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Index Spec v1
GMU Disaster Decision Support Indices PR

Evaluate, Validate, and Enrich

February 26, 2026

Index Spec v1 — GMU Disaster Decision Support Indices (Puerto Rico)

Project: GMU open-source class project (notebook-derived data + geospatial layers)

Goal: Operational decision support for life safety, infrastructure continuity, utility resilience, emergency response, and recovery.

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Design Principles

1. Defensible: Align to established risk/resilience concepts; every score is explainable.
2. Operational: Works pre/during/post event; supports escalation + prioritization.
3. Transparent MVP: Weighted sum baseline + optional AHP for eliciting weights.
4. Confidence-aware: Every index has a confidence score driven by data quality.
5. Scale-aware: Station-level → municipio-level aggregation with distance weighting.

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Taxonomy: Four Indices

1. Risk Index (R)

What it answers: “Where are we most likely to see harm if the hazard manifests?”

Core structure (defensible & standard):

$$R = H \times E \times V$$

- H (Hazard intensity/likelihood): event-driven (flood stage, rainfall alerts, quake shaking proxy)
- E (Exposure): people/assets in harm’s way (population, buildings, critical infra within hazard footprint)
- V (Vulnerability): susceptibility (social vulnerability + structural fragility + access constraints)

(ISO risk management framing supports consistent risk definition and governance.)

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Taxonomy: Four Indices

2. Resilience Index (Res)

What it answers: “How well can this place absorb disruption and keep functioning?”

NIST CRPG frames resilience planning around performance goals + dependencies + restoration targets across infrastructure and social functions.

3. Response Readiness Index (RR)

What it answers: “If something happens tonight, can we respond fast and effectively?”

Maps to FEMA mission area: Response and core capabilities conceptually (without needing every capability).

4. Recovery Capacity Index (RC)

What it answers: “How quickly can essential services and livelihoods be restored?”

Maps to FEMA Recovery mission area and “Build Back Better” intent.

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Scoring method you can implement now

Normalize each indicator to a 0–100 “goodness” or “badness” scale

For indicator x with min/max bounds:

- If “higher = worse” (risk drivers):

$$s = 100 \cdot \mathrm{clip}\left(\frac{x - L}{U - L}, 0, 1\right)$$

- If “higher = better” (capacity):

$$s = 100 \cdot \left(1 - \mathrm{clip}\left(\frac{x - L}{U - L}, 0, 1\right)\right)$$

Bounds (L,U): choose from (a) engineering/agency thresholds when available, else (b) robust percentiles (p05, p95) per PR baseline window.

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Scoring method you can implement now

Combine with a weighted sum (baseline MVP)

$$Index = \sum_i w_i \cdot s_i \quad ; \quad \sum_i w_i = 1$$

Baseline recommendation: Weighted sum for MVP (transparent, explainable), with **AHP** used only to elicit stakeholder weights (fast + defensible).

Advanced path: Bayesian/MCDA with uncertainty propagation once you have backtesting labels.

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Leading / coincident / lagging indicators (operational use)

- Leading (pre-event): drives staging, readiness posture, comms, inspections

Examples: forecast/alerts, antecedent saturation, infrastructure fragility, social vulnerability.

- Coincident (during-event): drives routing, rescue prioritization, resource allocation

Examples: observed stage/discharge trend, active warnings, road passability proxy, outage signals.

- Lagging (post-event): drives recovery prioritization, funding justification, after-action learning

Examples: restoration time, shelter utilization, claims/aid proxies, school reopening.

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Indicator

Units: keep original units in the data layer; the index layer consumes normalized scores $s \in [0, 100]$.
Cadence: how often you should refresh, given typical feeds.

Risk Index (R) indicators

Component	Indicator	Formula (raw → score)	Unit	Direction	Cadence	Category
Hazard (Flood)	**Stage exceedance ratio**	$x = \frac{WL - WL_{minor}}{WL_{major} - WL_{minor}}$ then normalize	unitless	↑ worse	6–15 min	Coincident
Hazard (Flood)	**Stage rise rate**	$x = \Delta WL / \Delta t$ (e.g., cm/hr) → normalize	cm/hr	↑ worse	6–15 min	Coincident
Hazard (Flood)	**NWS alert severity**	map Watch/Warning/Flash Flood to 25/60/100	ordinal	↑ worse	1–5 min	Leading/Coincident
Exposure	**Population in flood influence zone**	$x = Pop_{zone}$ (or %) → normalize	persons / %	↑ worse	annual	Leading
Vulnerability	**SVI overall/theme**	use percentile (0–1) ×100	percentile	↑ worse	annual	Leading

Data sources: NOAA CO-OPS water levels & metadata (incl. flood thresholds); NWS API alerts; Census/ACS; CDC/ATSDR SVI.

