Hydropower Energy Storage Capacity

Dataset Overview

Dataset Title: Hydropower Energy Storage Capacity Dataset

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Summary: The Hydropower Energy Storage Capacity (HESC) dataset catalogs characteristics that are relevant to evaluating reservoir storage and estimates of energy storage capacity based on varying levels of detail. Hydropower dams and reservoirs were included based on information from the National Inventory of Dams (NID 2021) and Global Reservoir and Dam (GRanD v1.3) and Existing Hydropower Assets datasets. These data provide a foundation for understanding available resources at existing hydropower facilities and their potential to provide storage of energy and more flexible generation. Estimates of energy storage capacity include:

- **Level 1** – nominal energy storage capacity based on maximum storage capacities and hydraulic head
- **Level 2** – nominal energy storage capacity based on historical models or observations of reservoir volume and hydraulic head. These estimates are provided based on capacity from the entire historical period as well as monthly values.
- **Level 3** – modeled energy generation based on volume-elevation relationships, historical storage and observed/modeled inflows, and hydraulic capacity of turbines and calculated both as overall and on a monthly basis.
- **Level 4** – modeled energy generation incorporating information from Level 3 and operational constraints.

For facilities where installed capacity is known, there are also estimates for discharge duration (the length of time when a facility could provide generation at a given capacity).

Keywords: Existing Assets, Hydrography, Energy Storage

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Related Publication: Hansen, C. H., Ghimire, G. and Kao, S.-C. 2022. Evaluation of Nominal Energy Storage at Existing Hydropower Reservoirs in the US. *Water Resources Research.*

Related Datasets:

- Existing Hydropower Assets
- HILARRIv2 (Hydropower Infrastructure – LAkes, Reservoirs, and Rivers)

Dataset Characteristics

Spatial Resolution: point locations describing approximate locations of hydropower dams

Projection Information: EPSG 4269, NAD83

Temporal Coverage: represents the current state of hydropower infrastructure, as of May 2022 (last published Existing Hydropower Assets operational plants dataset)

File Format: .csv

File Naming Convention:

All tables are provided as separate comma separated value (CSV) files with the prefix "HESC_vX," where X is the major release used in versioning. Tables include:

- HESC_vX_Field_Descriptions.csv – data dictionary
- HESC_vX_Core_Characteristics.csv – describes location, types of facility/operations, installed capacity, volume, dam height, historical statistics of volume and hydraulic head
- HESC_vX_Level1_Nominal.csv - nominal energy storage capacity estimates based on volume and dam heights reported in national inventories of infrastructure and waterbodies
- HESC_vX_Level2_Nominal.csv - nominal energy storage capacity estimates based on volume and reservoir elevation from historical records
- HESC_vX_Level3_Modeled.csv - modeled generation based on 50% of volume, incorporating inflow and volume-elevation relationships. Overall (maximum 1-year generation) and monthly (maximum 1-month) estimates.
- HESC_vX_Level4_OpModeled.csv - modeled generation based on information from Level3 and normal operation ranges. Overall (maximum 1-year generation) and monthly (maximum 1-month) estimates.

Application & Derivation

These data provide a foundation for understanding available resources at existing hydropower facilities and their potential to provide storage of energy and more flexible generation. Some examples of uses include:

- Hydrodynamic and power system modelers benefit from the robust documentation of reservoir storage characteristics, which provides upper or lower bounds for reservoir characteristics.
- Water/Energy management entities can use estimates of energy storage and discharge duration to help inform long-term modeling and planning for the grid.
- Facility owners/operators can use energy storage to identify reservoirs where flexible operations should be further evaluated.

Quality Assessment

Estimate of Uncertainty: The HESC dataset incorporates information from multiple datasets to facilitate more effective and accurate analysis. The origin of the data is included (for example, G_VOL is the volume from GRanD while NID_VOL is the maximum volume reported by the National Inventory of Dams).

A series of quality and informational flags help describe if certain restrictions might exist based on the type of facility or if there are known issues with the data:

- "MODEFLAG" describes if the facility has been identified as part of a conduit project or operates as a "run-of-river"
- "DATASET" describes if the facility has a known, inventoried dam, power plant, and/or reservoir.
- "STATUSFLAG" describes which data set identifies the feature as a hydropower facility (NID, EHA, and/or GRanD)
- "LOCKFLAG" indicates whether the facility contains a lock which may limit storage and flexibility at a facility
- "PSFLAG" indicates whether a facility is already used for hybrid pumped storage
- "QANOTE" describes whether a core characteristic reported by an underlying data set is believed to be erroneous. If a particular value is flagged as being erroneous, this value is not used in calculations of nominal energy storage capacity.

