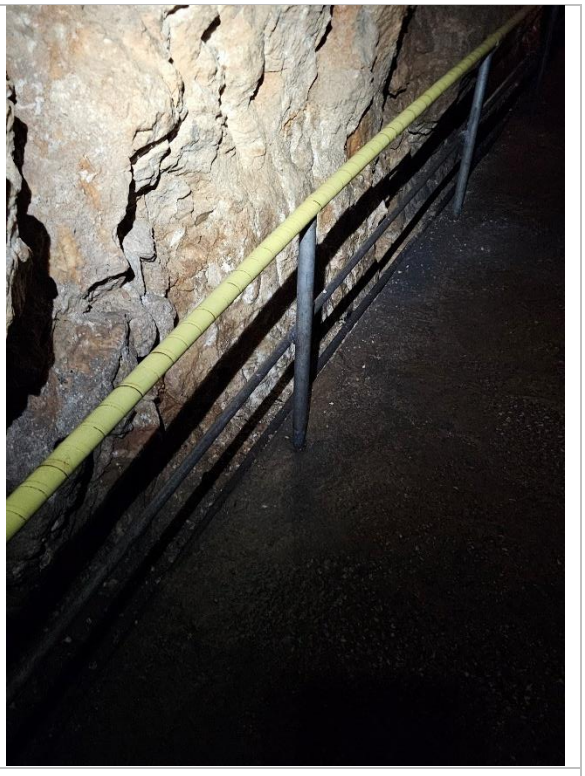


Figure 2-13. Condition of Concrete Structures

2.3.2 *Metal Structures*

Metal structures such as handrails are significantly more corroded in the Lower Gallery; this can be explained by potentially lesser maintenance and by submergence of the dock and stairway during end of winter-spring time in most years. Handrails must be changed to stainless steel grade 316, welded outside the cave and assembled inside.







Steel Base of Handrails

Figure 2-14. Condition of Metal Structures Including Handrails

2.3.3 Electrical System

The following key deficiencies were observed with regard to electrical system:

- Corroded or exposed wiring
- Non-waterproof junction boxes
- Non-compliant and obsolete light fixtures
- Non-operational UPS system (dead batteries)

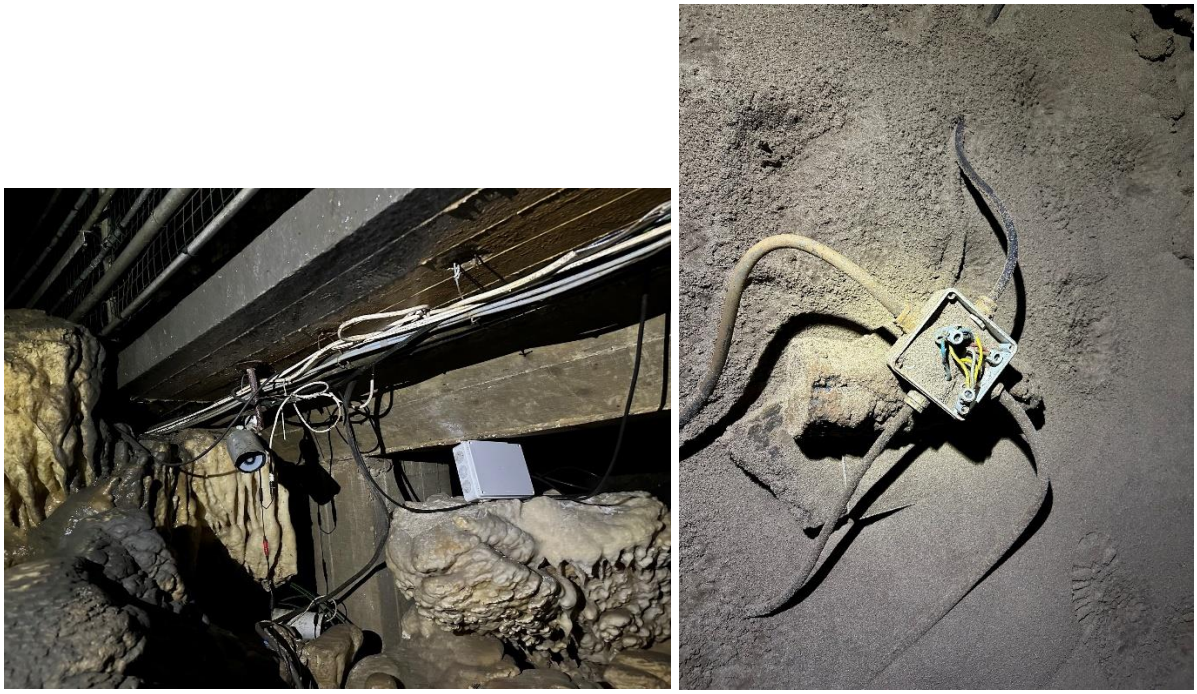


Figure 2-15. Exposed Cabling



Figure 2-16. Non-Waterproof Junction Boxes



Figure 2-17. Obsolete Light Fixtures

2.3.4 Lighting

According to the accompanying operation and maintenance staff, Most High Intensity Discharge **(HID)** Lights have been replaced. More than 60% of light fixtures today consists of LED lamps while the remaining consist of HID. HID Lights have currently become obsolete in show caves from a conservation perspective due to the excessive heat they generate that enhances bio growth.

Based on observations and reported information current lighting consists of the following:

- Upper Gallery:
    - 185 lighting points

- Majority are LED
- Some HID fixtures (~150 W each)

- Lower Gallery:
  - 110 lighting points:
  - 35 underwater
    - 10 HID fixtures (up to 400 W)
    - 25 LED fixtures (50-150 W)
  - 75 above water (mostly LED plus few HID)

2.4 OPERATIONAL GAPS

Based on compiled information, a number of past operational gaps were identified as follows:

2.4.1 Tourist Access and Management

- There was no set limit on the number of tourists allowed inside the cave at one time.
- Visitors enter individually or in an unstructured flow, without being organized into guided groups.
- 7 to 9 watchmen are stationed throughout the cave to monitor visitor behavior, but there is no guide leading or managing groups during the visit.
- When visitor numbers are high, both the upper and lower gallery doors are left open to improve air circulation, which considerably changes microclimatic conditions inside the cave.
- Visitors currently enter the cave without any shoe disinfection measures, despite international show cave guidelines increasingly requiring footwear sanitization to prevent the introduction of contaminants, microbes, or invasive organisms that can damage cave ecosystems and speleothems.

2.4.2 Internal Communication Protocols

- Staff communicate with each other inside the cave using handheld radios.
- However, radio coverage is limited and does not reach either the first station near the entrance or the last station at the far end of the cave.
- 7 to 9 watchmen are assigned to different sections of the cave to observe visitor behavior and stay in contact with one another where radio signal is available.
- When communication with the outside is needed from deeper sections of the cave, messages must be relayed through staff positioned closer to the entrance.

2.4.3 Emergency Procedures and Equipment

- No emergency equipment is currently available inside the cave; first aid kits are stored outside in the main office, which could delay response in the event of a medical

emergency. It is not clear whether Automated External Defibrillators (AED) are available and staff were trained on their use.

