Analysis Report Comparing Newly Acquired Data versus the Conceptual Model

Authors: DALE BOWMAN (Affiliate) Digitally signed by DALE BOWMAN (Affiliate) Date: 2025.12.11 15:45:29 -07'00'
Dale O. Bowman II, 8882
Repository Performance Department

Technical Review: Mahawa-Essa Mabossani Akara Digitally signed by Mahawa-Essa Mabossani Akara Date: 2025.12.11 15:50:21 -07'00'
Mahawa-Essa Akara, 8882
Repository Performance Department

QA Review: Catrina Renee Carrillo Digitally signed by Catrina Renee Carrillo Date: 2025.12.16 09:50:58 -07'00'
Catrina Carrillo, 8883
Edgewater, Inc.

Management Review: CHAMMI MILLER (Affiliate) Digitally signed by CHAMMI MILLER (Affiliate) Date: 2025.12.16 10:05:31 -07'00'
Chammi Miller, 8882
Repository Performance Department

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Contents

1. Introduction....3
2. Data Selection and Approach....6
3. Results....10
4. Discussion....15
5. Summary and Conclusions....20
6. References....21
7. Appendix A – Evaluated Data....22
8. Appendix B – Scatter and Box Plots....45
9. Appendix C – Regression Code....65

Tables

Table 1. Fresh Water Head Calibration Targets for CRA-2014. 8
Table 2. Fresh Water Head Calibration Targets for CRA-2026. 9
Table 3. Fresh Water Head Calibration Targets. 11
Table 4. Regression model parameters. 14

Figures

Figure 1. Culebra flow model domain and boundary conditions.... 4
Figure 2. WIPP monitoring well network.... 5
Figure 3. Screened data used for H-4bR data analysis. 7
Figure 4. Scatter and boxplot comparisons of calibration data and targets for well H-4bR.... 11
Figure 5. Regression model and residuals plot for the CRA-2014 steady-state head calibration targets.... 12
Figure 6. Regression model and residuals plot for the CRA-2026 steady-state head calibration targets.... 13
Figure 7. Regression model and residuals plot for the full data steady-state head calibration targets.... 13
Figure 8. A hydrograph of all current WIPP monitoring network wells. 15
Figure 9. A contour map of the differences between CRA-2026 and full data steady-state calibration targets.... 16
Figure 10. A contour map of the differences between CRA-2026 and full data regression models. 17
Figure 11. The H-10 hydro graph. The break in data in 2016 distinguished the former H-10c and current H-10cR wells. 18
Figure 12. A hydrograph of wells with currently increasing head above normalized mean zero. 19
Figure 13. A hydrograph of wells with currently stabilized head below -4 m of normalized head. 19
Figure 14. Hydrographs of wells with currently stabilized head between 0 and -4 m of normalized head over two time periods.... 20

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1. Introduction

This Analysis Report (AR) discusses the evaluation of recent (post 2018) Culebra Dolomite water levels measured in the Waste Isolation Pilot Plant (WIPP) monitoring well network with respect to the conceptual flow model and its numerical model implementation. The data analysis used for the comparisons was accomplished under the direction of AP-150, Rev 1: Analysis Plan for the Analysis of Observed Water Level Fluctuations (Bowman, 2021). Requirement 40 CFR 194.25b (EPA, 2025), directs that the WIPP geologic and hydrologic compliance models are to assume natural environmental future conditions. In the case of the Culebra flow model, a natural aquifer condition is expressed as steady-state representation used for model calibration.

The Culebra Dolomite Member of the Rustler Formation is conceptualized as variably fractured, heterogeneous medium with flow consistent with a double-porosity, multi-rate flow model (Holt 1997). The Culebra is modeled as a single porosity, heterogeneous medium with multi-rate flow and double porosity applied through transport calculations. With respect to the Culebra flow model, heterogeneity is expressed using a multi-linear regression equation to generate transmissivity fields which are provided variability through an ensemble. As part of the modeling process, water level measurements taken from the WIPP monitoring network are used to generate constant head boundaries values (Figure 1), initial heads, and to calibrate the ensemble transmissivity fields.

In this report, the application of new heads as applied to the Culebra flow model will be investigated. Past representations of steady-state water level targets will be compared to larger data sets calculated in a similar fashion, that include new, more recent water level data. Similarly, an investigation of the regression changes across data sets will be explored and compared. Normalized water level trends in the Culebra for the WIPP monitoring network (Figure 2) will be investigated through comparative hydrographs.