Data Acquisition, Materials & Methods

Data were acquired from the NID (USACE, 2021), GRanDv1.3 (Lehner et al., 2011,), HydroLAKES (Messager et al., 2016), Existing Hydropower Assets (Johnson et al., 2022), USACE via the Duke Nicholas Institue Reservoir Data efforts (Patterson et al., 2018), USBR RISE, the "Hydropower reservoir data in the CONUS" dataset (Gao and Huilin, 2020) and ResOpsUS (Steyaert et al., 2022) datasets. The HILARRIv2 database of hydropower-hydrographic links was used to cross-walk between NID, GRanD, and HydroLAKES (obtaining inventoried volumes, dam height, and surface area characteristics). Statistics were derived for historical observed and modeled volumes/head records. The EHA (Johnson et al., 2022) dataset was used to obtain installed capacity, hydraulic capacity, and basic operational mode information.

Nominal energy storage was calculated using the basic equation:

$$E = \frac{\rho \times g \times V \times H}{3.6 \times 10^9}$$

where E is the energy storage in MWh, ρ is the density of water in kg/m^3, V is the storage volume in m^3, H is the hydraulic head in m, and 3.6×10^9 is a unit conversion factor to go from Joules to MWh.

For Level 1 estimates:

- Inventory-reported volumes and heads were used. If the user would like to consider partial volume or efficiency, these can be incorporated by multiplying the estimate by a factor. For example, assuming 50% volume and 90% efficiency, following the method used in the IEA Special Hydropower Market Report (IEA, 2022), E is multiplied by 0.45. applying a scaling factor to the estimates).

- These estimates are available for 2,115 dams in the US (including AK, HI, and PR). An additional 50 dams are included in the inventory but have no nominal energy storage estimates because some key information is missing.

For Level 2 estimates:

- Historical volumes and heads were used.
- These estimates are available for 233 dams, mostly larger, federally-owned facilities.

Modeled energy storage was calculated at a daily resolution by applying the nominal energy equation and including daily inflow from Dayflow (Ghimire et al., 2023) dataset and discharges to reflect changes in volume with inflow and discharge. A power-law relationship between elevation and volume was used to reflect how the hydraulic head decreases as volume is discharged.

For Level 3 estimates:

- Estimates are available for 175 dams with sufficient historical records (including volume and elevation), and inflow data. Energy storage estimates are limited to generation for 1 year for ENRGY03A-F and 1 month for ENRGY03JAN-DEC, and by a lower bound of volume = 50% of the initial volume.
- The Coefficient of Determination (R^2) > 0.5 between historical reservoir volume and historical reservoir elevation is used as the criteria for determining a sufficient performance of the volume-elevation relationship for a particular facility. For 225 facilities for which these relationships are developed, 95% of them show $R^2 > 0.9$. A few facilities with $0.5 < R^2 < 0.9$ are manually checked to determine whether they depict a typical storage-elevation relationship for hydropower reservoirs.

For Level 4 estimates:

- Estimates are available for 142 dams with additional data describing the upper and lower bounds of normal operations, retrieved from the ISTARF dataset (Turner et al., 2021). The same volume-elevation relationships are applied, with the additional constraint of the upper and lower operating levels. Generation is limited to a maximum of 1 month.

Change Log

Version 1 contained only estimates of nominal energy storage capacity

- Level 1 - based on inventoried data and
- Level 2 - based on historical records of volume

In version 2, we:

- include estimates of nominal energy storage capacity with additional QA performed to exclude anomalous values of volume/dam height from the calculations of Level 1 and 2 estimates.
- have added additional QA and informational flags that help further describe the facilities.
- provide all reported values of volume and dam height from the various input sources rather than the maximum and minimum values.
- provide surface area because of interest in related characteristics at these storage facilities.

- provide equations used to approximate volume-elevation relationships from historical records of storage and volume
- include modeled generation:
    - Level 3 – incorporates inflow and physical volume-elevation relationships and reflects storage overall and on a monthly resolution
    - Level 4 - incorporates information from Level 3 as well as operational limits

References

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Supplemental Files

- HESC_v2_README.pdf