- There is no evidence of regular emergency drills, and staff assigned first aid duties do not appear to receive refresher training or hold valid, up-to-date certifications.
- The cave lacks adequate emergency signage and lighting, including illuminated exit signs and directional indicators, which are essential for safe evacuation.
- It is unclear whether a formal Emergency Management Plan (EMP) exists or is actively followed, despite such a plan being a standard requirement in professionally managed show caves.
- Steel handrails are visibly corroded; although some have been wrapped with colored tape to protect visitors' hands, this solution is aesthetically intrusive and inadequate. These should be replaced with inert, corrosion-resistant sleeve grips that align with conservation standards.

2.4.4 Microclimate Stability and Air Quality Risks

- To improve air circulation during the high season, the doors of both the upper and lower galleries are typically kept open.
- This creates a passive airflow from the outside into the upper gallery and out through the lower gallery along the river.
- The cave relies on this non-mechanized ventilation to lower CO_2 levels during periods of high visitor traffic.
- While effective in reducing CO_2 concentrations, this practice is known to contribute to speleothem degradation, particularly near the entrances.
- Despite the importance of maintaining environmental stability and visitor safety, there is no continuous monitoring system in place to track key microclimatic parameters such as temperature, relative humidity, and CO_2 levels. This poses a significant limitation both for long-term conservation and for managing emergency risks related to elevated CO_2 concentrations.
- In addition, no radon monitoring program appears to be in place, despite the well-documented potential for radon accumulation in karst systems and the occupational exposure risk it poses to cave staff.

2.4.5 Waste Management and Visitor Conduct

- Waste bins are currently placed along the concrete passageway in the Upper Gallery, which is highly discouraged in cave environments. Their presence can unintentionally encourage visitors to bring food or wrappers into the cave, increasing the risk of ecological disturbance from organic and putrescible waste.
- If water bottles are permitted, this should be clearly indicated through both signage and bin design. In such cases, waste bins should be limited to transparent, mesh-style containers that visibly restrict disposal to bottles only, preventing misuse for general waste.
- Signage within the cave is also inadequate, with little to no guidance on proper visitor behavior or emergency exit routes.

- Despite instructions prohibiting food, staff report that some visitors still bring food into the cave and dispose of it improperly, contributing to littering and potential harm to the cave environment.

2.4.6 Cave Concretion Fragments in Souvenir Shop

- Several small pieces of broken speleothems were observed on display in the souvenir shop outside the cave entrance (Figure 2-18). This practice sends a misleading message that removing formations from inside the cave is acceptable and could encourage vandalism.



Figure 2-18. Broken Speleothem Pieces in Souvenir Shop (center of photo)

2.4.7 Speleothem Cleaning

- At Station 3 in the Upper Gallery where rimstone pools are located, visitors often throw coins into shallow pools of water beneath the concrete passageway. These pools are periodically emptied, and the coins are removed by Jiita Cave operations staff, after which the pools may be refilled with water sourced from the lower gallery.
- Water is also used more broadly for the general cleaning of speleothems throughout the cave.
- In addition, hydrogen peroxide is reportedly applied to remove green biofilms from affected concretions, although the extent and frequency of this practice are not clearly documented.
- Manual cleaning and brushing of speleothems has led to visible surface bleaching, while runoff from cleaning may be responsible for black staining observed on adjacent formations. (refer to Section 2.2).

3. RECOMMENDED CORRECTIVE ACTIONS

3.1 CORRECTIVE ACTIONS FOR RE-OPENING OF JIITA SHOWCAVE

Corrective actions for the reopening of Jiita Cave are provided in Table 3-1, with further details on Radon and microclimate monitoring in Section 3.2, on electrical, lighting, and audio systems in Section 3.3, on walkway cleaning and shoe disinfection in Section 3.4, and on Recommended Visitor Management and CO_2 Control in Section 3.6.

Table 3-1. Corrective Actions for Reopening of Jiita Show Cave

Deliverable	Deadline (from Contract Start)	Core Requirements
Comprehensive Emergency Management Plan	Draft ≤ 3 mo, approve ≤ 6 mo	- Fire, flood, earthquake, CO_2, radon, medical. - Annual drills (align with ISCA).
Micro-climate & Radon Monitoring System	Commission ≤ 6 mo	- Equip 5 Lower Gallery monitoring stations (Stations 1 to 5) for temperature and relative humidity, of which 4 stations shall also include CO_2 monitoring (Stations 1, 2, 3 and 5), and 10 Upper Gallery monitoring stations (Stations 1 to 10) for temperature and relative humidity, of which 5 stations shall also include CO_2 monitoring (Stations 1, 2, 5, 8 and 10), plus 2 continuous radon loggers per gallery (deep "hot-spot" + entrance zone), as detailed in Section 3.2 and shown in Figure 3-1 and Figure 3-2. - Sensors log CO_2, T, RH, Rn every 1 min; accuracy and ingress-protection per Table 3-2 specs. - Networked via shielded Cat-6 PoE cabling in the new conduit or a LoRa mesh with gateway at the tunnel mouth; each node buffers ≥ 30 days of data. - Push data to a secure cloud at ≤5-minute intervals and provide a web dashboard and SMS/e-mail alarms using a staged CO_2 response framework: 2,800 ppm as a conservation watch/trend level, 3,200 ppm as the Amber throttling level, and 3,600 ppm as the provisional permitted ceiling / Red action level.
Engineered double-door airlocks	Install ≤ 9 mo	- Upper tunnel & lower river exit (if feasible for lower river exit). - Gasketed, inter-locked.
Electrical modernization	Complete ≤ 12 mo	See Section 3.3.

Deliverable	Deadline (from Contract Start)	Core Requirements
Lighting retrofit - Lower Gallery (river section)	Install ≤ 9 mo	See Section 3.3.
Full LED relighting (entire cave)	Complete ≤ 12 mo	See Section 3.3.
Handrail replacement	Design ≤ 3 mo, install ≤ 9 mo	316 L stainless or marine-grade anodized aluminum (or epoxy-coated if approved by competent authorities).
Walkway-Cleaning System (see Section 3.4.1)	Procure & commission ≤ 6 mo	- Wet-vacuum cleaner (e.g., disc scrubber 60 L tank, ≥ 2 000 $m^2 h^{-1}$) for debris removal without wastewater discharge. - Cleaning agents must be non-toxic and cave-safe.
Shoe-Disinfection Mats (See Section 3.4.2)	Install & operate ≤ 3 mo	- Absorbent mats at cave entrance soaked in 1 % Virkon S (or equivalent) solution. - Disinfectant replenished or replaced as needed to maintain effectiveness without excess liquid or runoff. - Signage and staff supervision.
Speleothem conservation plan	Plan ≤ 6 mo, first survey ≤ 12 mo	- Dry-ice / CO_2 snow cleaning by qualified specialists or trained staff only under a specialist-approved method statement. - Pilot testing on limited representative areas before wider cleaning. - Fixed-point photography, condition mapping, and annual specialist survey. - Hydrogen peroxide, chemical, abrasive, brushing, or uncontrolled washing methods prohibited unless specifically approved by the conservation specialist.
Visitor-flow system	Operational ≤ 6 mo	Guided groups ≤25; dynamic capacity tied to continuous CO_2 monitoring, with visitor throttling at 3,200 ppm and a provisional permitted ceiling of 3,600 ppm, subject to adaptive reduction if cave-health monitoring indicates deterioration.
On-site first-aid clinic	Ready ≤ 3 mo	Treatment room, AED, O_2, trauma supplies; attendant on duty.
Accessibility & safety upgrades	Complete ≤ 9 mo	Non-slip paths, tactile edging, CCTV, wheelchair access.
Annual sustainability report	First ≤ 15 mo	Energy, water, visitor load, conservation metrics.

