Metbuoy+ Early Warning System:

Engineering a Field-Reliable, Data-Driven Algorithm for Fish-Kill Early Warning in Philippine Inland Aquaculture

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PHILIPPINES

BACKGROUND

Taal Lake in Batangas is the third-largest lake in the Philippines, after Laguna de Bay and Lake Lanao. It supports the livelihoods of lakeshore communities through tilapia and bangus cage culture, capture fisheries (including the endemic tawilis) and tourism, making it an important contributor to the local economy. Yet it suffers recurring fish kills, with losses of ₱140 million (≈US$3.2 million) in 2011 and 586.38 metric tons in July 2023. Most are attributed to lake overturn — a rapid disruption of thermal stratification driven by wind, rainfall, or temperature change — which can collapse dissolved-oxygen levels within hours and leaves little margin for manual detection.

LAKES IN THE PHILIPPINES

Many Philippine lakes are volcanic or tectonic in origin. Three stand out for size or economic importance:

1. Laguna de Bay (Luzon)
2. Lake Lanao (Mindanao)
3. **Taal Lake (Batangas): 234.2 km², and the deepest at 172 m**



Year / Date	Reported impact	Reported cause or contributing factors
January 2006	~720 metric tons of tilapia and bangus lost, valued at ₱50.4 million (≈US$0.98 million). *Philstar*	Changing wind patterns, oxygen depletion, and suspected sulfur-related effects.
June 2006	~ 25 metric tons of bangus lost in Agoncillo and San Nicolas, affecting 22 fish cages. *Philstar.com*	Lake overturn or upwelling and possible hydrogen sulfide exposure.
2011	~ ₱140 million (≈US$3.2 million) in losses. *World Bank*	Lake overturn, water pollution, drastic weather
May 29, 2019	More than 600 metric tons of tilapia lost, valued at ₱43.13 million (≈US$0.83 million); 121 fish cages were affected. *Dept of Agriculture Portal*	Depleted DO, heavy rain, sudden wind-direction changes, thermal turnover
2021	Recorded fish losses of ~303 metric tons, valued at ₱24.42 million (≈US$0.50 million).	See the caveat below regarding the available annual records.
2022	Recorded fish losses of ~204 metric tons, valued at ₱19.04 million (≈US$0.35 million).	See the caveat below regarding the available annual records.
July 2023	586.38 metric tons of fish lost, valued at ~₱54.685 million (≈US$1.0 million), affecting 241 fish cages. *DOST-ASTI*	Declining dissolved oxygen and deteriorating water quality.
2024	Recorded fish losses of ~577 metric tons, valued at ₱45.162 million (≈US$0.79 million).	The accessible annual record does not establish one specific cause for all losses.

TARGETS

1. Develop a smart monitoring buoy system capable of automated data collection in real-time that is designed for lakes and rivers to enable easier, more cost-effective deployment and maintenance.

2. Develop an integrated and reliable **early warning system for fish kills**, incorporating predictive algorithms, data management infrastructure, web-based monitoring, and real-time visual/audible alerts.

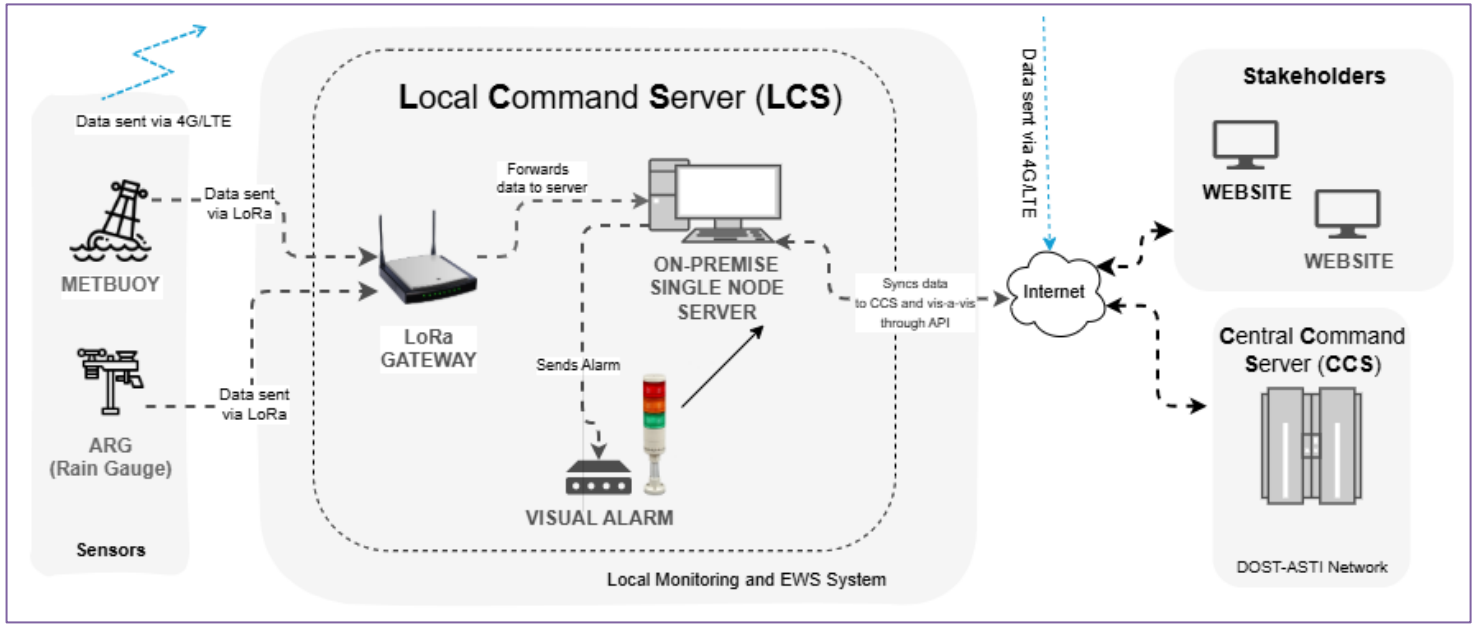
3. Strengthen local expertise through training on R&D and promote technological adoption among scientists and aquafarm operators.

PROPOSED METHOD

Part I: Development and deployment of a real-time automated sensing system for continuous, 24/7 acquisition of key water quality parameters and meteorological data.

