

Supplementary Materials: Continuous Satellite Monitoring of Reservoir Capacity Loss Using Deep Learning and Stochastic Mapping: The Poechos Reservoir and Regional Transferability in Northern Peru

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Supplementary Figure

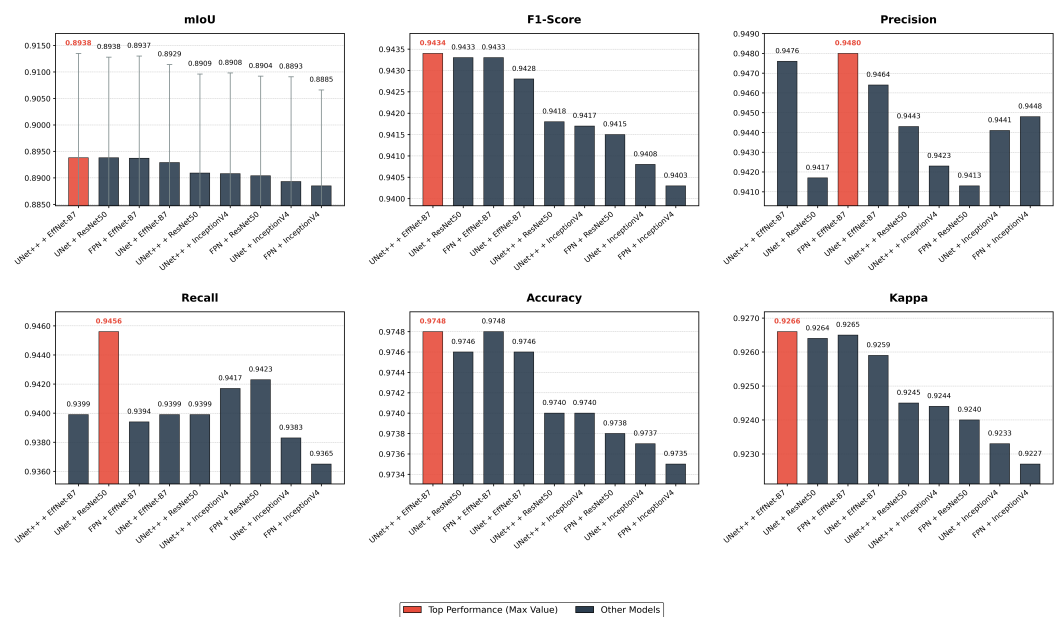


Figure S1. Performance ranking of the nine architecture-encoder combinations based on internal five-fold cross-validation at Poechos Reservoir. The bar charts display the mean values for six evaluation metrics (mIoU, F1-Score, Precision, Recall, Accuracy, and Kappa), with error bars indicating the standard deviation across folds. The y-axes are dynamically scaled to emphasize the fine-grained performance differences among the models. For each metric, the model achieving the highest value is highlighted in red (Top Performance), while the rest are shown in dark blue. This figure complements Table 1 of the main manuscript.

Poechos Reservoir (Primary Study Area)

Table S1. Summary of the Sentinel-1 SAR image inventory acquired over the Poechos Reservoir study area (2021–2026).

Year	Rel. Orbit	Pass Direction	Date Range	No. Images	Repeat Cycle	Annual Total
2021	R91	Ascending	Jan–May	7	~12 days	24
	R40	Descending	May–Dec	17	~12 days	
2022	R91	Ascending	Mar–Dec	25	~12 days	25
	R40	Descending	—	0	—	
2023	R91	Ascending	Jan–Dec	27	~12 days	50
	R40	Descending	Mar–Dec	23	~12 days	
2024	R91	Ascending	Jan–Dec	31	~12 days	61
	R40	Descending	Jan–Dec	30	~12 days	
2025	R91	Ascending	Jan–Dec	51	~6 days	101
	R40	Descending	Jan–Dec	50	~6 days	
2026	R91	Ascending	Jan–Mar	14	~6 days	26
	R40	Descending	Jan–Mar	12	~6 days	
Total						287

Note: Images were acquired in IW-GRD format with VV polarization. Ascending pass (R91) and Descending pass (R40) provide complementary viewing geometries over Poechos Reservoir, Piura, Peru. The repeat cycle improved from ~12 to ~6 days from 2025 onward due to the joint operation of Sentinel-1A and Sentinel-1C.