3.2 MICRO-CLIMATE & RADON MONITORING SPECIFICATIONS

Jiita Show-Cave shall continuously measure carbon-dioxide (CO_2), temperature (T), relative humidity (RH) and radon-222 (Rn) at the fixed monitoring layout shown in Figure 3-1 and Figure 3-2. Temperature and RH shall be monitored at all microclimate stations, while CO_2 sensors shall be installed only at the specified CO_2 monitoring stations. Recommended equipment performance requirements are provided in Table 3-2.

- Lower Gallery: 5 stations for T and RH (Stations 1 to 5), of which 4 stations shall also include CO_2 monitoring (Stations 1, 2, 3 and 5).
- Upper Gallery: 10 stations for T and RH (Stations 1 to 10), of which 5 stations shall also include CO_2 monitoring (Stations 1, 2, 5, 8 and 10).
- Radon (continuous): Two electronic loggers per gallery
  - Primary at the highest-radon location found by a 1-week walk-through survey.
  - Secondary near each gallery entrance to verify spatial variability as follows:
    - Mount the logger 5-10 m past the door so it is out of direct wind but still in the low-radon zone.
    - Install at 1.5 m above floor level approximately, on a wall bracket, away from water drips.

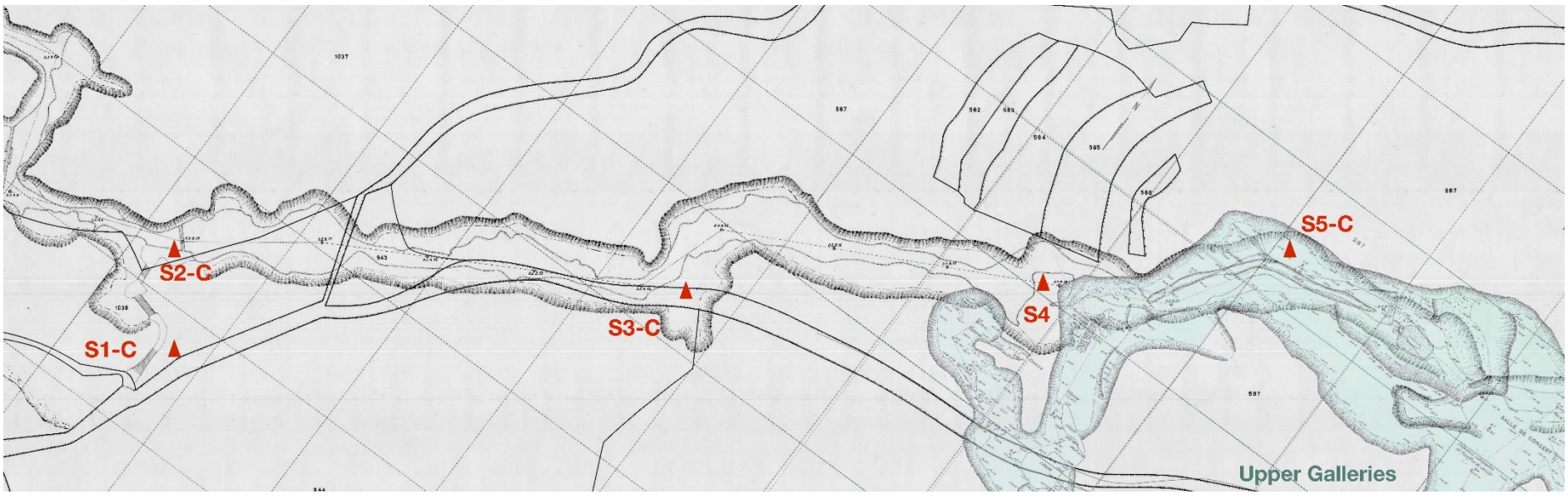


Figure 3-1. Monitoring Stations in Lower Gallery ("-C" indicates CO_2 monitoring)

