SUBJECTS: HYDROLOGY & WATER RESOURCES | ENVIRONMENTAL DATA SCIENCE | DROUGHT MONITORING

Historical capacity and storage of managed water reservoirs in Spain (1988–2026): A standardized relational dataset

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Code & License: github.com/Aimarus22/etl-eem | Data: CC BY 4.0 / Code: MIT

ABSTRACT

Multi-decadal, standardized baselines of surface water storage are essential for hydrological modeling, climate-driven drought assessment, and agricultural water policy in the Mediterranean basin. Although the Spanish Ministry for the Ecological Transition and the Demographic Challenge (**MITECO, 2026**) routinely compiles weekly reservoir observations across Spain, direct computational reuse of the historical archive is hindered by distribution inside legacy proprietary Microsoft Access (`.mdb`) containers, local decimal-comma formatting, and highly redundant geographical text strings. Here we present a continuous, harmonized nearly four-decade relational dataset (1988–Present, **Rollán-González, 2026a**) consolidating 724,217 weekly observations across N = 402 managed reservoirs and N = 16 hydrographic demarcation basins in Spain. Using a deterministic, low-memory Python ETL pipeline (**Rollán-González, 2026b**), the raw database was normalized into a two-table Star Schema compliant with Tidy Data (**Wickham, 2014**), FAIR principles (**Wilkinson et al., 2016**), and Frictionless Data specifications (**Fowler et al., 2017**), achieving 100% volumetric reconciliation (0.0 hm^3 deviation) while reducing the uncompressed storage footprint to 25 MB.

1. BACKGROUND & SUMMARY

Spain operates one of the most extensive surface-water regulation networks in the world, relying on over four hundred major dams and reservoirs to buffer extreme inter-annual precipitation variability across the Iberian Peninsula. Since 1988, the Directorate-General for Water of the Spanish Ministry for the Ecological Transition and the Demographic Challenge (**MITECO, 2026**) has published the Weekly Hydrological Bulletin (*Boletín Hidrológico Semanal*), recording total structural capacity and stored water volume across all inter-community and intra-community river basins. This longitudinal archive captures critical hydroclimatic extremes, including the severe structural droughts of 1995 and 2022–2024 as well as extraordinary flood-routing episodes.

Despite the high institutional quality of the official monitoring network, automated ingestion of the historical time series into modern data-science environments (Python, R, SQL, GIS, or cloud machine-learning pipelines) faces severe technical friction. The primary historical archive is distributed inside monolithic Microsoft Access (`.mdb`) binary databases requiring proprietary ODBC drivers, encodes floating-point measurements with Spanish decimal commas, and repeats full UTF-8 geographical names for river basins and reservoirs across hundreds of thousands of rows.

This Data Descriptor documents an independent data-curation initiative focused exclusively on extracting, auditing, and restructuring these public records into an immutable, machine-actionable Star Schema (**Rollán-González, 2026a**). Full institutional credit and primary authorship for physical gauge measurement, telemetry maintenance, and administrative compilation belong exclusively to MITECO and the respective Hydrographic Confederations (**MITECO, 2026**). By decoupling static basin and reservoir topographies into a compact dimension catalog (`miteco_reservoirs_dim.csv`, 11 KB) and retaining only integer surrogate keys and standardized physical metrics in the central fact table (`miteco_reservoirs_1988_2026_facts.csv`), the resulting architecture eliminates text redundancy and enables immediate longitudinal analysis.

1. Binary Source & Extraction	2. Metadata & Encoding Audit	3. Relational Star Schema ETL	4. Stream QC & FAIR Release
MITECO Access (`.mdb`) Binary Mobile Extraction to Flat CSV 16 River Basins | 402 Reservoirs **Unbanning Legacy Data (1988–2026)**	Safe UTF-8-BOM Scanning Toponymic Entity Extraction String Anomaly Detection **16 Basin & 402 Dam Keys**	Dimension Decoupling (1:N) ISO 8601 Temporal Formatting Explicit Null & Flood Retention **724,217 Rows (~25 MB CSV)**	Zero-RAM Line-by-Line Scanner 100% Volumetric Reconciliation Frictionless `datapackage.json` **Zenodo v1 (CC BY 4.0 / MIT)**

Figure 1. Methodological workflow and hardware-agnostic Star Schema ETL architecture. End-to-end curation pipeline (**Rollán-González, 2026b**) liberating proprietary Microsoft Access (`.mdb`) records published by the Spanish Ministry for the Ecological Transition (**MITECO, 2026**) into a normalized, FAIR-compliant relational database (**Rollán-González, 2026a**).