Table S2. Complete temporal inventory and annual summary of the 53 SWOT altimetry observations utilized for the Elevation-Area-Volume curve reconstruction.

Acquisition Date	Track	Acquisition Date	Track	Acquisition Date	Track
2023-07-27	188	2024-08-01	035	2025-09-01	035
2023-10-13	035	2024-08-21	035	2025-09-06	188
2023-11-24	035	2024-08-27	188	2025-09-22	035
2023-12-15	035	2024-10-02	035	2025-10-13	035
2024-01-05	035	2024-10-23	035	2025-10-18	188
2024-01-26	035	2025-01-14	035	2025-11-03	035
2024-02-16	035	2025-03-18	035	2025-11-08	188
2024-03-07	035	2025-05-04	188	2025-11-23	035
2024-04-03	188	2025-05-20	035	2025-11-29	188
2024-04-18	035	2025-05-25	188	2025-12-14	035
2024-04-24	188	2025-06-09	035	2026-01-04	035
2024-05-09	035	2025-06-15	188	2026-01-10	188
2024-05-15	188	2025-06-30	035	2026-01-25	035
2024-05-30	035	2025-07-06	188	2026-02-15	035
2024-06-20	035	2025-07-21	035	2026-03-08	035
2024-06-25	188	2025-07-27	188	2026-03-29	035
2024-07-11	035	2025-08-11	035	2026-04-18	035
2024-07-16	188	2025-08-17	188	—	—
Annual Observation Summary (Science Phase - 21-day repeat cycle)					
2023: 4 observations		2024: 19 observations		2025: 23 observations	
2026: 7 observations		Total: 53 valid observations			

Note: Inventory of KaRIn observations leveraging crossing orbits (Tracks 188, 035) to enhance temporal cadence. All dates represent valid data that passed rigorous quality control prior to stochastic EAV reconstruction. Columns read vertically.

Table S3. Summary of the 23 concurrent Sentinel-1 SAR and PlanetScope (Ground Truth) acquisitions used for deep learning model training, internal cross-validation, and external validation.

ID	Year	Acquisition Date	Pass Dir.	Rel. Orbit	Dataset Split
1	2021	2021-01-01	Ascending	R91	External Validation
2		2021-03-26	Ascending	R91	Internal (5-Fold CV)
3		2021-04-07	Ascending	R91	Internal (5-Fold CV)
4		2021-05-10	Descending	R40	Internal (5-Fold CV)
5		2021-07-21	Descending	R40	Internal (5-Fold CV)
6		2021-08-14	Descending	R40	Internal (5-Fold CV)
7		2021-11-30	Descending	R40	Internal (5-Fold CV)
8	2022	2022-03-15	Ascending	R91	Internal (5-Fold CV)
9		2022-07-01	Ascending	R91	Internal (5-Fold CV)
10		2022-10-05	Ascending	R91	Internal (5-Fold CV)
11		2022-12-16	Ascending	R91	Internal (5-Fold CV)
12	2023	2023-02-14	Ascending	R91	Internal (5-Fold CV)
13		2023-05-06	Descending	R40	Internal (5-Fold CV)
14		2023-07-20	Ascending	R91	External Validation
15		2023-12-08	Descending	R40	Internal (5-Fold CV)
16	2024	2024-01-25	Descending	R40	Internal (5-Fold CV)
17		2024-06-29	Descending	R40	Internal (5-Fold CV)
18		2024-12-02	Descending	R40	Internal (5-Fold CV)
19	2025	2025-01-22	Ascending	R91	Internal (5-Fold CV)
20		2025-08-20	Ascending	R91	Internal (5-Fold CV)
21		2025-12-21	Descending	R40	Internal (5-Fold CV)
22	2026	2026-01-17	Ascending	R91	Internal (5-Fold CV)
23		2026-03-24	Ascending	R91	External Validation

Note: ‘Acquisition Date’ indicates concurrent Sentinel-1 and PlanetScope (3 m) passes (Ascending R91, Descending R40). Dates strictly isolated for External Validation: 2021-01-01, 2023-07-20, and 2026-03-24.