Major Components:

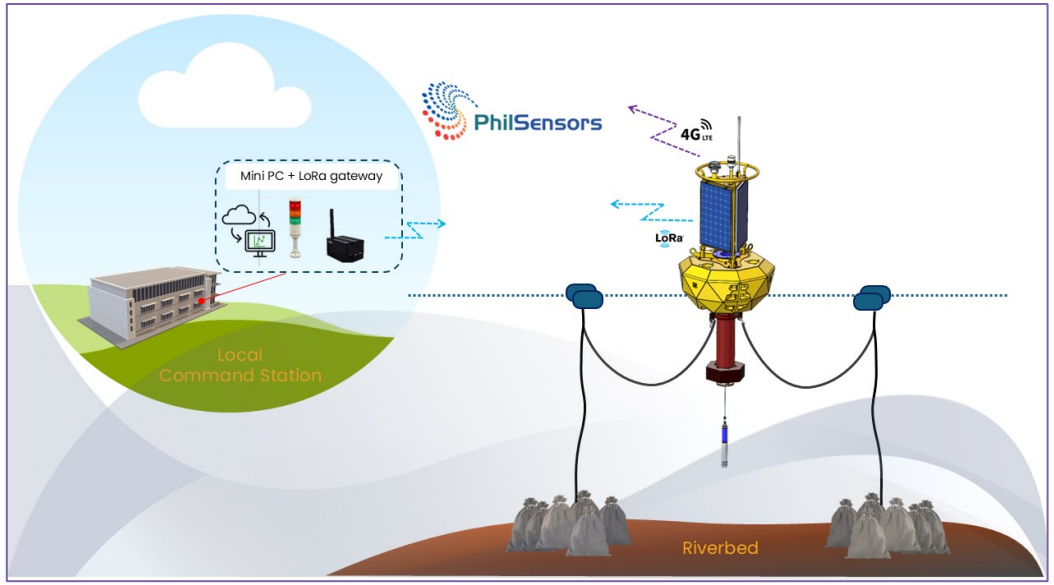
- Meteorological buoy (Metbuoy)
- Automated rain gauge
- Local and centralized data collection and online monitoring platform



Part II: Development and deployment of an integrated digital platform (on-site and online) for aggregating and analyzing sensor data, and formulating a **robust, data-driven algorithm** to enable early detection and warning of potential fish-kill events.

Major Components:

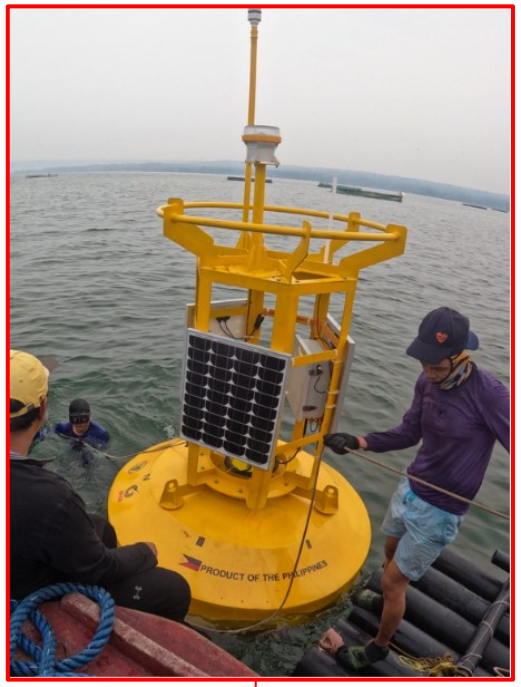
- Local Command Server (LCS)
- Web-based and mobile app
- External Audio/Visual alerting beacon
- LoRa Gateway