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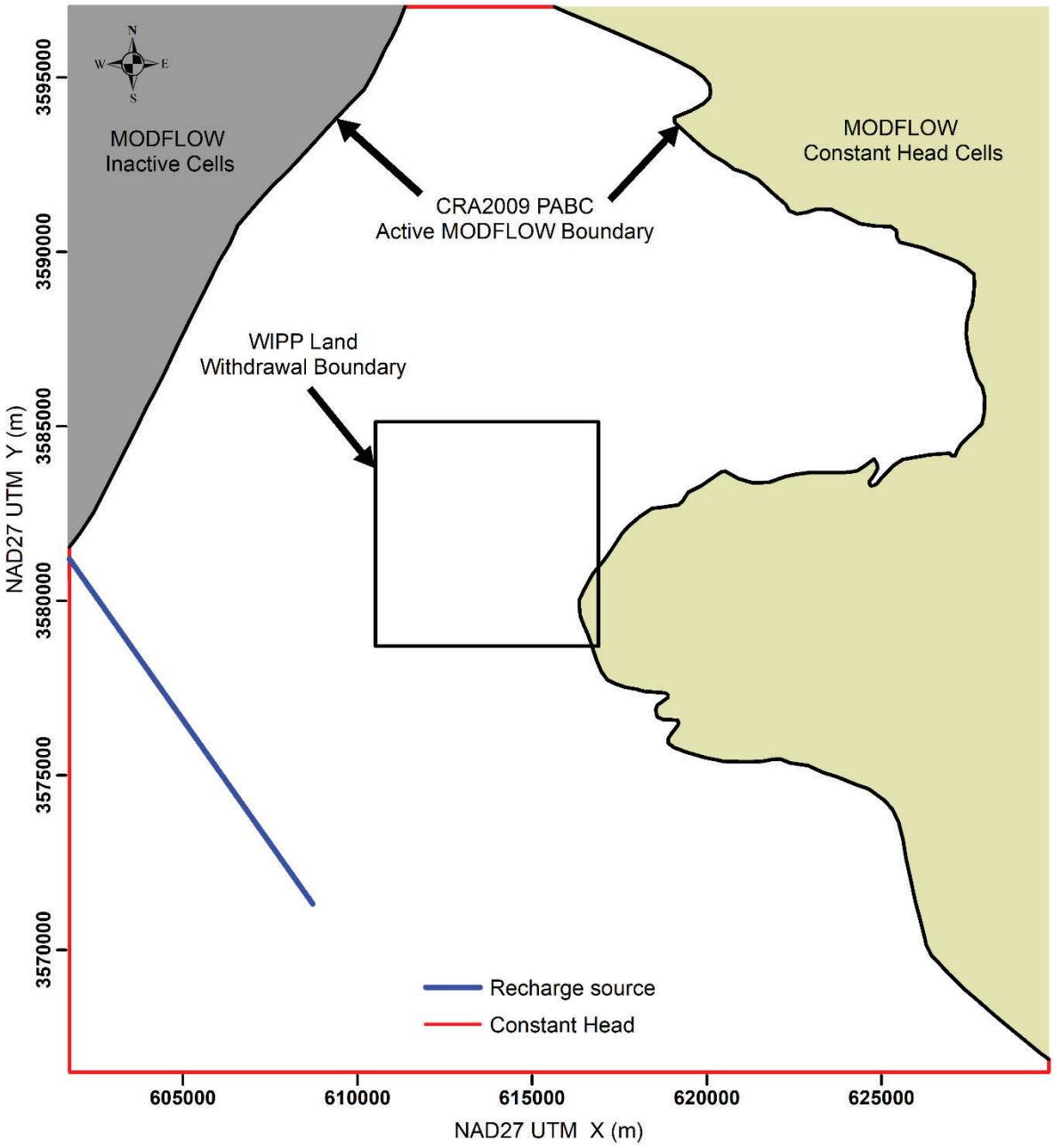

Figure 1. Culebra flow model domain and boundary conditions.

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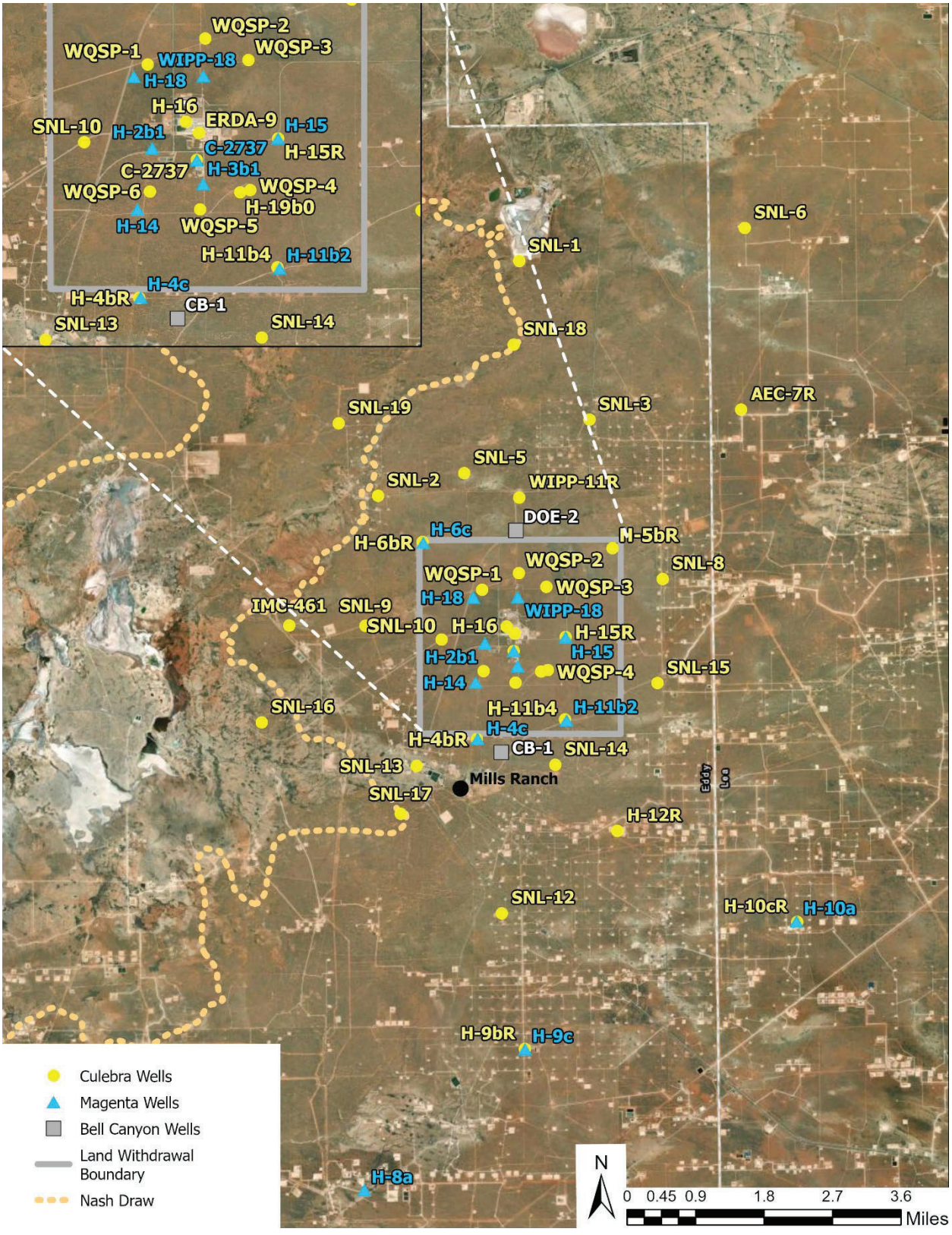