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Resilience Index (Res) indicators (critical continuity)

Sector	Indicator	Formula	Unit	Direction	Cadence	Category
Power	**Redundancy proxy**	$x =$ (# feeders/substations within municipio) per load	count ratio	↑ better	quarterly	Leading
Water	**Service criticality**	% population dependent on single plant/intake	%	↑ worse	annual	Leading
Roads	**Access fragility**	% of critical facilities with ≤1 viable access route	%	↑ worse	quarterly	Leading
Hospitals	**Surge capacity proxy**	beds per 1k pop; backup power presence	beds/1k	↑ better	annual	Leading
Telecom	**Coverage robustness**	# towers / area; backup power flag	density	↑ better	quarterly	Leading

Framework anchor: NIST CRPG's dependency + restoration performance-goals approach

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Cadence: how often you should refresh, given typical feeds.

Response Readiness (RR) indicators

Indicator	Formula	Unit	Direction	Cadence	Category
Alert-to-action readiness	% of municipios with active alert + staffed EOC/ shelter flag	%	↑ better	daily/hourly	Leading
Route reliability	share of routes to shelters not intersecting flood-prone segments	%	↑ better	hourly	Coincident
Resource proximity	travel time from emergency facilities → hotspots	minutes	↓ better	hourly	Coincident
Comms reach	% population covered by warning channels / cell coverage proxy	%	↑ better	quarterly	Leading

(Incident management guidance alignment: ISO 22320.

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Indicator

Units: keep original units in the data layer; the index layer consumes normalized scores $s \in [0, 100]$.
Cadence: how often you should refresh, given typical feeds.

Recovery Capacity (RC) indicators

Indicator	Formula	Unit	Direction	Cadence	Category
Utility restoration velocity	$\Delta(\%customersrestored)/\Delta t$	%/day	↑ better	daily	Lagging
Housing habitability proxy	% housing in high-risk condition (pre) × damage proxy (post)	%	↓ better	annual + post	Lagging
Healthcare access restoration	travel time to open facilities vs baseline	minutes	↓ better	daily	Lagging
School reopening proxy	% schools operational vs baseline	%	↑ better	weekly	Lagging

(Incident management guidance alignment: ISO 22320.

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Flood-specific design (NOAA + NWS + USGS)

Station-level Flood Hazard Score $H_f^{station}$

Use whichever feeds you have per station (CO-OPS tide gauge OR USGS stream gage).

Option A (NOAA CO-OPS stations)

- WL_t: water level time series from CO-OPS API api.tidesandcurrents.noaa.gov
- Flood thresholds from CO-OPS metadata (MDAPI includes flood thresholds) api.tidesandcurrents.noaa.gov

$$H_f = 0.6 \cdot s(\text{exceedance}) + 0.4 \cdot s(\text{rise rate})$$

Option B (USGS streamgages)

- discharge (00060), gage height (00065) from NWIS instantaneous values Water Services Web

$$H_f = 0.5 \cdot s(\text{gage height}) + 0.5 \cdot s(\Delta Q/\Delta t)$$

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Add the “official alarm” channel (NWS)

Use NWS CAP/alerts endpoint to force escalation regardless of sensor quirks.

Example mapping to score:

- Flood Watch = 40
- Flood Warning = 70
- Flash Flood Warning = 100

Final during-event flood hazard:

$$H_f^{final} = \max(H_f,\ s(\text{NWS alert}))$$

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Earthquake-specific design (USGS events + vulnerability)

Event severity proxy per municipio

From USGS earthquake events (mag, depth, distance).

A simple intensity proxy:

$$x = \frac{M}{\log(1+d)} \cdot g(depth)$$

Where d = km from epicenter to municipio centroid; $g(depth)$ downweights deep events.