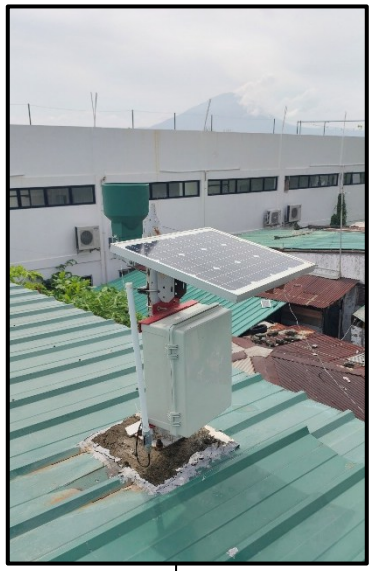


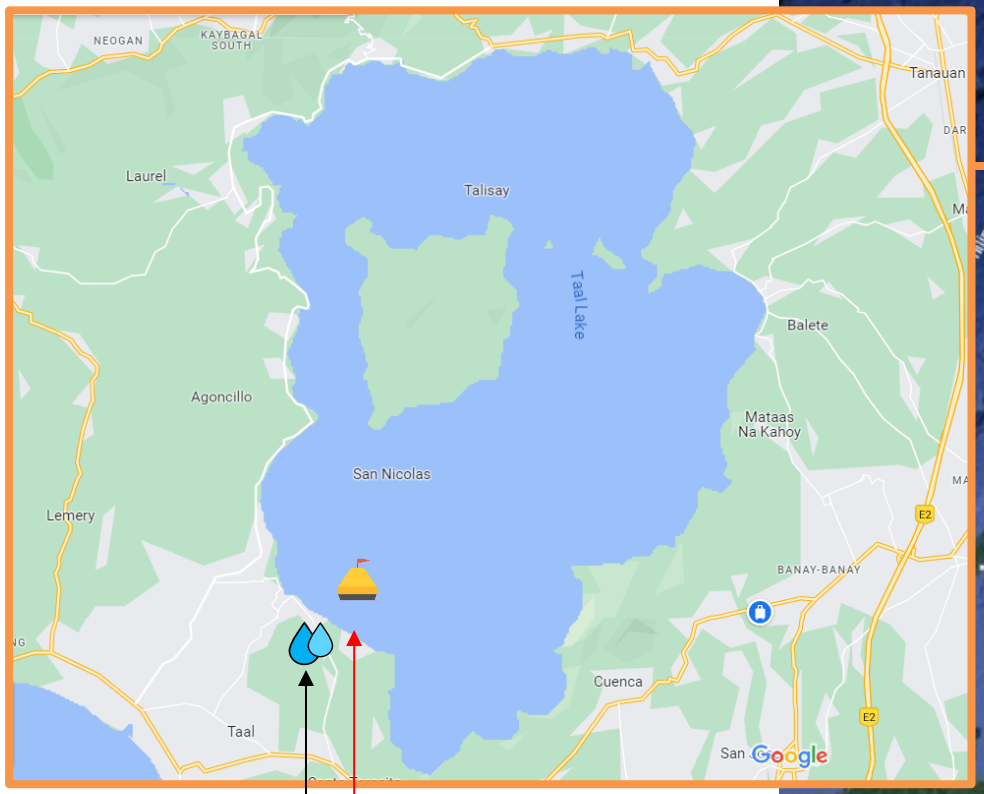
IMPLEMENTATION

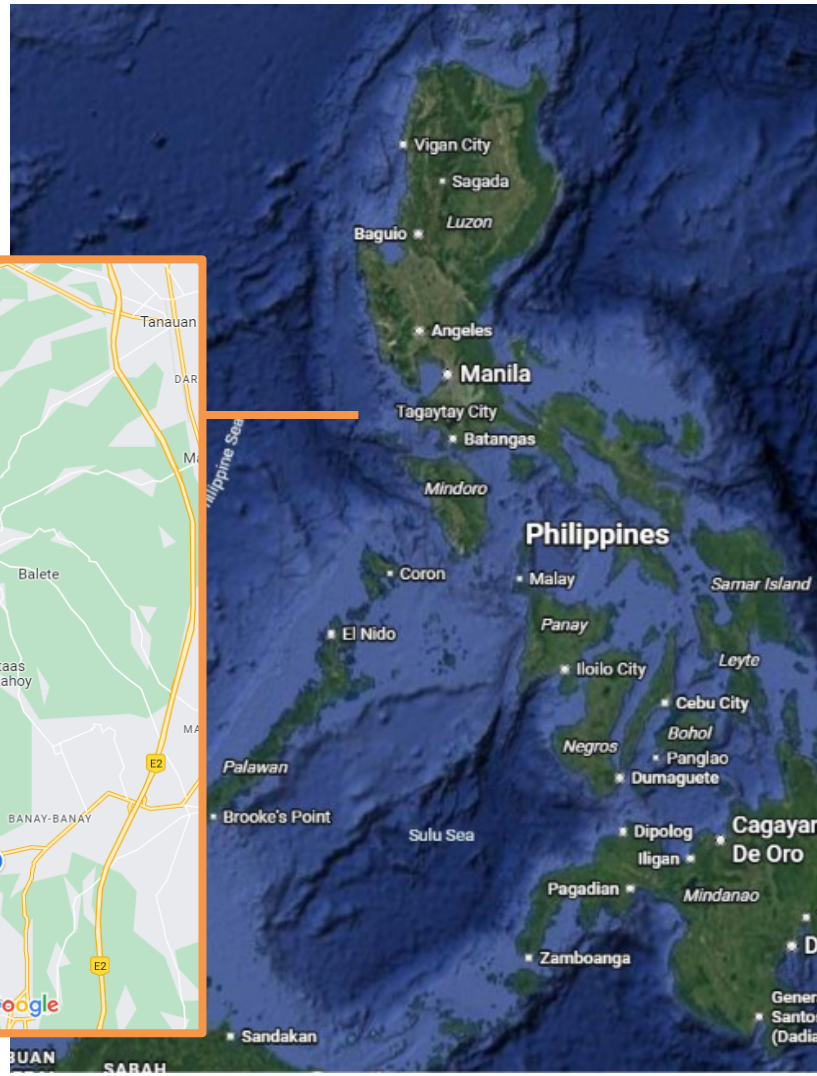
Part I: Deployment of one (1) ASTI-designed smart buoy and one (1) automated rain gauge(ARG) prototypes at San Nicolas, Batangas that is capable of sending real-time key water quality parameters and meteorological data wirelessly over 4G/LTE and LoRa network.

Date of Installation: May 23-25, 2023
Status: Operational









IMPLEMENTATION

Part II: Early Warning System Algorithm

1 Automated Data Cleaning

Captures 6 hours of DO sensor data: The system retrieves the previous 6 hours of DO readings and computes their median and interquartile range. A new reading is accepted only if it falls within 1.5 times the interquartile range of the median, and within the physical limits of 0 to 20mg/L. Readings outside this range are treated as sensor errors and set as missing.

3 Statistical Thresholding

Threshold lookup. Uses season- and hour-specific DO limits to account for diurnal and seasonal variation. Watch, Warning, and Critical limits are learned from the past 365 days of real readings (25th percentile, 10th percentile, and a spread-adjusted lower value), then compared with the DENR's standards (5, 4, and 3 mg/L), using whichever is lower. With insufficient history, it falls back to broader groupings, then to the fixed DENR values.

PIPELINES

2 Dissolved Oxygen (DO) Imputation

KNN imputation. If DO is missing, the system first tries K-Nearest Neighbor (KNN) imputation using pH, ammonium, air temperature, wind speed, rainfall count, and water temperature, rejecting the estimate if it deviates too far from the previous smoothed value. If KNN can't be used, it falls back to spline interpolation, which requires real readings before and after the gap. If neither applies, it uses extrapolation.

4 Alarm Generation

- **EWMA smoothing**. Uses exponentially weighted moving average with **α**=0.29
- State transition depends on persistence or sudden drop criteria
- The alarm escalates one level at a time (Normal → Watch → Warning → Critical), no skipping.
- **Debouncing.** Debouncing uses consecutive-bin counters per limit (reset on recovery), plus counters for rapid drops of ≥20% and for clearing,

1. Aggregation and Data Cleaning:

Total data point collected from 2023-05-25 to 2026-10-31:

931,835

Total no. of errors:

29,308 (3.14%)

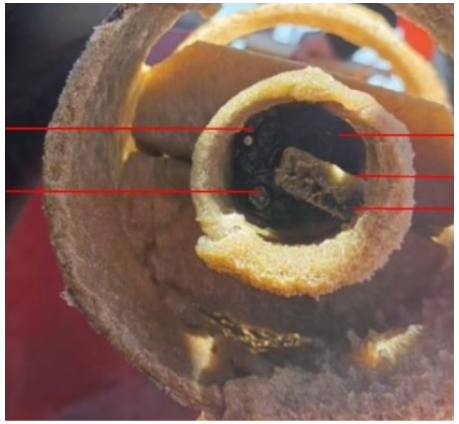
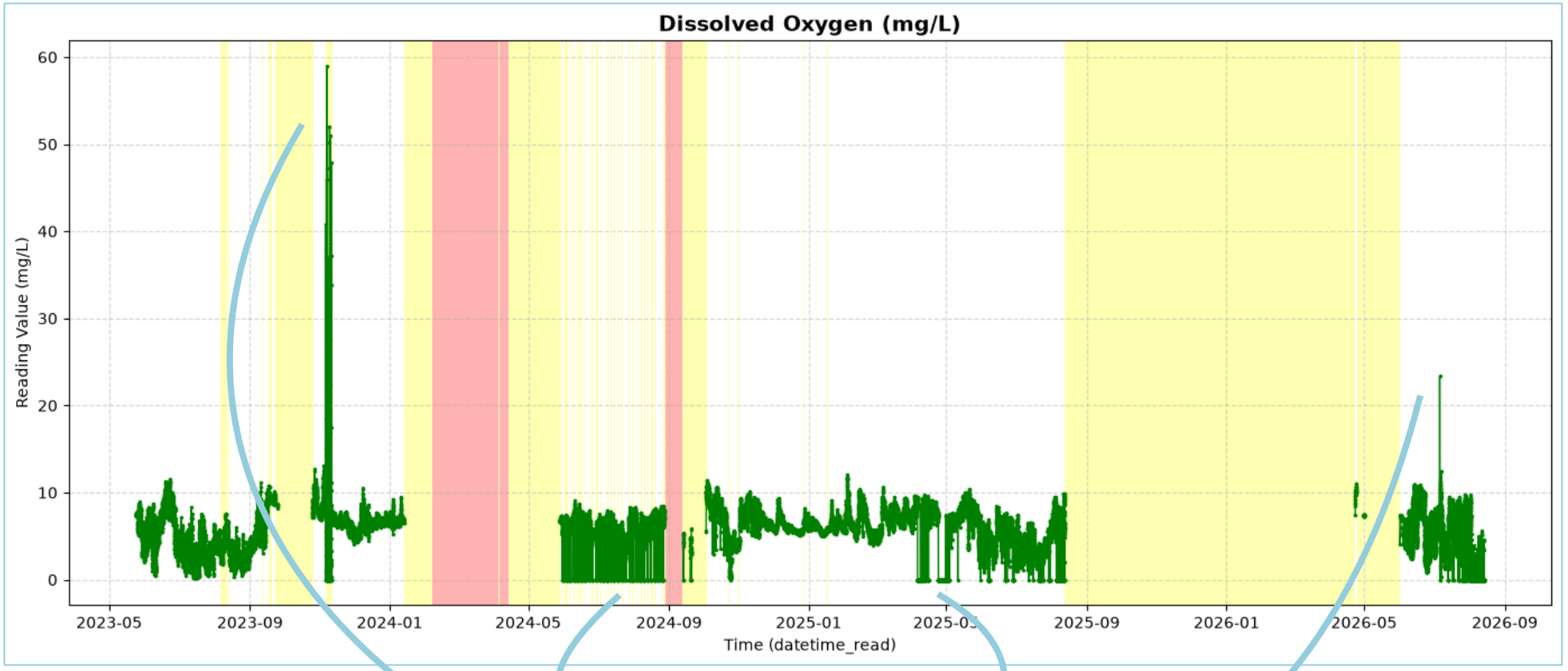