Figure 2. WIPP monitoring well network.

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2. Data Selection and Approach

The conceptual representation of steady-state water levels that lead to the assignment of boundary condition values and calibration targets have changed throughout iterations of the Culebra flow model. The overall objective of this report is to compare past conceptual representations of heads considering the inclusion of new data. This report will include two past water level interpretations, the representative heads used in CRA-2014 and CRA-2026 and compare their values when more recent data is included. The new data that will be incorporated in the analysis are water levels recorded post-2018 (the data cutoff used for CRA-2026).

The objective of generating proper calibration head values representative of those in WIPP monitoring wells is to use water level values that reflect a natural head fluctuation profile of the Culebra, which is as near to steady-state as can be calculated in a real system. For CRA-2014, optimization targets were generated using head values over a concise span of time, specifically depth-to-water measurements made in May 2007 (DOE 2014). Post 2007, Culebra monitoring wells experienced varied water level changes that later indicated that May 2007 held no unique characteristic making it an optimal time in which to represent steady-state aquifer conditions.

For CRA-2026, cumulative water-level data was used to represent steady-state conditions. The general thought was that the averaging of heads obtained through long-term monitoring of the Culebra, devoid of anthropogenic affects, could better represent steady-state conditions, averaging out localized climate-based water level fluctuations. To achieve this end, water level measurements taken over the life of current and past (plugged and abandoned) monitoring wells were screened for anthropogenic changes in water level. The remaining water level measurements were used to calculate a statistical representation of equivalent freshwater head for each well. Histograms and continuous frequency distributions were generated from this data for each monitoring well. The distribution function type (normal, skewed, or modal) was used to choose an appropriate centralization representation (mean, median or mode) per well.

Four initial sets of data are used in this analysis report:

1) CRA 2014 Calibration Targets
2) CRA 2026 Calibration Targets
3) Pre-2018 Water Level Data
4) Cumulative Water Level Data

The 2014 calibration targets were taken from Appendix TFIELD 2014 (DOE, 2014) given in Section TFIELD-5.1, which were used to calibrate base transmissivity fields for that CRA (Table 1). The 2026 calibration targets were taken from Farinacci and Bowman (2022), which were similarly used to calibrate base transmissivity fields for the upcoming CRA 2026 (Table 2). The pre-2018 water levels data set was taken from Bowman (2019). These were the water levels used to generate the statistical representation of head for the WIPP monitoring network used by Farinacci and Bowman (2022) to generate CRA 2026 calibration targets. The final data set used in this analysis were the cumulative water level data measured in the WIPP monitoring well network. These sets included all the data used in the pre-2018 set but added all water levels measured since 2018 and is referred to as the “full data” set for the rest of this report. The new

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data that is incorporated in this report was sourced from both Sandia National Laboratories and RES/LATA water level measurements.

The water level data was filtered in a similar fashion to that used in CRA-2026 where anthropogenically affected data were removed. Removal criterion was based upon known pumping events (e.g., Mills Ranch Pumping) and visual inspection (recognizable pumping depressions in water level, water level outliers). An example of data selection results for well H-b4R is given in Figure 3 where red data indicates anthropogenically affected data excluded from analysis, blue data indicates data used in the calculation of 2026 calibration targets, and green data indicates new data added to the 2026 dataset for comparative analysis. The data used for each well in this report is illustrated in Appendix A, though the illustrations in Appendix A do not distinguish between included and newly included data.

