Fusion Logic Map

The Fusion Logic Map defines how normalized, individually-trusted telemetry signals are combined into a single operational view for each measurement type of interest. Fusion is the step where conflicting sources are reconciled, freshness-weighted composites are produced, and the composite confidence_band is determined — driving every downstream alert, recommendation, and agent action. This map is not a machine-learning model; it is an explicit, auditable set of weighting rules and conflict-resolution policies that a practitioner can inspect, override, and version. e5-alert-design-spec and e5-decision-support-layer read the fusion output, not the raw signals.

1. Fusion Principles

1. Explicit over implicit. Every weighting factor and conflict-resolution rule is declared in this map, not inferred at runtime.

2. Composite band = minimum contributing band after weights. A fusion result is only as trustworthy as its weakest significant contributor. If a low-band source carries more than a declared maximum share of the composite value, the composite band is capped at low.

3. Freshness degrades trust. A measurement that has aged past its declared staleness window is treated as if its confidence_band is one notch lower for the purpose of weighting.

4. Conflict forwarding, not silent merge. When e5-normalization-layer forwards a conflict-group, fusion must choose a winner by rule — not by averaging silently — and must record the rule applied and the losing values.

5. The fusion layer produces one record per measurement type per fusion window. Downstream systems do not re-fuse; they consume the canonical fusion output.

2. Fusion Window

The fusion window controls temporal alignment across sources with different emission frequencies.

```
default_fusion_window_seconds: 60
per_type_overrides:
  water-level: 30          # high-frequency pond sensors warrant tighter window
  rainfall-rate: 60
  tide-height: 30
  soil-moisture-volumetric: 120   # slower-moving measurement
  flow-rate: 30
  rainfall-accumulation: 300      # rolling 5-min window
```

At the end of each fusion window, the fusion engine collects all normalized records with timestamp_utc within the window for each measurement_type and applies the weighting rules below. Records older than the window are archived, not re-fused.

3. Weighting Rules

Each source contributing to a fused measurement is assigned a composite weight W as the product of three factors:

```
W = W_band × W_freshness × W_authoritative
```

3.1 Band weight (W_band)

confidence_band	W_band
high	1.00
medium	0.60
low	0.20
unknown	0.00 (excluded from fusion)

A source with confidence_band: unknown is never included in the composite value. Its record is forwarded to pipeline monitoring only.

3.2 Freshness weight (W_freshness)

Let age_ratio = record_age_seconds / staleness_ceiling_seconds where staleness_ceiling is 2 × emission_frequency converted to seconds.

age_ratio	W_freshness
≤ 0.50	1.00
0.51 – 0.75	0.80
0.76 – 1.00	0.50
> 1.00	0.10 (stale; flag for pipeline monitoring)

3.3 Authoritative weight (W_authoritative)

authoritative	W_authoritative
true	1.00
false	0.50

3.4 Composite value formula

After computing W_i for each contributing source i:

```
W_total = Σ W_i
fused_value = Σ (W_i × normalized_value_i) / W_total
```

The fused value is a weighted average. If only one source has a non-zero weight, the fused value equals that source's value exactly.

4. Composite Confidence Band

After computing the fused value, the composite confidence_band is determined by the following rules applied in order:

1. Any unknown contributor present? — Composite band = low (the unknown source flagged in provenance; the composite is still produced but capped).

2. Weighted share of low-band sources > 30%? — Composite band = low.

3. Weighted share of medium-or-lower sources > 60%? — Composite band = medium.

4. All contributing sources are high? — Composite band = high.

5. Otherwise: Composite band = medium.

The threshold of 30% for low-band share is the primary guard against a degraded secondary sensor inflating a medium or high composite into a consequential alert. Implementations may tighten but not relax these thresholds without a MINOR version bump to this map.

5. Conflict Resolution Rules

When e5-normalization-layer forwards a conflict-group, fusion applies rules in this priority order:

Priority	Rule	Applied when
1	Higher authoritative wins	One source is authoritative: true, the other is not
2	Higher confidence band wins	Both same authoritative status; one has higher band
3	More recent wins	Same band; one record is fresher
4	Conservative value wins	Tie on all above; use the value that would trigger a higher alert level (safety-conservative)

The conflict resolution outcome is recorded in the fused record:

```
conflict_resolution:
  rule_applied: <1|2|3|4>
  winner_source_id: <source_id>
  loser_source_ids: [<source_id>, ...]
  loser_values: [<value>, ...]
  delta: <absolute difference>
```

This record is written to the provenance store via e5-decision-support-layer before any alert is raised.