2. METHODS: DATA HARMONIZATION & HYDROLOGICAL CURATION

Hardware-agnostic data rescue and mobile ETL workflow: Because MITECO distributes the historical hydrological series exclusively inside a proprietary Microsoft Access (`.mdb`) binary container rather than open text files, a preliminary extraction stage (Phase 0) was required prior to programmatic normalization. To guarantee maximum resource efficiency and demonstrate hardware-agnostic reproducibility, the entire workflow was executed on a consumer mobile ARM64 environment (Android OS, Xiaomi Redmi Note). First, the official MITECO `.mdb` database was parsed and exported to an intermediate flat CSV file (`T_Datos_Embalses_1988-2026.csv`) using the mobile utility "MDB & ACCDB: Visor de Access" (developed by Akshay C P). Subsequent auditing, relational Star Schema normalization, and automated quality control were executed locally via a memory-optimized Python 3 pipeline in Pydroid 3 (**Rollán-González, 2026b**).

Because the mobile Linux kernel writes native Unix line endings (LF, \n), the resulting tables combine universal cross-platform compatibility with minimal byte overhead, proving that curating over 724,000 climatic records does not require high-performance computing clusters or proprietary desktop software licenses when algorithms are engineered for low-memory footprints.

Following Phase 0 binary extraction, five deterministic standardization rules governed the transformation from the intermediate extracted table to the published relational database:

1. **Phase 1 — Safe-mode metadata auditing and entity isolation (`audit_reservoirs_miteco.py`):** Following extraction from the primary `.mdb` container into the intermediate flat file, raw records were scanned in safe UTF-8-BOM mode to prevent character corruption across Spanish diacritics and internal commas. The audit isolated all unique geographical pairs of hydrographic demarcations (`AMBITO_NOMBRE`) and reservoir facilities (`EMBALSE_NOMBRE`), verifying the absence of corrupted alphanumeric strings inside numerical measurement fields prior to transformation.
2. **Phase 2 — Dimensional decoupling and surrogate key generation (`etl_reservoirs_miteco.py`):** To eliminate millions of repeated text strings, unique geographical entities were sorted alphabetically and assigned sequential integer primary and foreign keys: `id_basin` (1 to 16) and `id_reservoir` (1 to 402). These attributes were exported to the master dimension catalog (`miteco_reservoirs_dim.csv`). Active garbage collection (`gc.collect()`) was enforced during table decoupling to guarantee stable execution on low-memory environments.
3. **ISO 8601 temporal normalization and precursor record protection:** Raw date strings were converted to strict ISO 8601 extended format (`YYYY-MM-DD`). While the nominal series begins in January 1988, selective chronological auditing preserved two valid precursor records from October 1987 (`1987-10-06` and `1987-10-13`) corresponding to the start of the 1987/1988 hydrological year at the La Aceña reservoir (`id_reservoir = 345`, Tagus Basin, `id_basin = 15`), while purging any malformed or undated rows.
4. **Floating-point standardization and hydroelectric boolean typing:** Physical water magnitudes —nominal storage capacity (`AGUA_TOTAL`) and stored volume (`AGUA_ACTUAL`), both measured in cubic hectometers (hm^3)—were converted from local comma-decimal notation to IEEE 754 floating-point format using a period (`.`) separator. The administrative hydroelectric indicator (`ELECTRICO_FLAG`) was standardized into a strict binary integer flag (`hydroelectric_flag`: `0` for non-hydroelectric or consumptive regulation, `1` for hydroelectric exploitation).
5. **Explicit non-suppression of reporting omissions and flood-lamination retention:** In accordance with strict empirical data lineage, the pipeline applies zero statistical imputation. The 2 historical records containing missing physical readings in the raw MITECO source are preserved as explicit RFC 4180 empty strings (`""`), mathematically distinguishing reporting omissions from empty reservoir storage (`0.0` hm^3). Furthermore, the pipeline explicitly retains 1,264 records (0.17% of the dataset) where actual stored volume temporarily exceeds nominal design capacity (`volume_hm3 > capacity_hm3`), preserving empirical evidence of extraordinary flood-routing (*laminación de avenidas*) and surcharge storage episodes.