Image of retrieved sonde after 3 months



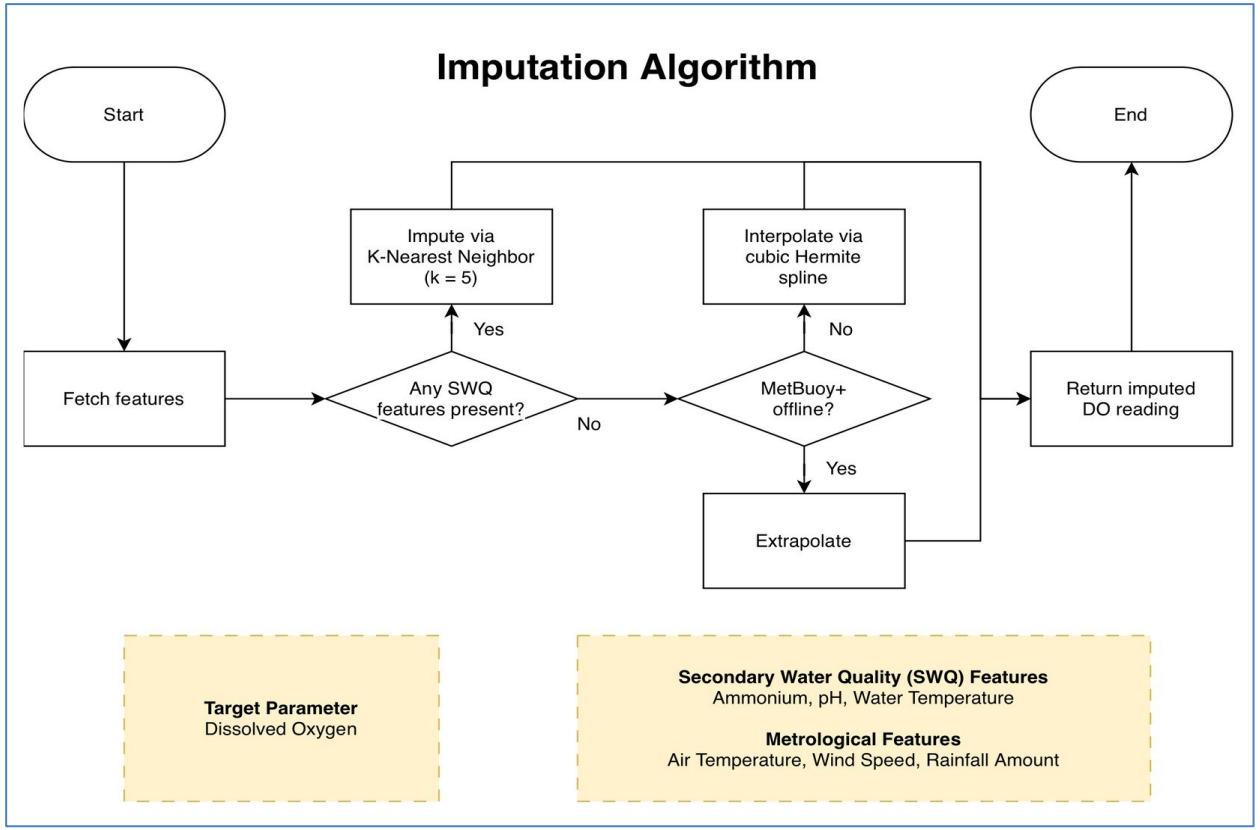
Clear signs of noise/ erroneous sensor reading