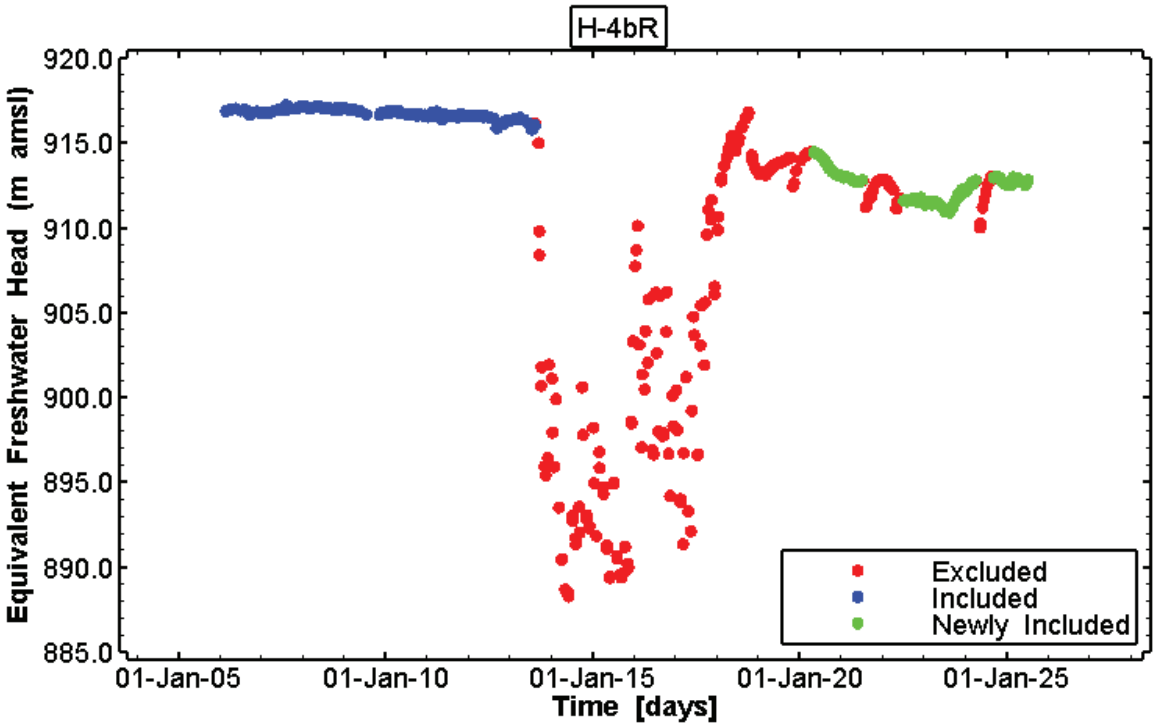

Figure 3. Screened data used for H-4bR data analysis.

Water level data was adjusted for elevation, measurement reference, and density to produce potentiometric equivalence between wells. These adjustments were first calculated when generating the pre-2018 water level data set. The specific gravities, surface elevations, Culebra midpoints, and well casing measurements used in those calculations were also used in generating the cumulative water level data set. The data, in all cases, are represented in units of equivalent freshwater head.

To investigate the steady-state calibration targets, centrality analysis and comparative calibration target analysis will be performed on equivalent freshwater head values for the three calibration

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time periods. Changes between the data sets and representative centrality values will be compared. Investigation into the cumulative water level environment connected to boundary condition assignment will be investigated using multi-variate regression. Scaled hydrographs, utilizing regression data, will be produced to visually investigate water level trends in comprehensive and localized portions of the WIPP monitoring network.

Table 1. Fresh Water Head Calibration Targets for CRA-2014.

CRA-2014 Freshwater Head Calibration Targets (m amsl)			
Well	FWH	Well	FWH
C-2737	921.23	SNL-9	932.05
ERDA-9	924.88	SNL-10	931.54
H-2b2	929.62	SNL-12	915.24
H-3b2	918.68	SNL-13	918.19
H-4b	916.34	SNL-14	916.33
H-5b	939.12	SNL-15	1060
H-6b	936.44	SNL-16	918.68
H-7b1	914.58	SNL-17a	916.78
H-9c	912.8	SNL-18	939.87
H-10c	922.02	SNL-19	937.58
H-llb4	917.09	USGS-4	911.11
H-12	916.53	WIPP-11	940.65
H-15	920.32	WIPP-13	939.78
H-17	916.24	WIPP-19	933.66
H-19b0	918.84	WIPP-25	937.57
IMC-461	928.95	WIPP-30	939.37
SNL-1	941.86	WQSP-1	938.28
SNL-2	937.65	WQSP-2	939.87
SNL-3	939.81	WQSP-3	936.43
SNL-5	938.59	WQSP-4	919.5
SNL-6	1110	WQSP-5	918.18
SNL-8	929.94	WQSP-6	921.96

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Table 2. Fresh Water Head Calibration Targets for CRA-2026.