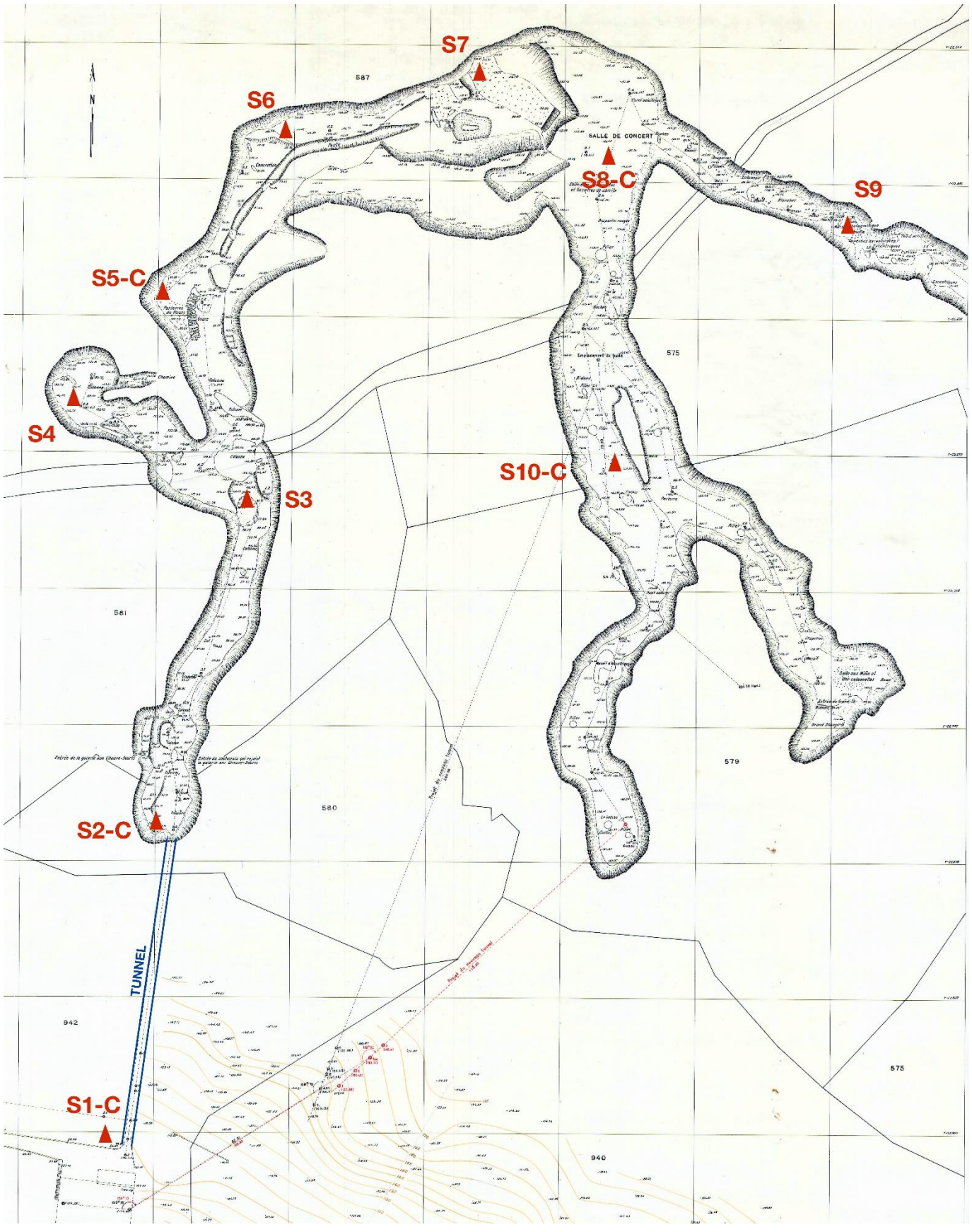


Figure 3-2. Monitoring Stations in Upper Gallery ("-C" indicates CO_2 monitoring)

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Table 3-2. Monitoring Equipment Performance Requirements

Parameter	Minimum Specification	Notes / Examples*
CO_2	- NDIR, 0-10,000 ppm - accuracy ±(3% reading + 50 ppm) preferred; ±(5% reading + 100 ppm) maximum acceptable - $t_{63} \leq 120$ s - Auto RH/pressure comp	Probe in IP-65 polycarbonate "cave-case" with Gore-Tex® vent. DOL 139 CO_2, IP67, iDOL139
Temperature	- -10 °C to +50 °C - Accuracy ±0.25 °C	Digital sensor; conformal-coated PCB. HOBO MX2301A Data Logger, temperature & RH , IP67
Relative Humidity	- 0-100 % RH suitable for condensing or near-condensing cave conditions - Accuracy ±3 % RH at 40-95% RH, or manufacturer-declared accuracy at >95% RH to be stated in the tender submission	HOBO MX2301A Data Logger, temperature & RH , IP67
Radon-222	- Pulsed-ion or alpha-spectroscopy logger - 30-45,000 Bq·m^{-3} - Sensitivity ≤ 0.4 cph per Bq·m^{-3}	Units equivalent to RAD7 / AlphaGUARD class*
Ingress Protection	IP-65 (IP-67 preferred)	
Power	Lithium battery ≥ 15 Ah for ≥ 12 mo @ 1-min logging or 12 V DC PoE feed with DC-UPS	Field-swappable batteries.
Data Logging	- 1-min samples - ≥ 63,488 records	Time-stamped CSV.
Communication	• Option 1: Integrated PoE-capable RJ45 Ethernet port (IEEE 802.3af) to support shielded Cat-6 cabling up to 100 m and 10/100 Mbps link for cloud push. • Option 2: Low-power LoRa mesh repeaters with one repeater every 80–100 m and an IP-65 gateway at tunnel mouth. Each node must carry an SD-card buffer that stores at least 30 days of 1-min readings in case of RF outage. • Local USB-C/BLE service port for maintenance.	Each node must buffer ≥ 30 days of 1-min data in non-volatile memory.

Calibration	- CO_2 span check yearly (certified 1,000 ppm gas) - RH/T salt-kit yearly - Radon lab re-calibration every 24 months	Certificates kept on-file.

*Brands are examples only; any equipment meeting these numeric specs is acceptable.

Alarm & Response Logic

CO_2 alarms and operational responses shall be based on a 5-minute rolling average from the relevant control sensor(s), except where an obviously abnormal or rapidly rising value requires immediate operational verification. Sensor faults, communication loss, or implausible readings shall trigger manual verification before resuming normal operation.

- **CO_2 Watch / Conservation Trend Level: 2,800 ppm**
  - This level is used as an early conservation and trend-review level. Guides and operations staff shall monitor visitor density, group spacing, and CO_2 trends, but automatic suspension of entry is not required solely at this level.
- **CO_2 Amber / Throttling Level: 3,200 ppm**
  - Ticketing, group release, or boat dispatch shall be automatically slowed or paused.
  - Guides shall reduce crowding and prevent accumulation at stopping points, stairs, docks, and narrow sections.
  - If CO_2 continues rising, the relevant gallery shall prepare for pulse ventilation.
- **CO_2 Red / Provisional Permitted Ceiling: 3,600 ppm**
  - New entries, group releases, or boat departures into the affected gallery shall be halted.
  - Short pulse ventilation shall be initiated in accordance with Section 3.6.
  - Operations may resume only after CO_2 falls to ≤3,200 ppm and remains stable for at least 10 minutes.
- **CO_2 Critical Escalation: ≥4,000 ppm or repeated exceedance of 3,600 ppm**
  - The operating capacity, group spacing, dispatch frequency, and pulse-ventilation protocol shall be reassessed.
  - Repeated exceedance shall trigger a reduction in visitor capacity and review of cave-health monitoring results.
- **Radon: Weekly average > 3,000 Bq·m^{-3}**
  - Rotate staff assignments to limit exposure and consult the occupational-health authority.
  - During the first year of operation, maintain staff occupancy logs and review them with measured radon concentrations to assess annual worker exposure in accordance with applicable national requirements and authority guidance.

3.3 TECHNICAL SPECIFICATIONS FOR ELECTRICAL SYSTEMS

3.3.1 General Technical Requirements

- All components must be compatible for use in **extreme humidity environments** (98% RH).
- Preference will be given to suppliers providing **complete product documentation**, including test certifications (IP rating, IK rating, CRI, lumen output, etc.).
- Preference will be given to suppliers with previous proven experience in cave installations.
- All hardware, fixtures, and accessories shall be corrosion-resistant and cave-safe.
- Installation must comply with **IEC, NEC**, or **local electrical standards**, with a special focus on low-voltage systems and environmental protection.
- Each luminaire in the system has its own built-in control unit.
- Show cave area is only fitted with ELV DC lighting system and isolated 220V General Purpose sockets.
- Lighting system should be controllable via central control unit (main controller). Control is by wire and radio.
- The lighting themes are defined and saved via the central control unit. Lighting themes are switched on via the remote control or manually via buttons on the viewing platforms.
- Lighting points' distribution and themes are coordinated with the Architect in charge.
- Emergency exit lighting along the walkway are of the maintained non-contained type fed by TWO redundant sources.
- Sound system is used interchangeably for Background music and Public Address.
- Sound system and Lighting system should be integrated.
- Wired intercom between fixed station inside the cave and management office.