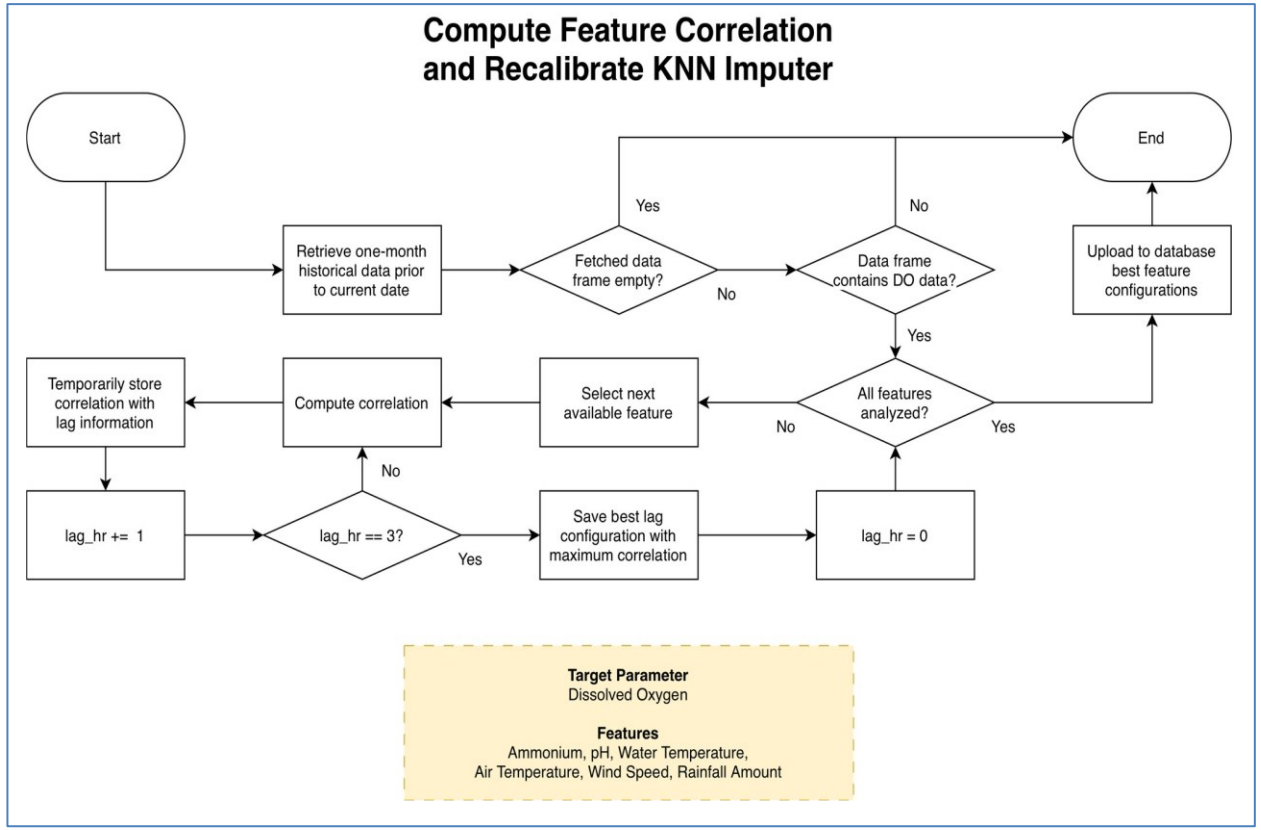
Legend

Offline

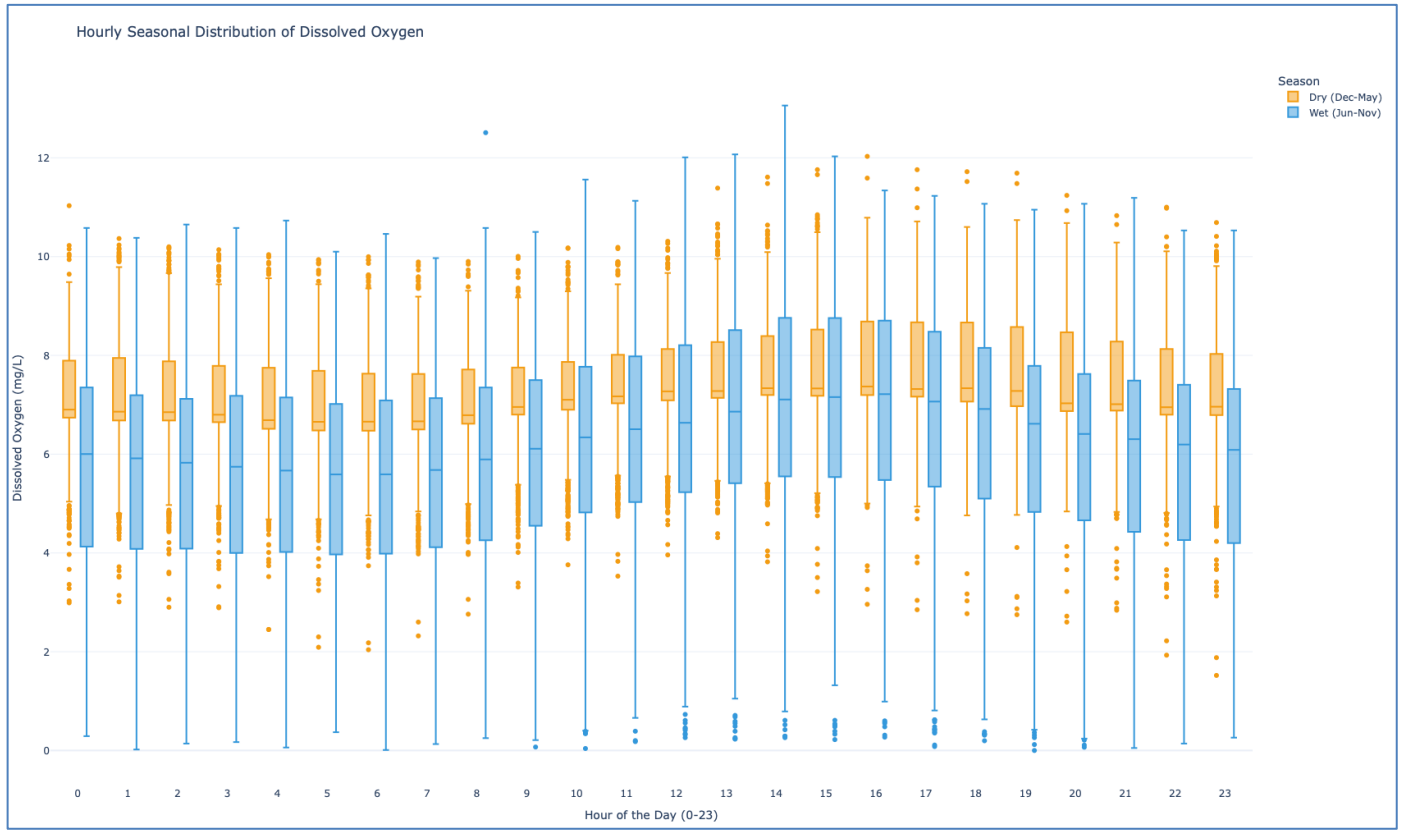
Missing/Invalid Data

2. Imputation Algorithm





3. Statistical Thresholding:



Hourly and Seasonal DO Distribution

Parameter	Unit	Water Body Classification								
		AA	A	B	C	D	SA	SB	SC	SD
BOD	mg/L	1	3	5	7	15	n/a	n/a	n/a	n/a
Chloride	mg/L	250	250	250	350	400	n/a	n/a	n/a	n/a
Color	TCU	5	50	50	75	150	5	50	75	150
Dissolved Oxygen[a] (Minimum)	mg/L	5	5	5	5	2	6	6	5	2
Fecal Coliform	MPN/100mL	<1.1	<1.1	100	200	400	<1.1	100	200	400
Nitrate as NO_3-N	mg/L	7	7	7	7	15	10	10	10	15
pH (Range)		6.5-8.5	6.5-8.5	6.5-8.5	6.5-9.0	6.0-9.0	7.0-8.5	7.0-8.5	6.5-8.5	6.0-9.0
Phosphate	mg/L	<0.003	0.5	0.5	0.5	5	0.1	0.5	0.5	5
Temperature[b]	°C	26-30	26-30	26-30	25-31	25-32	26-30	26-30	25-31	25-32
Total Suspended Solids	mg/L	25	50	65	80	110	25	50	80	110

Minimum water quality parameter based from DENR Administrative Order (DAO) No. 2016-08: Water Quality Guidelines and General Effluent Standards of 2016