6. Fusion Output Schema

```
fused_record:
  measurement_type: <enum from e5-normalization-layer §2.1>
  fused_value: <number>
  unit: <canonical unit>
  confidence_band: <high|medium|low|unknown>
  composite_band_rule: <1|2|3|4|5>    # which composite-band rule applied
  fusion_window_end_utc: <ISO 8601 Z>
  contributing_sources:
    - source_id: <string>
      normalized_value: <number>
      weight: <W_i computed above>
      age_seconds: <integer>
      confidence_band: <band at time of fusion>
  conflict_resolution: <null or object from §5>
  stale_sources: [<source_id>, ...]    # sources with age_ratio > 1.0
```

7. Worked Example — Water Level Fusion (illustrative)

Scenario: South Walton stormwater network, fusion window ending 2026-05-29T19:33:00Z, measurement type water-level.

Inputs from e5-normalization-layer:

source_id	normalized_value (m)	confidence_band	authoritative	age_seconds
sw-water-level-j1	0.753	medium	true	22
sw-tide-noaa-destin	0.481	high	true	18
sw-flow-culvert-c4	0.802	low	true	55

Note: sw-tide-noaa-destin measures coastal tide height at Destin, not pond level, so in a real deployment its measurement_type would differ. For this illustrative example, assume all three are measuring the same drainage reference plane.

Weight calculation (staleness ceiling for water-level = 60 s):

source_id	W_band	age_ratio	W_freshness	W_auth	W_i
sw-water-level-j1	0.60	22/60 = 0.37	1.00	1.00	0.600
sw-tide-noaa-destin	1.00	18/60 = 0.30	1.00	1.00	1.000
sw-flow-culvert-c4	0.20	55/60 = 0.92	0.50	1.00	0.100

W_total = 0.600 + 1.000 + 0.100 = 1.700

Fused value:

```
fused_value = (0.600×0.753 + 1.000×0.481 + 0.100×0.802) / 1.700
            = (0.452 + 0.481 + 0.080) / 1.700
            = 1.013 / 1.700
```

```
            = 0.596 m
```

Composite band check:

- No unknown contributors.
- low-band weighted share = 0.100 / 1.700 = 5.9% — below 30% threshold.
- medium-or-lower share = (0.600 + 0.100) / 1.700 = 41.2% — below 60%.
- Not all high (sw-water-level-j1 is medium).
- Composite band = medium (rule 5).

Fused record output:

```
fused_record:
  measurement_type: water-level
  fused_value: 0.596
  unit: meters above NAVD88
  confidence_band: medium
  composite_band_rule: 5
  fusion_window_end_utc: "2026-05-29T19:33:00Z"
  contributing_sources:
    - source_id: sw-water-level-j1
      normalized_value: 0.753
      weight: 0.600
      age_seconds: 22
      confidence_band: medium
    - source_id: sw-tide-noaa-destin
      normalized_value: 0.481
      weight: 1.000
      age_seconds: 18
      confidence_band: high
    - source_id: sw-flow-culvert-c4
      normalized_value: 0.802
      weight: 0.100
      age_seconds: 55
      confidence_band: low
  conflict_resolution: null
  stale_sources: []
```

If sw-water-level-j1 had instead arrived 70 seconds after the window start (age_ratio = 70/60 = 1.17), it would have been flagged as stale, its W_freshness would drop to 0.10, and its weight would become 0.060. The fused value would shift toward the NOAA tide reading, and sw-water-level-j1 would appear in stale_sources.

8. Operational View

The fusion layer produces one fused_record per measurement_type per window. An operational view is the set of current fused records across all active measurement types. The operational view is the input surface for e5-alert-design-spec and e5-decision-support-layer. Stale or unknown-band entries in the operational view are surfaced to the pipeline monitoring channel defined in e5-pipeline-resilience-playbook — they are not hidden from operators.

9. Versioning and Change Control

Adding a measurement_type or a new weight factor is MINOR. Changing a weighting constant (W_band, W_freshness, W_authoritative) or a composite-band threshold is MINOR but requires re-validation against historical data. Removing a measurement type or changing the fused_record schema shape is MAJOR and triggers coordinated review with e5-alert-design-spec and e5-decision-support-layer.