Vulnerability overlay

- building age/type proxy (if you have it)
- slope/landslide susceptibility (if in our layers)
- SVI themes (especially disability/transport)

Then:

$$R_{eq} = H_{eq} \times E \times V$$

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Social vulnerability factors (weights + caveats)

Use CDC/ATSDR SVI as baseline, because it's widely used, documented, and available for Puerto Rico; do not compare percentile values across years without care (SVI warns against that).

https://www.atsdr.cdc.gov/place-health/php/svi/svi-data-documentation-download.html
https://www.fema.gov/emergency-managers/practitioners/resilience-analysis-and-planning-tool

Recommended weight split inside Vulnerability V (MVP)

- SVI overall: 0.60
- Access constraints (roads/transport/no-vehicle): 0.25
- Housing fragility proxy: 0.15

Caveats to state explicitly

- SVI is relative rank; it is not "absolute vulnerability."
- Use theme-level drilldown in explainability ("this area scored high due to no-vehicle + crowded housing," etc.).

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Critical infrastructure continuity factors (what to compute)

Create an **Infrastructure Continuity Score (ICS)** per municipio:

$$ICS = \sum_{sector} w_{sector} \cdot s_{sector}$$

Suggested sector weights (tunable):

- Hospitals 0.20
- Power 0.20
- Water 0.15
- Roads/Bridges 0.15
- Telecom 0.10
- Ports 0.08
- Airports 0.07
- Emergency facilities (EOC/fire/police) 0.05

Anchor your narrative to **NIST CRPG** dependencies + restoration targets.

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Uncertainty + confidence scoring (must-have for defensibility)

Data Quality / Provenance rubric (per source + per observation)

Score each observation with:

- **Freshness** (time since last update)
- **Completeness** (% missing in last N hours)
- **Validity** (range checks / unit checks)
- **Cross-check consistency** (e.g., NOAA stage vs USGS nearby trend, if applicable)

$$Conf = 0.35F + 0.25C + 0.25V + 0.15X \quad \in [0,1]$$

Confidence-adjusted index

$$Index^{*} = Conf \cdot Index + (1 - Conf) \cdot Index_{baseline}$$

Where $Index_{baseline}$ is last good value or climatological median.

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Threshold bands (green/yellow/orange/red)

Use two triggers:

1. Quantile bands (stable, works everywhere)
    - Green: 0–50
    - Yellow: 50–70
    - Orange: 70–85
    - Red: 85–100

2. Hard overrides (authoritative signals)

    - If NWS Flash Flood Warning → Red regardless of quantile score.
    - If NOAA/USGS exceed “major flood” threshold → at least Orange/Red (depending on our threshold metadata coverage).

https://www.weather.gov/documentation/services-web-alerts
https://api.tidesandcurrents.noaa.gov/mdapi/prod/

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Station-level + municipio-level architecture

Station → municipio

For each municipio m, aggregate nearby stations j with distance weights:

$$H_m = \frac{\sum_j \exp(-d_{jm}/\lambda) \cdot H_j}{\sum_j \exp(-d_{jm}/\lambda)}$$

- λ ~ 10–25 km (tune by PR basin scale)
- If a municipio contains a station, allow **max()** override for worst-case.

Municipio total indices

- **Risk:** $R_m = H_m \times E_m \times V_m$
- **Readiness** and **Recovery**: weighted sums of operational indicators (routes, facilities, restoration velocity).

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Dynamic weighting by phase (pre / during / post)

Define phase weights W^{phase} that shift emphasis:

- **Pre-event:** prioritize leading readiness + vulnerability
$w_H = 0.35, w_E = 0.25, w_V = 0.40$

- **During-event:** prioritize hazard & access constraints
$w_H = 0.55, w_E = 0.20, w_V = 0.25$

- **Post-event:** prioritize infrastructure continuity + recovery velocity
$w_{ICS} = 0.45, w_{RC} = 0.55$

Phase can be driven by NWS alert state transitions
https://www.weather.gov/documentation/services-web-alerts

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Response performance indicators (KPIs)

- Dispatch time (median, p90)
- Travel time reliability (variance of ETA)
- Shelter reach (% pop within X minutes, adjusted for route disruption)
- Accessibility score for vulnerable populations (no-vehicle + distance to shelters)
- Utility restoration priority queue score (critical facilities first)