3.3.2 Lighting Specifications

- **Type**: High lumen output LED lighting (CREE, CAVE LIGHTING or equivalent)
- **Voltage Rating**: 12 to 48 VDC
- **Driver**: Constant current drivers
- **Polarity Reversal protection**
- **Power Consumption**: Maximum 50 Watts per luminaire
- **Beam Angle**: Adjustable or selectable range between 10° and 120°
- **Color Rendering Index (CRI)**: ≥ 90%
- **Ingress Protection (IP):** IP67 for non-submersible fixtures, IP68 for submersible fixtures
- **Casing & Mounting Materials:** Non-corrosive body and housing made of: Stainless Steel Grade 316L, Coated Aluminum for heat control, High-impact Polycarbonate. Any combination or interlocking between two different metals (even for screws) should be insulated with non-ferric material.

- **Operating Temperature:** 5°C to 45°C
- **Relative Humidity:** Up to 98%
- **Cable:** Built-in cable minimum length: 3 meters, extended lengths must be available by manufacturer upon request
- **Lighting point distribution to be coordinated with Spéléo Club du Liban.**

3.3.3 Junction Boxes

- **Ingress Protection (IP):** IP66 minimum
- **Impact Resistance**: IK10
- **Material:** Stainless Steel 316L or UV-stabilized Polycarbonate
- **Cable Entry:** Glanded entries with IP-rated seals compatible with installed cables
- **Mounting:** Surface mount with Polycarbonate or stainless-steel brackets and anchors.
- **All junction boxes should be filled with sealant gel.**

3.3.4 Sound System

- **Speaker Type**: Weatherproof Barrel type or equivalent suitable for humid spaces (Brands: Cave Lighting, Mariner or equivalent)
- **Frequency range**: 100 Hz to 20 KHz
- **Audio Signal**: Compatible with the control system.
- **Casing & Mounting Materials**: Non-corrosive body and housing. Any combination or interlocking between two different metals (even for screws) should be insulated with non-ferric material.
- **Coverage**: Must ensure intelligible sound coverage throughout visitor-accessible areas
- **Power Supply**: Compatible with 24 VDC.
- **Ingress Protection (IP):** IP65 minimum

3.3.5 Control System

- **Casing & Mounting Materials**: Non-corrosive body and housing. Any combination or interlocking between two different metals (even for screws) should be insulated with non-ferric material.
- **Ingress Protection (IP):** IP65 minimum
- **Voltage Rating**: 12 to 48 VDC
- **Operating Temperature:** 5°C to 45°C
- **Relative Humidity:** Up to 98%

- **Communication Protocol:** communication protocol should be compatible with the different system components (DMX, RS232, RS485, CAN, Ethernet, RF for remote controls…)
- **Polarity reversal protection**

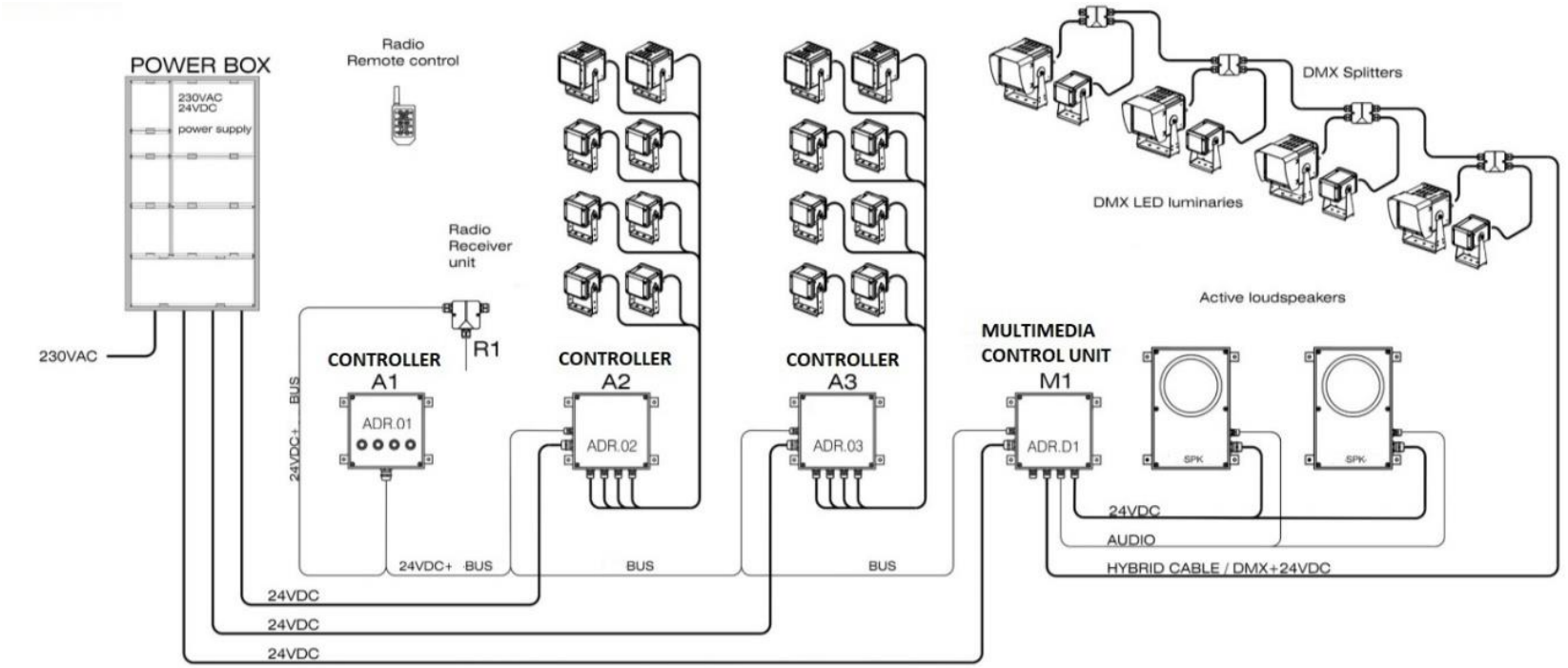


Figure 3-3. Example of Control System Setup Proposed for Jiita Show Cave (Cave Lighting CL GmbH & Co.KG.)

3.4 VISITOR WALKWAY CLEANING AND DISINFECTION MATS

3.4.1 Walkway Cleaning

Routine removal of litter, sediment, fibers, and bio-film from the concrete walkway is essential to protect adjacent speleothems and to minimize the introduction of pathogens (e.g., white-nose syndrome fungus) carried in by visitors (Figure 3-4). The recommended method is a wet-vacuum scrubber that washes and immediately extracts the rinse water, preventing contaminated run-off from reaching formations on either side of the walkway.

- Equipment – commercial disc-scrubber / wet-vac unit, ≈ 60 L recovery tank, ≥ 2 000 $m^2 h^{-1}$ capacity; for example, the Kärcher BD 50/60 C EP shown in Figure 3-5.
- Cleaning agents – only biodegradable, pH-neutral products certified for use in sensitive environments; chlorine or strong acids/alkalis are prohibited.
- Wastewater handling – all effluent is collected in the machine's tank and removed from the cave for off-site disposal; no discharge inside the cave is permitted.
- Frequency – minimum monthly during low-season; fortnightly during high-season or after heavy visitor days.