San Lorenzo Reservoir (Zero-Shot Validation Site)

Table S4. Summary of the Sentinel-1 SAR image inventory acquired over the San Lorenzo Reservoir study area (2021–2026).

Year	Rel. Orbit	Pass Direction	Date Range	No. Images	Repeat Cycle	Annual Total
2021	R40	Descending	May–Dec	16	~14 days	24
	R91	Ascending	Jan–May	8	~21 days	
2022	R91	Ascending	Mar–Dec	25	~12 days	25
2023	R40	Descending	Mar–Dec	21	~14 days	50
	R91	Ascending	Jan–Dec	29	~12 days	
2024	R40	Descending	Jan–Dec	30	~12 days	61
	R91	Ascending	Jan–Dec	31	~12 days	
2025	R40	Descending	Jan–Dec	51	~7 days	101
	R91	Ascending	Jan–Dec	50	~7 days	
2026	R40	Descending	Jan–Mar	13	~7 days	26
	R91	Ascending	Jan–Mar	13	~7 days	
Total						287

Note: Images were acquired in IW-GRD format with VV polarization, following the identical processing pipeline described in Section 2.2.4. Ascending and Descending passes provide complementary viewing geometries over the San Lorenzo Reservoir, northern Peru. Repeat cycle is the mean interval between consecutive acquisitions within each orbit/pass group.

Table S5. Summary of the four PlanetScope zero-shot ground-truth acquisitions used for external validation of the segmentation ensemble at San Lorenzo Reservoir.

ID	Acquisition Date	Dataset Role
1	2024-04-09	External Validation (zero-shot)
2	2024-11-20	External Validation (zero-shot)
3	2025-07-18	External Validation (zero-shot)
4	2026-01-02	External Validation (zero-shot)

Note: All four dates were strictly reserved

as independent ground truth and were never used to train or fine-tune the FPN-InceptionV4 ensemble, consistent with the strict zero-shot inference protocol described in Section 2.2.3.

Table S6. Temporal inventory and annual summary of the 74 validated SWOT altimetry observations utilized for the Elevation-Area-Volume curve reconstruction at San Lorenzo Reservoir.

Acquisition Date	Track	Acquisition Date	Track	Acquisition Date	Track
2023-09-28	188	2024-08-06	188	2025-09-06	188
2023-10-13	035	2024-08-21	035	2025-09-22	035
2023-10-19	188	2024-08-27	188	2025-10-13	035
2023-11-09	188	2024-10-02	035	2025-10-18	188
2023-11-24	035	2024-10-08	188	2025-11-03	035
2023-11-30	188	2024-10-23	035	2025-11-08	188
2023-12-15	035	2024-10-28	188	2025-11-23	035
2024-01-05	035	2024-11-13	035	2025-11-29	188
2024-01-26	035	2024-11-18	188	2025-12-14	035
2024-01-31	188	2025-01-14	035	2026-01-04	035
2024-02-16	035	2025-01-20	188	2026-01-10	188
2024-02-21	188	2025-03-18	035	2026-01-25	035
2024-03-07	035	2025-03-24	188	2026-01-30	188
2024-03-13	188	2025-05-04	188	2026-02-15	035
2024-03-28	035	2025-05-20	035	2026-02-20	188
2024-04-18	035	2025-05-25	188	2026-03-08	035
2024-04-24	188	2025-06-09	035	2026-03-13	188
2024-05-09	035	2025-06-15	188	2026-03-29	035
2024-05-15	188	2025-06-30	035	2026-04-03	188
2024-05-30	035	2025-07-06	188	2026-04-18	035
2024-06-20	035	2025-07-21	035	2026-04-24	188
2024-06-25	188	2025-07-27	188	2026-05-09	035
2024-07-11	035	2025-08-11	035	2026-05-15	188
2024-07-16	188	2025-08-17	188	2026-05-30	035
2024-08-01	035	2025-09-01	035	—	—
2023: 7 observations; 2024: 27 observations; 2025: 25 observations; 2026: 15 observations; Total: 74 valid observations					