3. DATA RECORDS & RELATIONAL VARIABLE CODEBOOK

The dataset replaces the monolithic historical table with a two-table Star Schema hosted on Zenodo (**Rollán-González, 2026a**). In this architecture, the central fact table stores only integer identifiers, ISO dates, and floating-point hydrological measurements, linking 1:1 with the master spatial dimension table. Table 1 defines the variable specifications for both relational files:

Table & Column	Data Type	Description & Standard Format	Analytical Function & Usage Notes
1. CORE FACT TABLE: MITECO_RESERVOIRS_1988_2026_FACTS.CSV (724,217 ROWS | ~25.0 MB)			
`id`	Integer	Sequential unique row identifier (`1` to `724217`).	**Primary key:** Guarantees immutable record-level traceability across the 1988–2026 series.
`date`	Date (String)	ISO 8601 calendar date (`YYYY-MM-DD`), spanning `1987-10-06` to `2026-10-27` .	**Temporal index:** Weekly administrative reporting timestamp for longitudinal time-series aggregation.
`id_basin`	Integer	Surrogate hydrographic demarcation identifier (`1` to `16`).	**Spatial foreign key:** Links with `miteco_reservoirs_dim.csv` for basin-level drought aggregation.
`id_reservoir`	Integer	Surrogate reservoir identifier (`1` to `402`).	**Facility foreign key:** Links 1:1 with `miteco_reservoirs_dim.csv` ; eliminates string redundancy.
`capacity_hm3`	Number (Float)	Total nominal storage capacity in cubic hectometers (hm^3, ≥ 0.0) or empty cell (`""`).	**Structural baseline:** Reflects dam commissioning, structural heightening, or bathymetric re-rating over time.
`volume_hm3`	Number (Float)	Actual stored water volume in cubic hectometers (hm^3, ≥ 0.0) or empty cell (`""`).	**Primary hydrological metric:** May exceed `capacity_hm3` during active flood-lamination episodes (N = 1,264 rows).
`hydroelectric_flag`	Integer (Binary)	Strict binary indicator (`0` = consumptive/general use; `1` = hydroelectric generation).	**Operational filter:** Separates irrigation/urban supply reservoirs from predominantly hydroelectric dams.
2. SPATIAL DIMENSION TABLE: MITECO_RESERVOIRS_DIM.CSV (N = 402 RESERVOIRS | ~11.0 KB)			
`id_reservoir`	Integer	Unique reservoir primary key (`1` to `402` , alphabetically ordered by basin and dam).	**Primary key:** Relational target for `facts.id_reservoir` .
`reservoir_name`	String (UTF-8)	Official reservoir name preserved from MITECO nomenclature (e.g., *La Serena*, *Buendía*).	**Facility label:** Canonical Spanish toponym for cartographic labeling and infrastructure cross-referencing.

Table & Column	Data Type	Description & Standard Format	Analytical Function & Usage Notes
1. CORE FACT TABLE: MITECO_RESERVOIRS_1988_2026_FACTS.CSV (724,217 ROWS | ~25.0 MB)			
`id_basin`	Integer	Hydrographic demarcation identifier (`1` to `16`).	**Basin grouping key:** Maps each reservoir to its managing Hydrographic Confederation or regional agency.
`basin_name`	String (UTF-8)	Official hydrographic demarcation name in UTF-8 Spanish (16 distinct domains).	**Regional label:** Enables grouping across inter-community and intra-community river basins.

Hydrographic demarcation coverage and RFC 4180 compliance: The dimension table catalogs all 16 official mainland hydrographic management domains monitored in the MITECO bulletin (Cantábrico Oriental, Cantábrico Occidental, Miño-Sil, Galicia Costa, Cuencas Internas del País Vasco, Duero, Tajo, Guadiana, Tinto-Odiel-Piedras, Guadalete-Barbate, Guadalquivir, Cuenca Mediterránea Andaluza, Segura, Júcar, Ebro, and Cuencas Internas de Cataluña). Replacing repetitive basin and reservoir text strings with integer keys ensures that the fact table contains zero quoted strings or internal commas, guaranteeing strict RFC 4180 compliance and rapid parsing across SQL engines, Apache Parquet, Python/pandas, and R.

4. TECHNICAL VALIDATION & USAGE NOTES

Automated stream quality control (`qc_reservoirs_miteco.py`): Following ETL compilation, the master fact table was audited using a standalone, native Python stream scanner that reads the 25 MB CSV line by line from disk (`f.readline()`) without loading external data-frame libraries into RAM (**Rollán-González, 2026b**). Across all 724,217 data rows, the scanner verified three strict invariants: (1) exact column geometry (strictly 6 commas / 7 columns per line, 0 structural errors); (2) 100% relational and domain integrity (all primary keys, ISO 8601 date masks, `id_basin` in `[1, 16]` , `id_reservoir` in `[1, 402]` , and `hydroelectric_flag` in `{0, 1}` present and valid); and (3) non-negative physical coherence across all floating-point cells (≥ 0.0 hm^3, 0 negative or corrupted values).