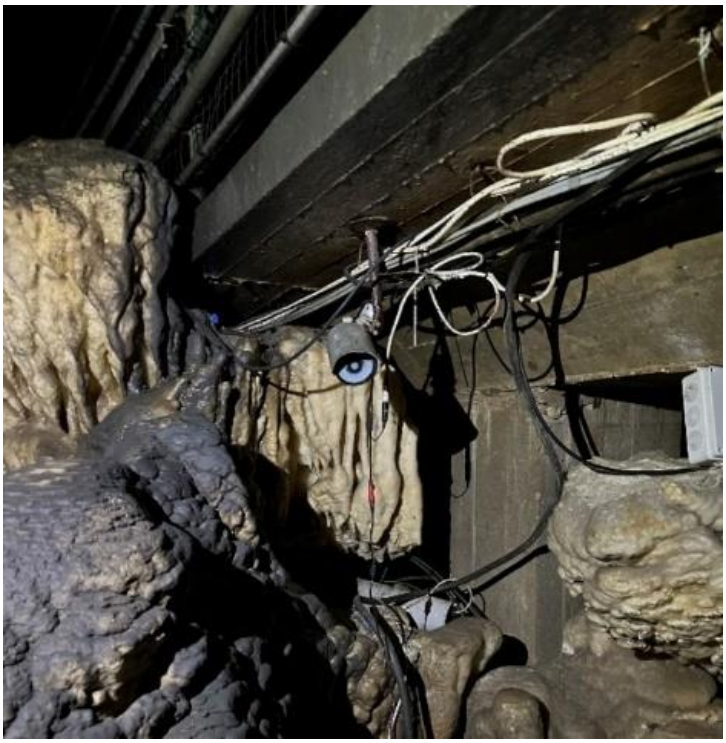


Figure 3-4. Stained Stalagmite Under Walkway, likely from Walkway Cleaning Wastewater



Figure 3-5. Wet Vacuum Cleaner BD50/60 C EP

3.4.2 Shoe Disinfection Mats

To prevent the transfer of invasive spores, bacteria, and fine soil into the cave ecosystem, absorbent disinfection mats (Figure 3-6) shall be installed at the main entrance as follows:

- Operation:
  - Visitors step on a disinfectant mat on entry.
  - Disinfection mats shall be placed in contained trays or an equivalent fully contained arrangement.
  - No disinfectant, rinse water, or contaminated runoff shall be allowed to enter the cave floor, drainage pathways, pools, river, or speleothem areas.
  - Mats shall be sized and managed so that footwear is disinfected without leaving visible dripping before visitors proceed into the cave.
  - Staff shall inspect the mat area during opening hours and remove or contain any excess liquid immediately.
  - Used disinfectant and contaminated liquid shall be collected and disposed of outside the cave; no discharge inside the cave is permitted
  - Staff shall inspect mats during opening hours and replenish or replace disinfectant solution only as needed to maintain effectiveness without creating excess liquid or runoff.

- Mat inserts shall be replaced or cleaned in accordance with the manufacturer's schedule and whenever visibly soiled.

- Disinfectant:
  - 1 % Virkon S (or equivalent broad-spectrum biocide).
  - A 1 % solution is effective yet non-hazardous under EU classification.
- Signage & supervision:
  - Clear multilingual signs instructing use.
  - Guide stationed nearby during peak periods to ensure compliance.



Figure 3-6. Disinfection Absorbent Matt with Disinfectant Solution.

3.5 ELECTRIC BOAT CHARGING STATIONS FOR LOWER GALLERY:

3.5.1 Scope of Work

This section covers the design, supply, installation, testing, and commissioning of fixed pedestal-mounted electric boat charging stations to serve a fleet of DC-powered boats operating in a freshwater river located inside a cave. Each charging station shall deliver regulated **DC output at 24 V DC** with a rated power of **3 kW to 5 kW**, supplied from a single-phase AC input. The system shall be suitable for continuous operation in underground, high-humidity, splash-exposed environments, compliant with relevant **IEC standards**.

3.5.2 Applicable Standards

The equipment, materials, and installation shall conform to the latest editions of the following (or equivalent) standards:

Table 3-3. Applicable Standards

Category	Standard	Title
Charging system	IEC 61851	Electric vehicle conductive charging system
Connectors and interfaces	IEC 62196 series	Plugs, socket-outlets, vehicle connectors, and vehicle inlets – Conductive charging
Electrical installation	IEC 60364-7-709	Electrical installations – Marinas and similar locations
Protection degree	IEC 60529	Degrees of protection (IP code)
Insulation coordination	IEC 60664	Insulation coordination for equipment within low-voltage systems
Circuit protection	IEC 60947 / IEC 60898	Low-voltage switchgear and circuit-breakers
Earthing	IEC 60364-5-54	Earthing arrangements and protective conductors

3.5.3 Site and Environmental Conditions

- **Location:** Underground freshwater river inside a natural cave.
- **Ambient temperature:** Approximately 19 °C (constant year-round).
- **Relative humidity:** Up to 95%.
- **Exposure:** Water splashes, condensation, and possible dripping from cave ceiling.
- **Ventilation:** Natural airflow with limited air movement.
- **Corrosion:** High due to moisture; materials shall be corrosion-resistant (marine-grade).
- **Lighting and access:** Low-light conditions; all components shall have visible indicators.

3.5.4 Technical Requirements

3.5.4.1 Electrical Input

- Supply voltage: 230 V AC ±10%, single phase, 50 Hz
- Input power: 4–6 kVA per unit
- Power factor: ≥ 0.95 at rated load
- Efficiency: ≥ 90%

3.5.4.2 DC Output

- Rated output voltage: **24 V DC**
- Output current: Up to 200 A (adjustable / limited as per design)
- Rated power: 3 – 5 kW continuous
- Output type: Isolated, regulated DC suitable for marine battery charging
- Voltage regulation: ± 3%
- Charging method: Automatic multi-stage charging curve (IUoU type) consisting of:

  1- **Bulk (Constant Current) Phase:** Charger delivers constant current until battery voltage rises to the absorption level.

  Typical absorption voltage: **28.8 V DC ± 0.2 V** (for 24 V nominal system).

  2- **Absorption (Constant Voltage) Phase:** Charger maintains constant voltage at **28.8 V DC**, current gradually decreases until battery reaches ~100% state of charge.

  3- **Float (Maintenance) Phase:** Voltage reduced to **27 V DC ± 0.5 V** to maintain battery at full charge without overcharging.

  4- **Equalization / battery charging restrictions:**

  a. Equalization charging and charging of flooded lead-acid batteries shall not be carried out inside the cave.

  b. In-cave charging shall be limited to sealed AGM/GEL or $LiFePO_4$ battery systems using manufacturer-approved charging profiles, with peak charging voltage not exceeding 29.5 V DC for 24 V nominal systems unless otherwise approved by the boat/battery manufacturer and supported by a site-specific risk assessment.