CRA-2026 Freshwater Head Calibration Targets (m amsl)							
Well	Mean	Median	Mode	Well	Mean	Median	Mode
Normal Distributions				Skewed Distributions			
ERDA-9	**925.14**	925.16	925.33	C-2737	921.24	**921.32**	921.63
H-3b2	**919.00**	919.04	919.06	H-4bR	916.75	**916.78**	917.01
SNL-2	**936.31**	936.23	935.71	H-5b	939.70	**939.76**	939.90
SNL-9	**930.76**	930.71	930.63	H-9c	912.88	**912.97**	912.98
USGS-4	**911.13**	911.1	911.08	H-10cR	921.30	**921.07**	921.04
WQSP-2	**939.39**	939.21	937.81	H-15R	919.78	**919.86**	919.86
Bimodal Distributions				H-17	916.61	**916.66**	916.64
H-2b2	928.44	928.56	**928.61**	H-19b0	918.70	**918.73**	918.70
H-6bR	936.11	935.99	**935.63**	SNL-12	915.87	**915.87**	915.76
H-7b1	914.24	914.08	**914.04**	SNL-13	920.26	**920.37**	920.50
H-11b4R	918.04	918.37	**918.42**	SNL-14	915.93	**915.94**	916.12
H-12R	917.90	917.91	**917.91**	SNL-16	917.70	**917.63**	917.63
IMC-461	927.57	927.64	**927.52**	SNL-19	939.50	**939.25**	938.47
SNL-1	939.56	939.58	**938.46**	WIPP-13	936.14	**936.35**	937.23
SNL-3	938.27	938.25	**937.45**	WQSP-1	936.69	**936.57**	935.35
SNL-5	937.39	937.24	**936.57**	WQSP-4	918.49	**918.67**	919.21
SNL-8	931.75	931.66	**931.70**	WQSP-5	917.94	**918.17**	918.63
SNL-10	930.40	930.72	**930.74**	WQSP-6	921.17	**921.34**	922.05
SNL-17a	916.40	916.38	**916.26**	AEC-7R	933.34	**933.37**	933.37
SNL-18	937.37	937.21	**936.60**	P-15	917.67	**917.61**	917.55
WIPP-11	939.14	939.08	**938.29**	P-17	915.51	**915.55**	NA
WIPP-19	933.41	933.44	**934.64**	WIPP-12	934.08	**933.99**	934.23
WQSP-3	935.85	935.55	**934.80**	WIPP-25	933.76	**933.65**	933.65
				WIPP-26	922.41	**922.36**	922.36
				WIPP-30	938.64	**938.66**	937.82

*Colored/bolded values indicate the centrality value used in calibration

During the calibration process, some wells were disqualified or re-conceptualized in a non-traditional fashion. Two sets of wells were removed from analysis. The first set were those that have been plugged and abandoned. These wells were excluded as there is no new data from the wells since the CRA-2026 analysis for a comparative analysis in this report. Wells SNL-6 and SNL-15, currently active wells, were removed from comparative analysis. These wells have continually recovered from their initial drilling and testing for over a decade. Additionally, their projected stable water levels are much higher than the rest of the WIPP monitoring network. The two wells are situated to the far east of the network in the least transmissive portions of the Culebra.

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As their transmissivities are so low, their head values are likely representative of a past hydrologic setting where the cumulative, unaffected head of the Culebra was much higher.

Wells H-5b, H-9c, H-10c, and WIPP-11 were reconceptualized as a cumulative water level location with the newer H-5bR, H-9bR, H-10cR, and WIPP-11R wells, respectively. The data for these wells were merged into a single dataset per location. As the wells are co-located on a well pad, with respect to the Culebra flow model discretization, the distance between the wells is of minimal impact.

3. Results

Analysis results cover three categories: comparative freshwater head (FWH) data coverage with centrality calculations, comparative multi-variate regression models, and normalized WIPP monitoring well hydrographs.

Comparative Freshwater Heads

Freshwater head data coverages were generated to compare the steady-state and calibration targets for CRA 2014, CRA 2026, and the same methodology used for CRA-2026 with the inclusion of post 2018 data. A comparison was generated for each well with an example shown in Figure 4 for well H-4bR. The comparison contains:

1) the single head value used in CRA 2014 calibrations (red diamond),
2) the array of data used to calculate the CRA 2026 head calibration target (blue dots) accompanied by the CRA 2026 head calibration target (black square),
3) the full non-anthropogenic data set (green dots) accompanied by the calculated mean, median and mode of the set, and
4) box plots showing the mean values (red line), 25th and 75th percentiles that construct the interquartile range (box), whiskers that describe 1.5*the interquartile range, and outlier values (black circles).

A full set of scatter and boxplot comparisons is provided in Appendix B. A table of the centrality calculations and 2026 calibration target versus full data changes is shown in Table 3.

In most cases, centrality calculations decrease with the addition of water level measurements since 2018 (27 wells). Eight wells show no change but were those that had a bimodal distribution of head, so the frequency of change in the wells did not persist enough to sway the values. The only well that showed no change and was not calculated with a bimodal distribution was well H-17 in which all new data was anthropogenically affected. The largest decrease in average head across the WIPP monitoring network was 3.45 m. Five wells showed increases in average head, but all were below a magnitude of 0.2 m.