Note: Inventory of KaRIn observations from Track(s) 035, 188, filtered following the same quality-control protocol (C1–C7) described in Section 3.4 for the primary study area. Columns read vertically.

Tinajones Reservoir (Zero-Shot Validation Site)

Table S7. Summary of the Sentinel-1 SAR image inventory acquired over the Tinajones Reservoir study area (2021–2026).

Year	Rel. Orbit	Pass Direction	Date Range	No. Images	Repeat Cycle	Annual Total
2021	R142 R91	Descending	Jan–Dec	28	~12 days	36
		Ascending	Jan–May	8	~21 days	
2022	R142 R91	Descending	Mar–Dec	23	~12 days	48
		Ascending	Mar–Dec	25	~12 days	
2023	R142 R91	Descending	Jan–Dec	31	~12 days	61
		Ascending	Jan–Dec	30	~12 days	
2024	R142 R91	Descending	Jan–Dec	30	~12 days	61
		Ascending	Jan–Dec	31	~12 days	
2025	R142 R91	Descending	Jan–Dec	54	~7 days	105
		Ascending	Jan–Dec	51	~7 days	
2026	R142 R91	Descending	Jan–Mar	15	~6 days	28
		Ascending	Jan–Mar	13	~7 days	
Total						339

Note: Images were acquired in IW-GRD format with VV polarization, following the identical processing pipeline described in Section 2.2.4. Ascending and Descending passes provide complementary viewing geometries over the Tinajones Reservoir, northern Peru. Repeat cycle is the mean interval between consecutive acquisitions within each orbit/pass group.

Table S8. Summary of the four PlanetScope zero-shot ground-truth acquisitions used for external validation of the segmentation ensemble at Tinajones Reservoir.

ID	Acquisition Date	Dataset Role
1	2024-01-08	External Validation (zero-shot)
2	2024-11-23	External Validation (zero-shot)
3	2025-06-03	External Validation (zero-shot)
4	2026-01-09	External Validation (zero-shot)

Note: All four dates were strictly reserved

as independent ground truth and were never used to train or fine-tune the FPN-InceptionV4 ensemble, consistent with the strict zero-shot inference protocol described in Section 2.2.3.

Table S9. Temporal inventory and annual summary of the 61 validated SWOT altimetry observations utilized for the Elevation-Area-Volume curve reconstruction at Tinajones Reservoir.

Acquisition Date	Track	Acquisition Date	Track	Acquisition Date	Track
2023-08-01	313	2024-06-09	313	2025-05-09	313
2023-09-28	188	2024-06-25	188	2025-05-30	313
2023-10-02	313	2024-06-30	313	2025-06-19	313
2023-10-19	188	2024-07-16	188	2025-07-06	188
2023-10-23	313	2024-07-21	313	2025-07-10	313
2023-11-09	188	2024-08-06	188	2025-07-31	313
2023-11-13	313	2024-08-10	313	2025-08-21	313
2023-11-30	188	2024-08-27	188	2025-09-06	188
2023-12-04	313	2024-08-31	313	2025-09-11	313
2024-01-15	313	2024-10-08	188	2025-10-02	313
2024-02-05	313	2024-10-12	313	2025-10-18	188
2024-02-21	188	2024-10-28	188	2025-10-23	313
2024-02-26	313	2024-11-02	313	2025-11-08	188
2024-03-13	188	2024-11-18	188	2025-11-12	313
2024-03-17	313	2024-11-23	313	2025-11-29	188
2024-04-03	188	2025-01-20	188	2025-12-03	313
2024-04-07	313	2025-01-24	313	2025-12-24	313
2024-04-24	188	2025-02-14	313	2026-01-14	313
2024-04-28	313	2025-03-07	313	2026-01-30	188
2024-05-15	188	2025-03-28	313	—	—
2024-05-19	313	2025-05-04	188	—	—
2023: 9 observations; 2024: 27 observations; 2025: 23 observations; 2026: 2 observations; Total: 61 valid observations					