- **Charging curve transition:** Fully automatic, microprocessor-controlled, temperature-compensated (-30 mV/°C per 24 V nominal system).

- **Peak charging voltage limit:** Maximum 29.5 V DC for 24 V nominal systems, unless otherwise approved by the boat/battery manufacturer and supported by a site-specific risk assessment.
- **Temperature compensation sensor:** Optional, remote-mounted on battery terminal to ensure accurate charging in variable ambient conditions.
- **Battery type compatibility:** Compatible with sealed lead-acid (AGM/GEL) and lithium-iron-phosphate ($LiFePO_4$) batteries provided by the boat manufacturer; selectable via configuration menu or DIP switch.

3.5.4.3 Protection Features

- Input circuit breaker with residual current device (RCD Type B, 30 mA)
- Output over-voltage, over-current, and reverse polarity protection
- Short-circuit and overload automatic shutdown
- Thermal protection with automatic recovery
- Emergency stop push-button (mushroom type, latching) on front panel

3.5.4.4 Mechanical and Environmental

- Enclosure protection: **Minimum IP65** (as per IEC 60529)
- Material: **Marine-grade stainless steel (AISI 316L) or powder-coated aluminum alloy**
- Cooling: **Natural convection**
- Mounting: **Pedestal type**, floor-anchored with anti-corrosion fasteners
- Cable entry: Bottom gland with watertight seals
- Connectors: **Custom marine DC connectors** with locking system and watertight caps
- Enclosure temperature rise: ≤ 10 °C above ambient at full load

3.5.4.5 Indicators and Controls

- Power ON, Charging, Fault LED indicators (visible in low-light cave conditions)
- Local Start/Stop control pushbuttons
- Optional communication interface (Modbus RTU / RS-485/Ethernet) for monitoring

3.5.5 Installation and Cabling

- All conduits, junction boxes, and cables shall **waterproof, and halogen-free**.
- DC cables shall be **tinned copper, double-insulated**.
- All metal parts shall be **earthed** in accordance with IEC 60364.
- Cable terminations and glands shall be of Min**. IP66** rated.

3.5.6 Testing and Commissioning

Each station shall undergo:

- **Site Acceptance Test (SAT)**: Final verification of operation under site conditions, insulation resistance, earthing continuity, Temperature rise, and communication verification.
- All test results shall be documented and submitted for approval.

3.5.7 Documentation and Deliverables

The supplier shall provide for the Engineer's approval:

- Manufacturer's data sheets and IEC test certificates
- Wiring diagrams (AC & DC sides)
- Operation and maintenance manual
- Spare parts list
- Warranty certificate (minimum 2 years)

3.5.8 Quality and Warranty

- All materials should be **brand new, of first-class** quality, and from approved manufacturers.
- Equipment shall be covered by a **minimum two-year warranty** from the date of commissioning.

- Supplier shall maintain full compliance with **IEC 61851, IEC 62196**, and environmental protection standards.

3.5.9 Quantities

The system includes one charging station per boat, each with its own dedicated feeder and DC output circuit.
Exact quantity to be defined in the Bill of Quantities (BOQ).

3.6 RECOMMENDED VISITOR MANAGEMENT AND CO_2 CONTROL

All capacities, headways, and pulse-ventilation settings below are preliminary operating assumptions. They shall be confirmed and refined using real operational data and continuous microclimate measurements (CO_2, RH, and temperature). The adopted CO_2 framework uses 2,800 ppm as a conservation watch/trend level, 3,200 ppm as an Amber throttling level, and 3,600 ppm as a provisional permitted ceiling / Red action level. Capacities may be increased only where monitoring demonstrates compliance during peak periods and where speleothem and cave-health monitoring do not indicate deterioration.

3.6.1 Upper Gallery

3.6.1.1 Goal

The goal of operation is to run high-capacity guided visits while keeping CO_2 and microclimate within the adopted provisional operating thresholds, using ticket throttling as the first-line control and short "pulse" door openings only when triggered by live CO_2 readings.

3.6.1.2 Operating Concept

The operating concept is based on the following:

- Route length: 450 m each way (≈ 900 m total).
- Group format: Guided groups of 20 visitors; this requires hiring and training one guide per group with additional guides on standby to allow for rotating breaks.
- Dwell time: ≈ 30 min per group (walking + interpretation).
- Headway: groups released every 3 min (staggered).

Hourly and daily visitor capacity estimates are summarized in Table 3-4.

Table 3-4. Upper Gallery Visitor Capacity Estimates

Metric	Value	Notes
Theoretical groups on route	30 min ÷ 3 min = 10	Purely by dwell/headway math
Operational groups on route	8 – 9	Allows spacing at stops, buffers, loading/unloading
Instantaneous visitors inside	8 – 9 × 20 = 160 – 180	Recommended cap
Throughput	60 min ÷ 3 min × 20 = 400 vph	At 3-min headway
Daily (8 h)	≈3,200 vpd	If sustained all day

The operational concept starts with a visitor cap of ≤9 concurrent groups (≤180 persons) and only increases beyond this after continuous monitoring confirms that CO_2 remains below the 3,600 ppm provisional permitted ceiling during peak hours, with limited frequency of Amber conditions and no evidence of cave-health deterioration.

This translates to an hourly capacity of 300-400 visitors (≈ 2,400 - 3,200 visitors per day), which is comparable to the upper end of international practice for large show caves (ranging from 275 to 2,740 vpd), provided continuous monitoring confirms acceptable CO_2, RH, temperature, visitor-flow, and cave-health performance during peak conditions.

3.6.1.3 CO_2 Control

To prevent excessive CO_2 rise while minimizing unnecessary disturbance of humidity and natural cave airflow, the Upper Gallery shall use a staged response system based on the Upper Gallery CO_2 monitoring stations specified in Section 3.2. Station 1 shall serve primarily as an entrance/reference station; operational control shall be based on the relevant internal CO_2 stations, including Stations 2, 5, 8 and 10, with action taken based on the highest representative reading (Table 3-5).

At 2,800 ppm, CO_2 shall be treated as a conservation watch/trend condition. At 3,200 ppm, ticketing and group releases shall be throttled. At 3,600 ppm, new entries shall be halted and a short pulse-ventilation cycle shall be initiated. The 3,600 ppm value is adopted as a provisional permitted ceiling, not as a fixed cave-health threshold, and shall be reduced if continuous monitoring or speleothem/cave-health monitoring indicates deterioration.

Pulse frequency should not exceed one single-door pulse every 2 hours on average (i.e., no more than 4 pulses during an 8-hour period); exceeding this limit shall require reassessment of visitor capacity, group spacing, and ventilation practice. Monitoring data shall be evaluated monthly during the first operating year to assess effectiveness and refine the operational method.