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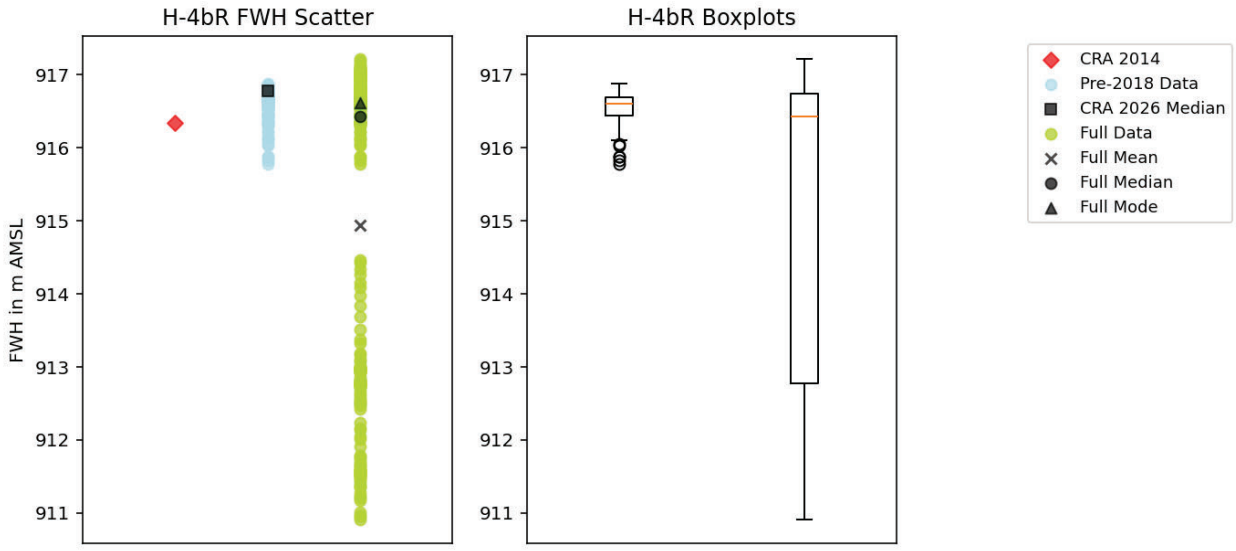

Figure 4. Scatter and boxplot comparisons of calibration data and targets for well H-4bR.

Table 3. Fresh Water Head Calibration Targets.

Well Name	2014 Cal. Target	2026 Cal. Target	Full Data Cal. Target	2026 vs Full Data Centrality Change	Well Name	2014 Cal. Target	2026 Cal. Target	Full Data Cal. Target	2026 vs Full Data Centrality Change
All values are in m FWH amsl									
AEC-7R	NA	933.37	933.31	-0.06	SNL-13	918.19	920.37	916.92	-3.45
C-2737	921.23	921.32	921.35	0.03	SNL-14	916.33	915.94	915.85	-0.09
ERDA-9	924.88	925.14	924.22	-0.92	SNL-16	918.68	917.63	917.38	-0.25
H-2b2	929.62	928.61	928.61	0.00	SNL-17a	916.78	916.26	914.71	-1.55
H-3b2	918.68	919.00	918.83	-0.17	SNL-18	939.87	936.6	933.88	-2.72
H-4bR	916.34	916.78	916.43	-0.35	SNL-19	937.58	939.25	938.71	-0.54
H-5merge	939.12	939.76	939.49	-0.27	WIPP-11	940.65	938.29	938.72	0.43
H-6bR	936.44	935.63	932.86	-2.77	WIPP-13	939.78	936.35	936.14	-0.21
H-7b1	914.58	914.04	913.92	-0.12	WIPP-19	933.66	934.64	935.07	0.43
H-9merge	912.8	912.97	913.10	0.13	WQSP-1	938.28	936.57	935.72	-0.85
H-10merge	922.02	921.07	920.89	-0.18	WQSP-2	939.87	939.39	937.55	-1.84
H-11b4R	917.09	918.42	918.42	0.00	WQSP-3	936.43	934.8	934.65	-0.15
H-12R	916.53	917.91	917.91	0.00	WQSP-4	919.5	918.67	918.57	-0.10
H-15R	920.32	919.86	919.80	-0.06	WQSP-5	918.18	918.17	917.82	-0.35
H-17	916.24	916.66	916.66	0.00	WQSP-6	921.96	921.34	921.28	-0.06
H-19b0	918.84	918.73	918.72	-0.01	P-15	NA	917.61	NA	NA
IMC-461	928.95	927.52	926.67	-0.85	P-17	NA	915.55	NA	NA
SNL-1	941.86	938.46	936.65	-1.81	SNL-6	1110	NA	NA	NA
SNL-2	937.65	936.31	935.30	-1.01	SNL-15	1060	NA	NA	NA

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Well Name	2014 Cal. Target	2026 Cal. Target	Full Data Cal. Target	2026 vs Full Data Centrality Change	Well Name	2014 Cal. Target	2026 Cal. Target	Full Data Cal. Target	2026 vs Full Data Centrality Change
SNL-3	939.81	937.45	937.45	0.00	USGS-4	911.11	911.13	NA	NA
SNL-5	938.59	936.57	936.14	-0.43	WIPP-12	NA	933.99	NA	NA
SNL-8	929.94	931.7	931.70	0.00	WIPP-25	937.57	933.65	NA	NA
SNL-9	932.05	930.76	929.87	-0.89	WIPP-26	NA	922.36	NA	NA
SNL-10	931.54	930.74	930.74	0.00	WIPP-30	939.37	938.66	NA	NA
SNL-12	915.24	915.87	915.83	-0.04					