Note: Inventory of KaRIn observations from Track(s) 188, 313, filtered following the same quality-control protocol (C1–C7) described in Section 3.4 for the primary study area. Columns read vertically.

Gallito Ciego Reservoir (Zero-Shot Validation Site)

Table S10. Summary of the Sentinel-1 SAR image inventory acquired over the Gallito Ciego Reservoir study area (2021–2026).

Year	Rel. Orbit	Pass Direction	Date Range	No. Images	Repeat Cycle	Annual Total
2021	R142	Descending	Jan–Dec	28	~12 days	36
	R91	Ascending	Jan–May	8	~21 days	
2022	R142	Descending	Mar–Dec	23	~12 days	48
	R91	Ascending	Mar–Dec	25	~12 days	
2023	R142	Descending	Jan–Dec	31	~12 days	61
	R91	Ascending	Jan–Dec	30	~12 days	
2024	R142	Descending	Jan–Dec	30	~12 days	61
	R91	Ascending	Jan–Dec	31	~12 days	
2025	R142	Descending	Jan–Dec	54	~7 days	105
	R91	Ascending	Jan–Dec	51	~7 days	
2026	R142	Descending	Jan–Mar	15	~6 days	28
	R91	Ascending	Jan–Mar	13	~7 days	
Total						339

Note: Images were acquired in IW-GRD format with VV polarization, following the identical processing pipeline described in Section 2.2.4. Ascending and Descending passes provide complementary viewing geometries over the Gallito Ciego Reservoir, northern Peru. Repeat cycle is the mean interval between consecutive acquisitions within each orbit/pass group.

Table S11. Summary of the four PlanetScope zero-shot ground-truth acquisitions used for external validation of the segmentation ensemble at Gallito Ciego Reservoir.

ID	Acquisition Date	Dataset Role
1	2024-05-19	External Validation (zero-shot)
2	2024-12-21	External Validation (zero-shot)
3	2025-03-23	External Validation (zero-shot)
4	2026-02-26	External Validation (zero-shot)

Note: All four dates were strictly reserved

as independent ground truth and were never used to train or fine-tune the FPN-InceptionV4 ensemble, consistent with the strict zero-shot inference protocol described in Section 2.2.3.

Table S12. Temporal inventory and annual summary of the 33 validated SWOT altimetry observations utilized for the Elevation-Area-Volume curve reconstruction at Gallito Ciego Reservoir.

Acquisition Date	Track	Acquisition Date	Track	Acquisition Date	Track
2023-07-27	188	2024-06-25	188	2025-06-15	188
2023-09-28	188	2024-07-16	188	2025-07-06	188
2023-10-19	188	2024-08-06	188	2025-07-27	188
2023-11-09	188	2024-08-27	188	2025-08-17	188
2023-11-30	188	2024-10-08	188	2025-09-06	188
2024-01-31	188	2024-10-28	188	2025-10-18	188
2024-02-21	188	2024-11-18	188	2025-11-08	188
2024-03-13	188	2025-01-20	188	2025-11-29	188
2024-04-03	188	2025-03-24	188	2026-01-10	188
2024-04-24	188	2025-05-04	188	2026-01-30	188
2024-05-15	188	2025-05-25	188	2026-02-20	188
2023: 5 observations; 2024: 13 observations; 2025: 12 observations; 2026: 3 observations; Total: 33 valid observations					

Note: Inventory of KaRIn observations from Track(s) 188, filtered following the same quality-control protocol (C1–C7) described in Section 3.4 for the primary study area. Columns read vertically.