(Align incident mgmt language to ISO 22320; align mission framing to FEMA mission areas.)

https://www.iso.org/cms/%20render/live/en/sites/isoorg/contents/data/standard/06/78/67851.html

https://www.fema.gov/emergency-managers/national-preparedness/mission-core-capabilities

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Recovery indicators

- Service restoration velocity (power/water/telecom)
- Housing habitability proxy (precondition × damage proxy)
- Healthcare access restoration (time-to-care)
- School reopening (%)
- Economic proxy: nighttime lights / business reopen counts (if you add later)

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Validation / backtesting (Puerto Rico)

Approach

Pick 3–5 historical events (hurricanes, major flood episodes, M6+ regional quakes impacting PR operations), then:

1. Recompute indices day-by-day through the event
2. Compare to outcomes:
   - fatalities/injuries (if available)
   - outage duration (power/water)
   - shelter occupancy
   - FEMA declarations/assistance intensity (if used carefully)

Metrics

- Rank correlation between R_m and damage/outage proxies
- Precision/recall for "red municipios" vs known hardest-hit
- Stability under missing-data simulation (drop 20–40% of feeds)

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Fairness & equity checks (so you don’t under-prioritize)

- No “capacity-only” bias: ensure high-SVI areas aren’t deprioritized simply because they have fewer assets.
- Check allocation parity: compare share of “red” classifications vs population share by SVI quartile.
- Ensure explainability always states which vulnerability drivers contributed (SVI themes).
- https://www.atsdr.cdc.gov/place-health/php/svi/svi-data-documentation-download.html
- https://hazards.fema.gov/nri/social-vulnerability

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Explainability template (stakeholder-ready)

“Why is Municipio X red?”

1. **Hazard:** stage exceeded minor flood by +0.42 (rising fast)
2. **Official alerts:** Flash Flood Warning active
3. **Vulnerability:** SVI overall 0.91; no-vehicle theme high
4. **Infrastructure:** hospital access has single-route fragility

Recommended actions (phase-aware):

- Pre-position swift-water rescue near hotspots
- Push targeted warnings to no-vehicle census tracts
- Stage generators at critical facilities in flood footprint

(Our dashboard should show these as a “scorecard” beside the map.)

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Map/dashboard visual encoding (time-pressure friendly)

- **Primary layer:** municipio choropleth (Risk or Readiness)
- **Secondary:** station sparkline trend + exceedance badge
- **Tertiary:** alert polygons (NWS)
- **Confidence overlay:** hatch/opacity tied to Conf score
- **Action panel:** top 5 municipios by “life safety priority” (not just risk)

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Data requirements mapped to notebook outputs (our GMU structure)

This is how we might map to typical notebook-derived frames:

- NOAA water level DF: station_id, t, water_level, datum, qc_flag (CO-OPS API)
- NOAA station metadata DF: station_id, flood_threshold_minor/major, lat, lon (MDAPI)
- USGS hydrology DF: site_no, t, discharge_00060, gage_height_00065 (NWIS)
- NWS alerts DF: id, event, severity, onset, ends, geometry, affected_zones (api.weather.gov)
- Census/ACS DF: geoid, pop, age, disability, income, housing, language, vehicle
- SVI DF: geoid, svi_overall, theme1..theme4 (CDC/ATSDR)
- Infrastructure GIS layers: hospitals, substations, water plants, towers, roads, ports, airports (our curated layers)

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Semester implementation roadmap (14 weeks / ~12 build weeks)

MVP (Weeks 1–6)

- Data Source Register + normalized schemas + refresh runbook (Done)
- Flood Hazard (station + municipio) + NWS escalation logic (Under review)
- Risk Index v1 (Flood) + SVI overlay + confidence scoring (Under review)

Validation Milestone (Weeks 7–10)

- Backtest on 1–2 historical PR events
- Tune bands + phase switching
- Add response overlays (route reliability + facility proximity)

Advanced Extension (Weeks 11–14)

- Earthquake module
- Dynamic weighting (phase + uncertainty-aware)
- Equity checks + stakeholder explainability pack

(capstone “pipeline + explainable index + dashboard + handoff” acceptance criteria.)