Comparative Regression Models

A 2D regression model is used to prescribe constant head boundary condition and initial head values for the Culebra flow model. To investigate the differences, 2D linear regression models were generated for the CRA-2014 steady state calibration targets, the CRA-2026 calibration targets, and the full data set. Figures 5, 6, and 7 illustrate the regression model surface (yellow plane), target data (blue/purple points), and an accompanying plot of the residual values for each regression model. While the CRA-2014 and CRA-2026 residual plots have similar value ranges, the full data set residuals range is slightly lower. A table of the regression model parameters is provided in Table 4. These regressions were calculated using the Linear Regression module from scikit-learn v1.7. Note that the differences between these 2D linear regression models in this report may not be the same as those generated by the multi-variate regression model used for the CRA.

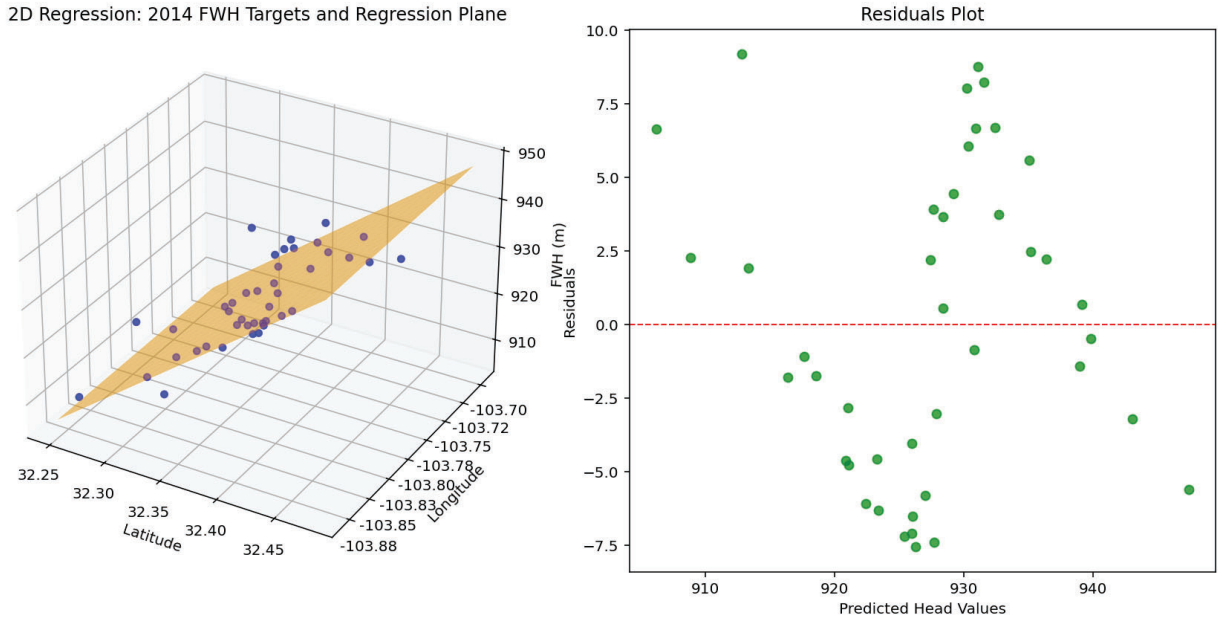

Figure 5. Regression model and residuals plot for the CRA-2014 steady-state head calibration targets.

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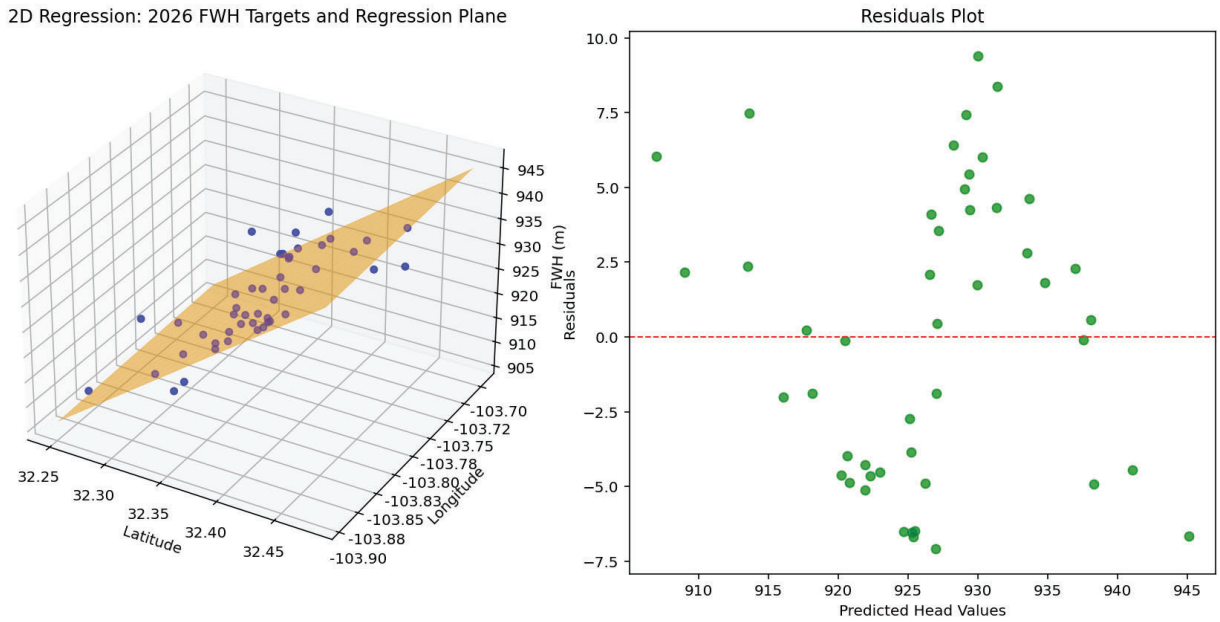