Taal Lake Water Quality Monitoring

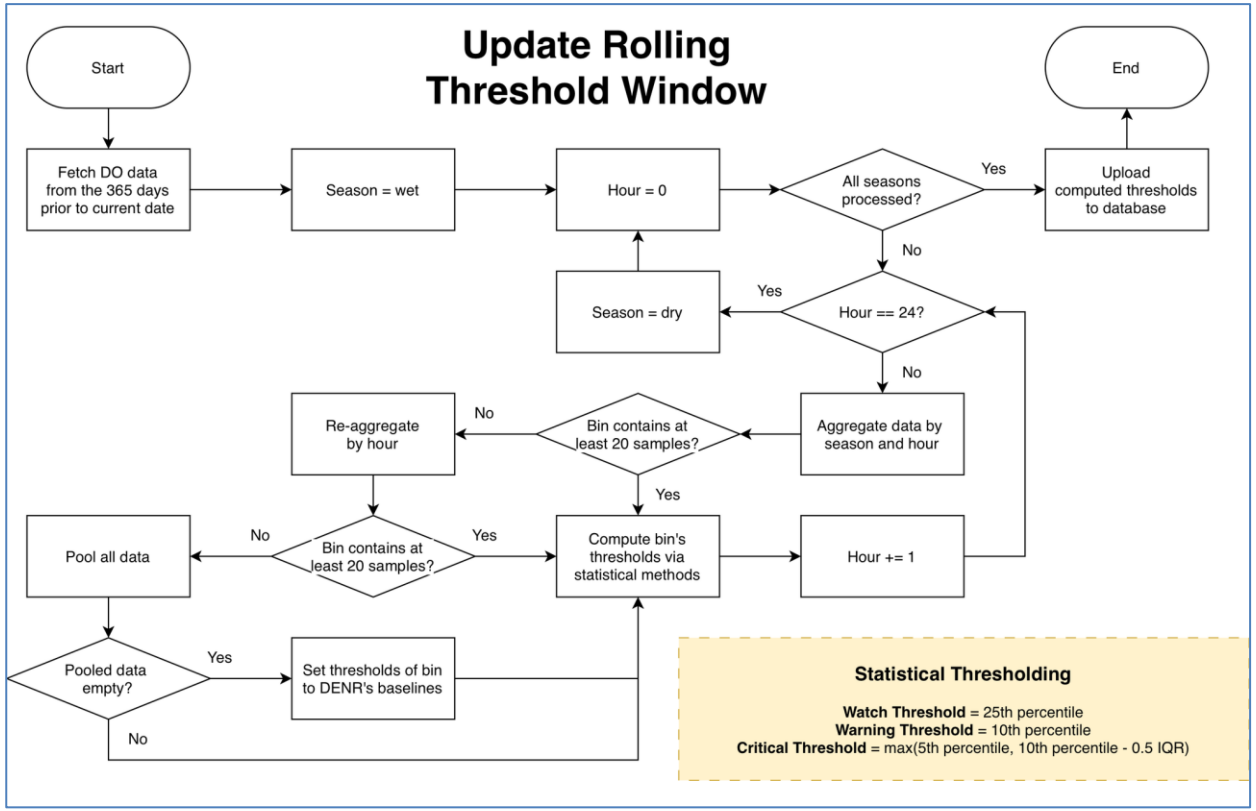
Water Parameters	Normal	Warning	Critical
Dissolved Oxygen (DO) (ppm)	6.0	4.0 -5.0	0.3 -3.8
Water Temperature (0C)	25-30	31-33	35
Transparency (m)	4.0 - 6.0	1.8 - 2.5	0.8 -1.5
Acidity (pH)	6.7 - 8.5	8.6 - 8.9	9.0 -10.0
Carbon Dioxide (CO) (ppm)	2.0 - 10.0	18-21	25
Nitrite (NO2) (ppm)	0.10	1.0 - 1.5	2.0
Ammonia (NH3) (ppm)	0.02	0.10 - 0.15	0.2 - 1.0
Hardness	120-450	500-700	800
Hydrogen Sulfide (H2S) (ppm)	0.002	0.08 - 0.25	0.50 - 10.0
Wind Direction			
Over - all Condition			

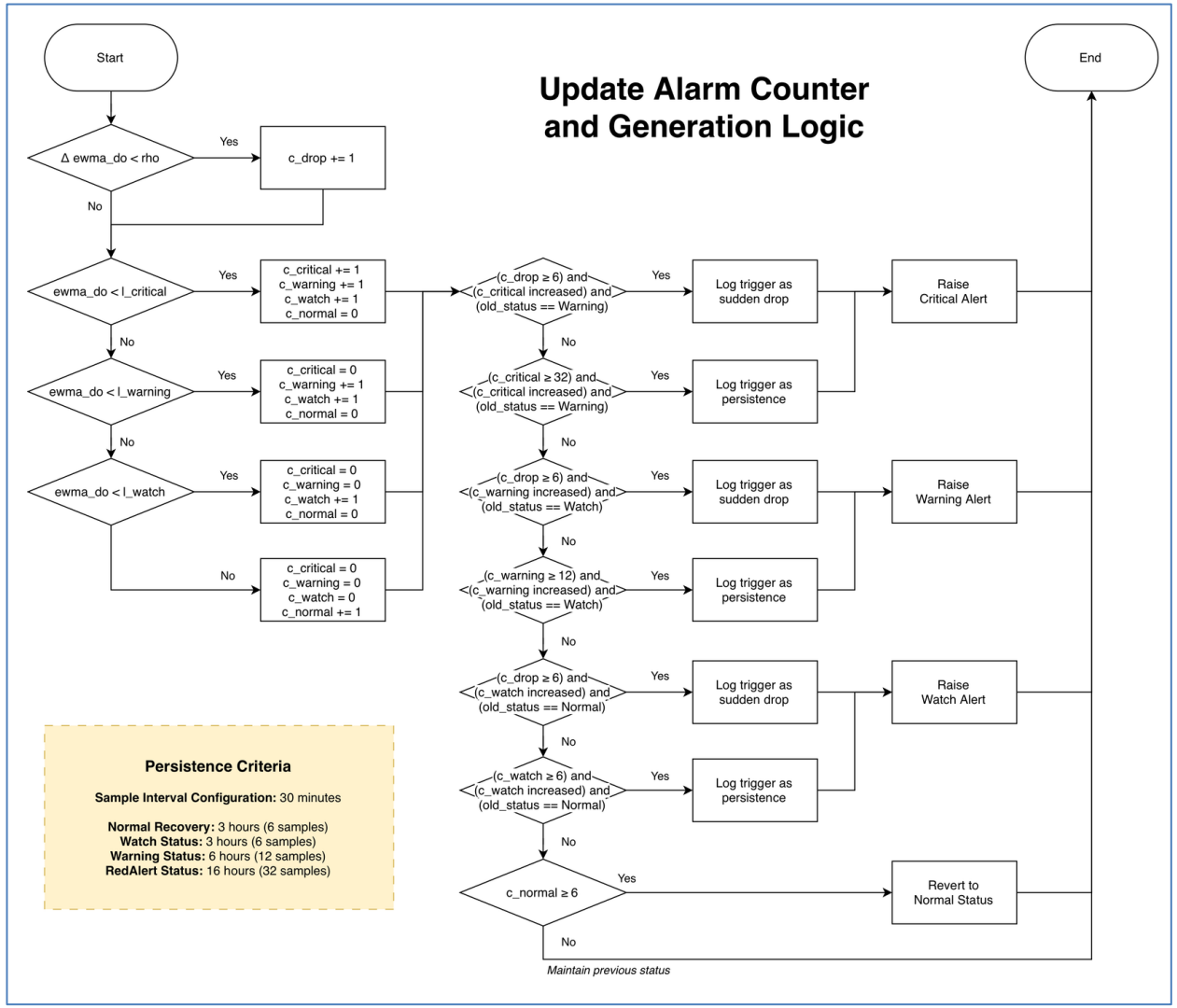
*Inland Fisheries Research Station Monitoring Station, BFAR - 4AMonitoring Bulletin