Volumetric reconciliation against the extracted MITECO `.mdb` table: To guarantee zero data loss or floating-point drift during relational normalization, an automated reconciliation audit compared the intermediate flat table extracted directly from the MITECO `.mdb` binary (`T_Datos_Embalses_1988-2026.csv`) against the final Star Schema tables. Table 2 summarizes the audit benchmarks:

Validation Metric / Audit Dimension	Extracted MITECO `.mdb` Table	Normalized Star Schema (`facts` + `dim`)	Empirical Deviation
Total Longitudinal Observations (Rows)	724,217 records	724,217 records	**0 rows (100% match)**
Unique Basin × Reservoir Entities	16 basins | 402 reservoirs	16 basins | 402 reservoirs	**0 entities (1:1 mapping)**

Validation Metric / Audit Dimension	Extracted MITECO `.mdb` Table	Normalized Star Schema (`facts` + `dim`)	Empirical Deviation
Cumulative Historical Capacity (∑ `capacity_hm3`)	107,744,254.00 hm^3	107,744,254.00 hm^3	**0.00 hm^3 (Exact)**
Cumulative Historical Storage (∑ `volume_hm3`)	61,296,171.00 hm^3	61,296,171.00 hm^3	**0.00 hm^3 (Exact)**
Missing Observation Cells (Null Preservation)	2 capacity | 2 volume	2 capacity | 2 volume (`""`)	**0 cells (Preserved)**

Longitudinal usage notes — Infrastructure growth, drought baselines, and flood routing: Researchers analyzing multi-decadal storage ratios should account for three empirical features confirmed during validation: (1) *Structural capacity expansion*: national monitored reservoir capacity increased by 30.8% over the study period, rising from 42,854 hm^3 in 1988 to 56,054 hm^3 in 2026 (+13,200 hm^3); consequently, long-term drought comparisons should evaluate both absolute stored volume (`volume_hm3`) and relative filling percentage (`volume_hm3 / capacity_hm3 × 100`). (2) *Historical extremes*: longitudinal aggregation identifies 1995 as the most severe national drought minimum in the series (mean annual storage at 34.7% of capacity), followed by 2022 (41.6%), whereas 2010 and 2014 represent the wettest hydrological years (~74% mean storage). (3) *Flood-lamination ratios (>100%)*: when computing relative storage percentages, users should not filter out the 1,264 records where `volume_hm3 > capacity_hm3` unless specifically capping indices at 100%, as these values reflect real hydraulic surcharge operations during peak runoff events.

5. DECLARATIONS, AUTHORSHIP & REPOSITORY INVENTORY

PRIMARY DATA ATTRIBUTION & COMPETING INTERESTS	DECLARATION OF GENERATIVE AI & CREDIT TAXONOMY
Primary raw measurements originate entirely from the Weekly Hydrological Bulletin published by the Spanish Ministry for the Ecological Transition and the Demographic Challenge (**MITECO, 2026**), which holds full institutional credit for physical monitoring. This dataset is an independent derivative work prepared under Spanish Law 37/2007 on the reuse of public-sector information. **Funding & Competing Interests:** This curation project was conducted autonomously and self-funded by the author without external grants. The author declares no competing financial or institutional interests.	In compliance with international publishing standards (ICMJE/COPE), AI-assisted tools were used strictly for code formatting, schema structuring, and academic English translation and syntax editing. No empirical data were generated, imputed, or hallucinated by AI; all 724,217 records were deterministically transformed and reconciled against the primary administrative source. **CRediT Roles:** A. Rollán-González: Conceptualization, Methodology, Software, Validation, Data Curation, Writing – Original Draft & Editing.

Repository Artifact (Zenodo v1 & GitHub)	Size / Format	Scope & Functional Role
`miteco_reservoirs_1988_2026_facts.csv`	~25.0 MB (CSV, UTF-8)	Core Star Schema Fact Table (724,217 weekly records, 7 columns)
`miteco_reservoirs_dim.csv`	~11.0 KB (CSV, UTF-8)	Spatial & Toponymic Dimension Table (N = 402 reservoirs, N = 16 basins)

`audit_reservoirs_miteco.py`
`etl_reservoirs_miteco.py`
`qc_reservoirs_miteco.py`
	Python 3 Scripts (MIT)
	Archived in Zenodo & GitHub
		Immutable 3-Phase Audit, Relational ETL & Zero-RAM Stream QC Pipeline preserved in Zenodo v1 and **Aimarus22/etl-eem**

`datapackage.json` | `schema.json`	JSON (Frictionless)	Machine-Actionable Relational Schema & FAIR Metadata Descriptors
`README.md`	Markdown (UTF-8)	Bilingual Methodological Documentation & Usage Guide

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