Table 3-5. Upper Gallery Pulse-Ventilation Protocol

Element	Setting
Live trigger	Highest representative internal Upper Gallery CO_2 reading ≥3,600 ppm, following Amber throttling at 3,200 ppm
Primary action	Single-door pulse: open the Upper Gallery entrance door for up to 15 min while tours already inside continue toward the exit; no new groups enter during the pulse
Close condition	Close when CO_2 falls to ≤ 3,200 ppm or after 15 min, whichever occurs first
Escalation (if insufficient)	If CO_2 remains >3,200 ppm after the Single-Entrance Pulse, initiate a short Dual-Entrance Pulse by opening the Upper and Lower Gallery doors simultaneously for up to 10 min, where feasible and only as an escalation measure
Safety ceiling	Alarm at 3,600 ppm; halt new entries at both ticketing and cave entry until CO_2 falls to ≤3,200 ppm and remains stable for at least 10 min
Pulse frequency cap	Avg ≤ 1 pulse / 2 h (≤ 4 pulses / 8-h day). If ≥ 2 pulses in any rolling 2-h window, reassess visitor capacity, group spacing, and ventilation practice
Time-weighted target	CO_2 to remain below 3,600 ppm during opening hours; monthly trend review to evaluate duration and frequency above 2,800 ppm and 3,200 ppm
Ticketing throttle	Link alarms to throttle group releases at 3,200 ppm and pause new entries at 3,600 ppm until recovery conditions are met

3.6.2 Lower Gallery

3.6.2.1 Goal

The goal is to operate high-quality, guided boat visits in the Lower Gallery while maintaining CO_2 and microclimate within the same staged operating framework adopted for the Upper Gallery, using real-time monitoring, automatic dispatch throttling, and short "pulse" door openings only when needed.

3.6.2.2 *Operating Concept*

The Lower Gallery visit is managed as discrete, guided boat departures (no free flow). The operating configuration is: 4 boats × 15 passengers = 60 passengers inside the visited river section at any one time (excluding staff). The cycle time is assumed to be 8-10 minutes per boat (8 min return trip + 30 seconds embark/disembark). This translates to an initial dispatch headway of 2.5 minutes (cycle time ÷ 4 boats) to be dynamically adjusted using live CO_2 readings. The dock area should be managed to avoid crowding; as a rule, keep the dock queue to ≤ 2 boatloads (≤ 30 passengers) at any time to minimize CO_2 buildup and safety risks. Once the first boat departs, the next group of 15 visitors is released to enter the Lower Gallery; given that the walk from the entry point to the docks takes 45 seconds approximately, this group arrives in time to embark and wait for 1-2 minutes before the next departure, and the sequence continues accordingly.

3.6.2.3 *CO_2 Control*

The primary operational control point is the mid-route CO_2 sensor at Station 3 (S3), supported by the other Lower Gallery CO_2 monitoring stations specified in Section 3.2. Boat dispatch, ticketing, turnstiles, and boarding release shall be continuously adjusted based on real-time CO_2 values, consistent with the report's approach of linking operations to live telemetry and throttling.

The Lower Gallery shall apply the same staged CO_2 response framework used for the Upper Gallery: 2,800 ppm as a conservation watch/trend level, 3,200 ppm as the Amber throttling level, and 3,600 ppm as the provisional permitted ceiling / Red action level.

- CO_2 Watch / Conservation Trend Level (2,800 ppm at S3):
  Operations staff shall monitor boat dispatch, dock crowding, and visitor accumulation. No automatic closure is required solely at this level, but continued upward trends shall trigger preparation for dispatch throttling.
- CO_2 Amber / Throttling Level (3,200 ppm at S3):
  Boat dispatch shall be automatically throttled by increasing headway or pausing discretionary departures. Dock queues shall be actively managed to prevent accumulation, and no additional visitors shall be released toward the docks unless boarding capacity is available.
- CO_2 Red / Provisional Permitted Ceiling (3,600 ppm at S3):
  All new entries and boat departures shall be halted immediately. Boats already inside the visited river section shall complete the normal exit cycle. Pulse ventilation shall be initiated until CO_2 falls to ≤3,200 ppm and remains stable for at least 10 minutes before departures resume gradually.

Pulse Ventilation Protocol

Doors should remain closed during normal operation, except for short pulses triggered by CO_2 exceedances, to avoid unnecessary disturbance of cave humidity and microclimate.

- Primary action – Single-Entrance Pulse:
  Open the Lower Gallery entrance door for up to 15 minutes when S3 reaches ≥3,600 ppm. Close earlier if CO_2 falls to ≤3,200 ppm, or at the 15-minute limit, whichever occurs first. No additional boats shall be launched during the pulse.

- Escalation – Dual-Entrance Pulse (use sparingly, if feasible):
  If, after the single-door pulse, S3 remains >3,200 ppm, a short 10-minute dual-door pulse may be applied by opening both relevant gallery doors to increase exchange. This is an escalation measure and shall trigger operational review of dispatch rate, dock crowding, and the need for improved engineered entrance control.

- Pulse frequency cap:
  Pulses should average no more than 1 per 2 hours (i.e., ≤4 pulses over an 8-hour day). Exceeding this indicates that the dispatch rate/cap is not sustainable without revising operations or assessing the feasibility of engineered ventilation or air-control solutions.

Operational performance target (Lower Gallery)

CO_2 shall remain below the 3,600 ppm provisional permitted ceiling during opening hours. Monthly trend review shall evaluate the duration and frequency of conditions above 2,800 ppm and 3,200 ppm, together with RH, temperature, and cave-health observations.

Integration with monitoring layout

The Lower Gallery monitoring system includes CO_2 sensors at selected stations, including Station 3 (S3) as the mid-route operational control point, with high-frequency logging and alarm capability. The Lower Gallery operational logic above shall be implemented directly through that telemetry and alarm framework.

Adaptive review

During the first year of operation, the operator shall prepare monthly monitoring summaries correlating visitor numbers, CO_2 levels, Amber/Red events, pulse-ventilation frequency, RH and temperature trends, and cave-health monitoring observations. If monitoring indicates repeated exceedance of the 3,600 ppm provisional ceiling, frequent Amber conditions, excessive pulse ventilation, declining RH stability, increased lampenflora, adverse drip-water or speleothem condition trends, the operator shall reduce visitor capacity, increase headways, adjust door/pulse protocols, or apply other conservation controls until stable conditions are demonstrated.

APPENDIX A: INSPECTION TEAM & MINIMUM QUALIFICATIONS

#	Position	Key Duties	Experience
1	**Johnny Tawk** Team Lead | Architectural & Structural Expert	Team Lead, Infrastructure and Operational Assessment	>20 yrs expertise in architectural projects. >25 yrs expertise in caving and show cave projects. Member of ISCA, International Show Cave Association
2	**Chady Chaker** Electrical Engineering	Electrical assessment	>20 yrs expertise in power system design and execution. 20 yrs expertise in caving and cave related projects.
3	**Marc Metni** Technical Environmental Lead	Environmental and Operational Assessment	>25 yrs Environmental and Geosciences Expertise, Speleology and Karst Research, Due Diligence and International Environmental and Social Standard Compliance.
4	**Ronald Sultanem**	Mission Support	>15 yrs expertise in mechanical projects. >15 yrs expertise in caving.
5	**Marwan Atallah**	Mission Support	>15 yrs expertise in caving.