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21 -22 November 2012

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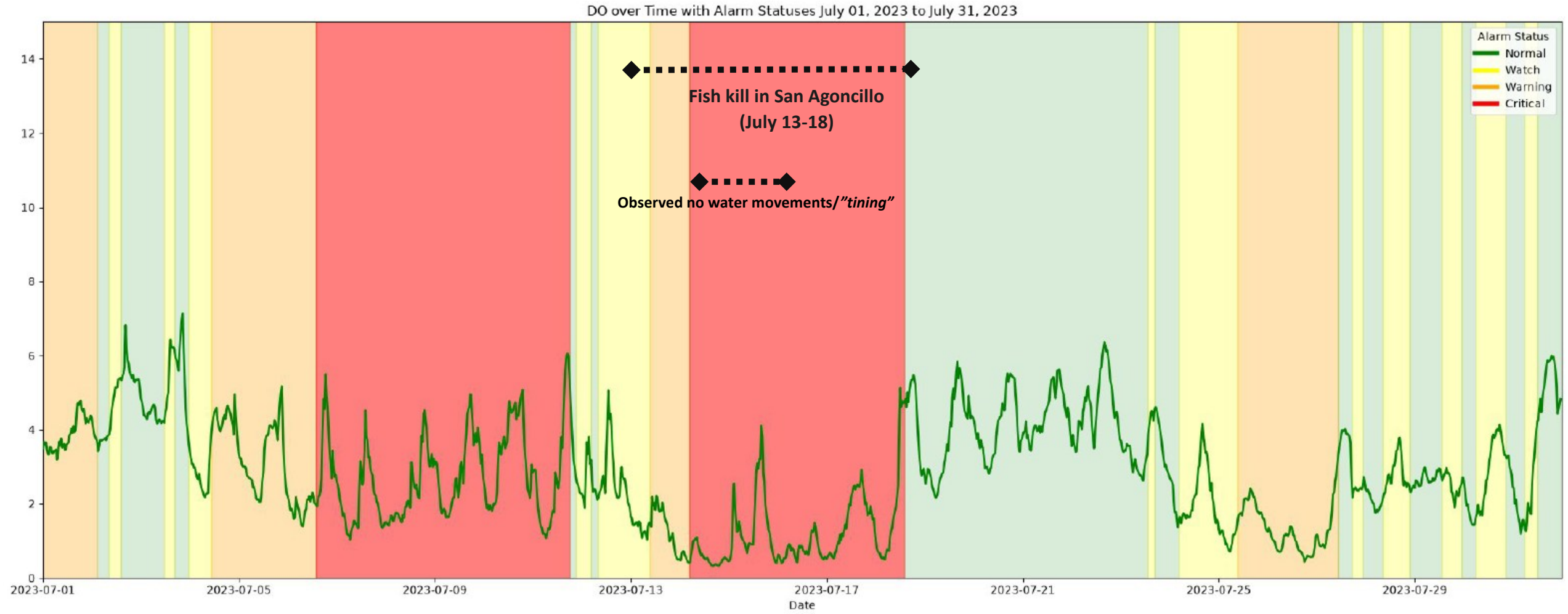
4. Alarm Generation Algorithm





FIELD TESTING

Simulation / Cross Validation:



A month worth of DO during the reported fish kill event at Brgy. Bilibinwang, Agoncillo with the closest proximity from the Metbuoy installation site

IMPACT

Scientific & Technological

- **Locally developed, cost-effective smart sensor buoy** that can measure key water quality parameters and meteorological data in real time.
- **Field-reliable DO algorithm:** cleans sensor noise, fills gaps, and learns season- and hour-specific thresholds from 365 days of data.
- **Growing long-term lake dataset** for modeling towards increasing accuracy and forecasting
- **Scalable and replicable model**

Societal

- **Protects livelihoods:** gives fish farmers and fisherfolk hours of lead time to aerate, harvest early, or move stock
- **From reacting to anticipating:** alerts via on-site LED beacon, dashboard, and soon mobile/API.
- **Easier to adopt:** a smaller, lower-cost next-generation buoy bundled with a packaged software suite, ready for local deployment.

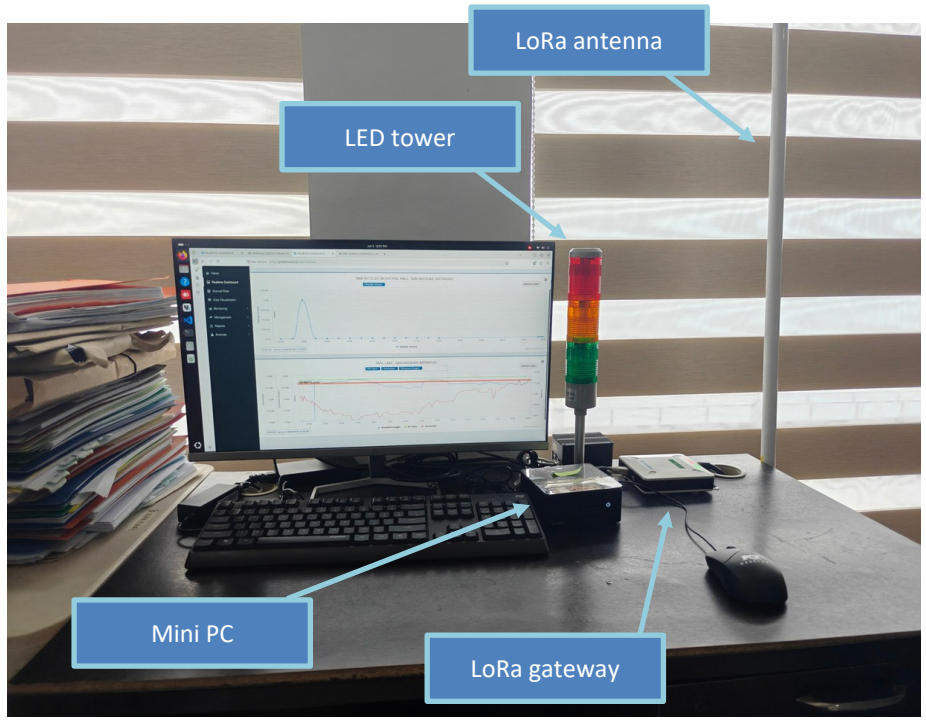
Collaborative

- **Local government partnership:** Local Command Server hosted at the San Nicolas Municipal Hall and in close coordination with the Bureau of Fisheries and Aquatic Resources (BFAR).
- **Capacity building:** R&D training and technology adoption for scientists and aquafarm operators.
- **Open to partners:** scale to other Philippine lakes and beyond.

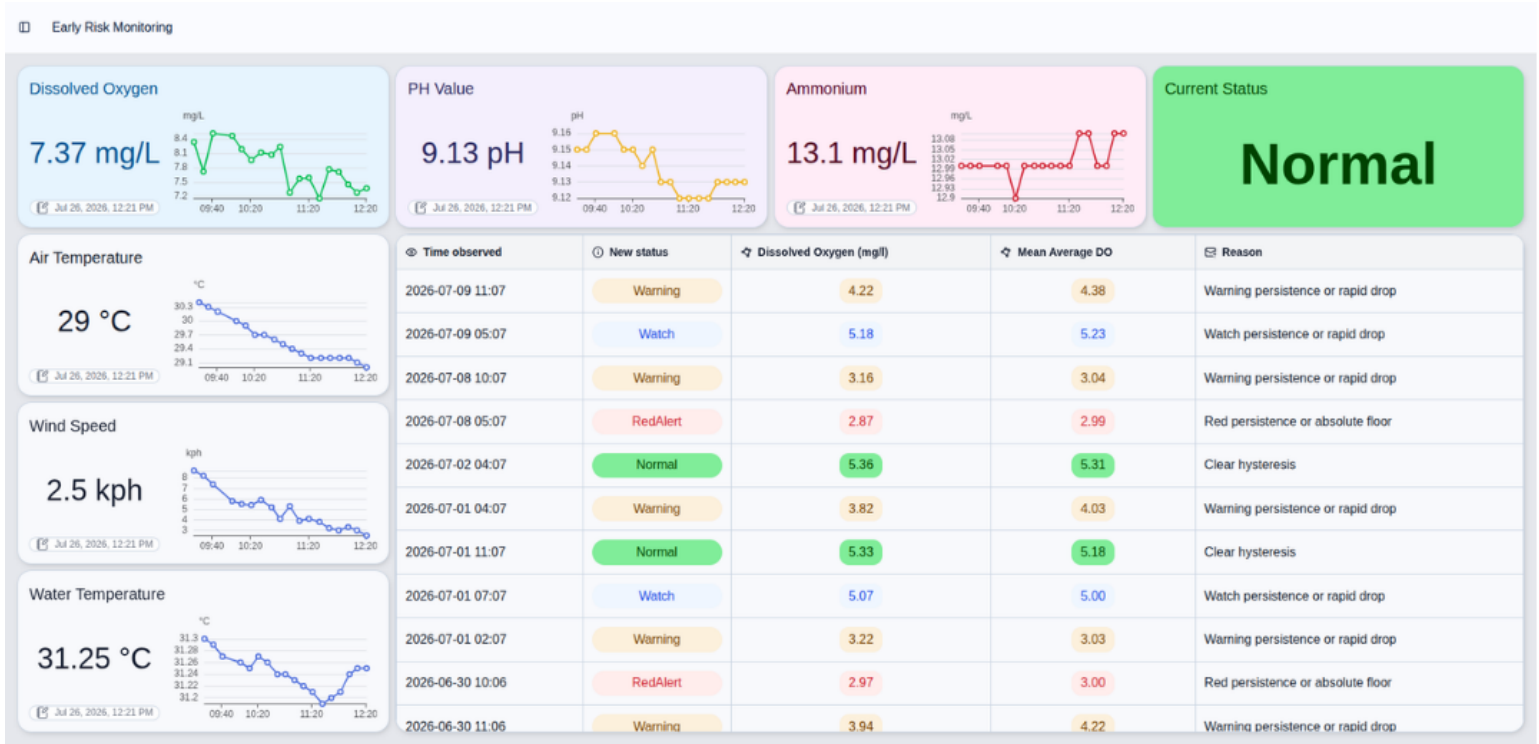
OUTPUT

Successful deployment of one(1) Local Command Server (LCS) at Municipal Hall of San Nicolas, Batangas using a mini desktop PC with LoRa gateway and a multi color LED tower as visual alerting beacon. The early warning algorithm is currently at version 4.

Date of Installation: May 23-25, 2023
Status: Operational



Local Command Server at Municipal Hall, San Nicolas



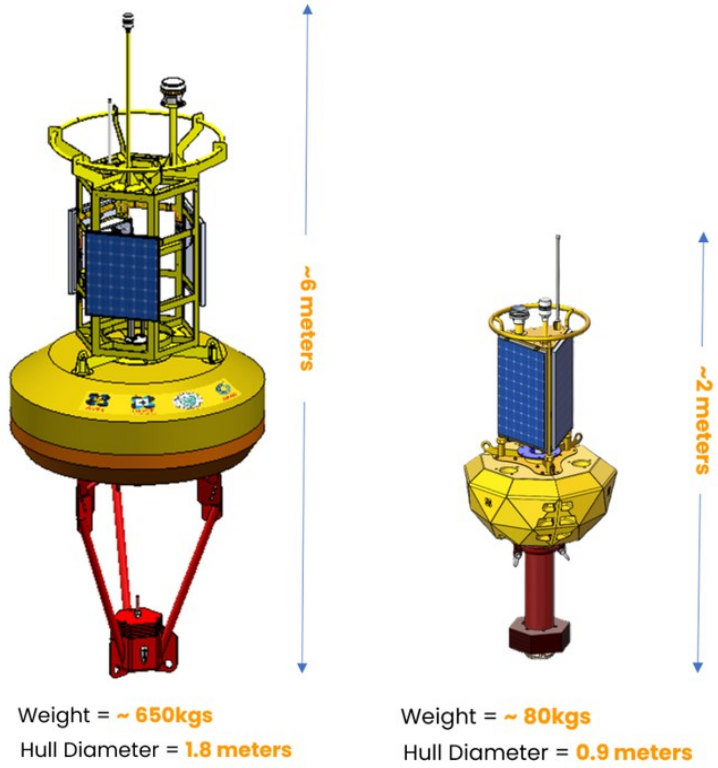
Web-based dashboard layout and user interface

Next activities

1. **Next-generation Metbuoy+:** The redesigned buoy is smaller, making it easier to deploy and more cost-effective. It also features a winch mechanism that keeps the water quality sonde stowed when not in use and lowers it underwater for vertical profiling down to 10 meters.
2. **Multi-node and deployment of Metbuoy+.** Another metbuoy node will be deployed at nearby town to increase the spatial coverage and dataset diversity. LoRa Mesh connectivity between nodes will be implemented.
3. **Alarm broadcasting for mobile and API users.** Extend the alerts beyond the local dashboard to mobile notifications and API where fisherfolks and other stakeholders including monitoring agencies can receive alerts and respond quickly.

Future enhancements and AI roadmap / Long-term output:

- **Spatial correlation & multi-node buoy networks**
- **Integration of Un-Ionized Ammonia (UIA) as a second line of detection**[1]
- **Forecasting instead of thresholding:** use of gradient-boosted trees or sequence models, including feeding on external weather forecasts, to predict DO ahead of time rather than react once it drops
- **Learned multi-parameter risk score**: fuse DO trend, UIA, weather, and thermal data into a single fish-kill probability, capturing factor interactions that single-point DO thresholds miss.
- **Incremental upgrades:** uncertainty-aware imputation and adaptive changepoint detection for the sudden-drop trigger.



[1] Z. Wang and K. M. Y. Leung, "Effects of unionised ammonia on tropical freshwater organisms: Implications on temperate-to-tropic extrapolation and water quality guidelines," Environmental Pollution, vol. 205, pp. 240–249, Oct. 2015, doi: 10.1016/j.envpol.2015.05.045.

CONCLUSION

From reacting to fish kills to anticipating them: a field-reliable early warning system for Taal Lake

- **The problem is recurring and costly.** Taal Lake fish kills keep returning, with 586 metric tons lost in July 2023 and about 577t in 2024. Lake overturn can collapse DO within hours, which is too fast for manual detection.
- **We built an end-to-end system.** A homegrown solution comprising of a real-time monitoring buoy, a local command server, a web and mobile dashboard, and on-site audio/visual alerts.
- **The algorithm is designed for field conditions.** Data cleaning keeps noise out of the alarm logic; contextual imputation keeps the alert running through outages; dynamic thresholding keeps the alarm calibrated to the season; and a dual sudden-drop/persistence alarm state machine keeps the system responsive without being overly sensitive.
- **It was validated against a real event.** In the July 13–18 fish kill at Brgy. Bilibinwang, Agoncillo, the buoy was close by. Only 3 documented events exist so far, so this is early validation.

Next:

- a smaller next-generation buoy
- multi-node coverage over LoRa Mesh technology
- mobile/API alerts for fisherfolk, and
- AI-enabled forecasting for earlier warning.

We welcome partners to scale this to other Philippine lakes and outside the country.

Thank you!

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