Figure 6. Regression model and residuals plot for the CRA-2026 steady-state head calibration targets.

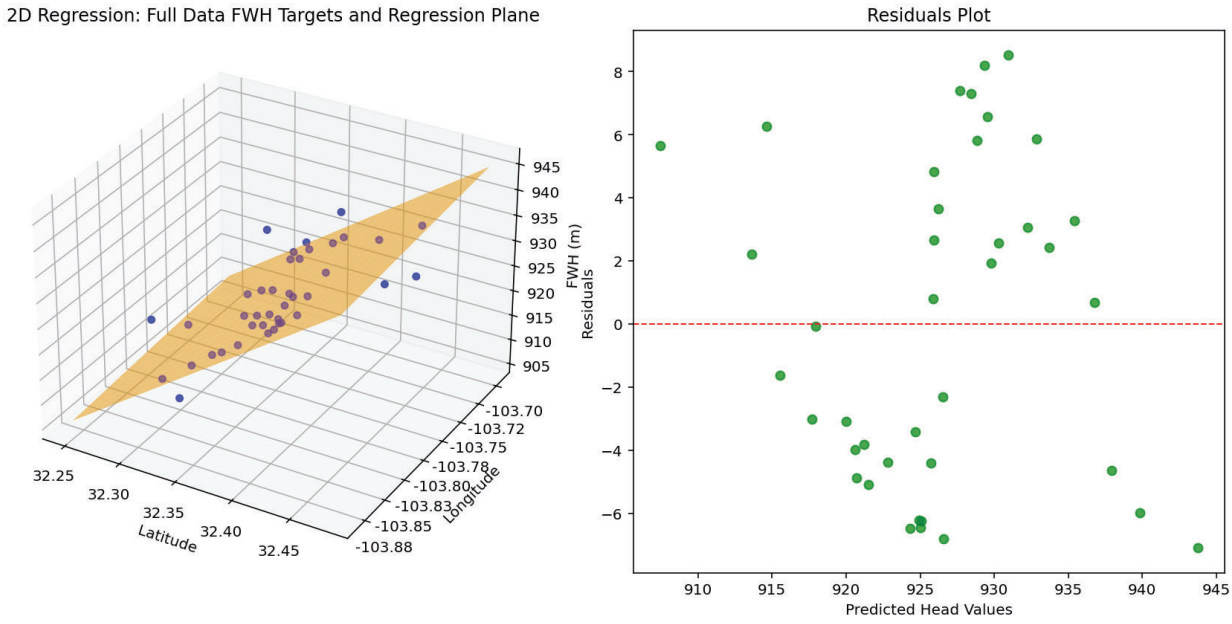

Figure 7. Regression model and residuals plot for the full data steady-state head calibration targets.

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Table 4. Regression model parameters.

Regression Model Values					
Cal. Target Set Regression	Regression Coefficients		Regression Intercept	Mean Absolute Residual	Root Mean Squared Error
	m1	m2	(b)		
2014	175.5033	1.3622	-4611.8475	4.4775	5.1211
2026	162.2736	6.3729	-3664.3958	4.2072	4.7829
Full Data	154.2400	15.0129	-2508.0934	4.4892	4.9692

Normalized Hydrographs

Farinacci and Bowman (2022) provided a hydrograph of the full set of WIPP monitoring well depth-to-water values used to generate CRA-2026 calibration target heads. The hydrographs were normalized to zero about the May 2007 water level measurements to understand the relative future change in water levels with respect to the CRA-2014 calibration target heads. Results showed that utilizing a concise temporal window to represent steady-state for an aquifer is non ideal. The hydrograph, however, did not provide a good comparison of the collective hydrographs for the WIPP monitoring well network.

To better explore this relationship, the hydrographs of the full data set wells were normalized utilizing values gained from the regression model. The modeled value and residual value derived from the regression model at each well were subtracted from the water levels of each corresponding well to generate a mean zero representation of water level data with respect to all other wells in the network. The resulting hydrograph is shown in Figure 8. For this representation, a majority of the water level data are indistinguishable by well. The intent of this figure is to provide a description of the general trend of non-anthropogenic Culebra water level data over the duration of the monitoring program. Representations of the data in this graph in which individual wells are distinguishable are provided in the discussion section of this report.

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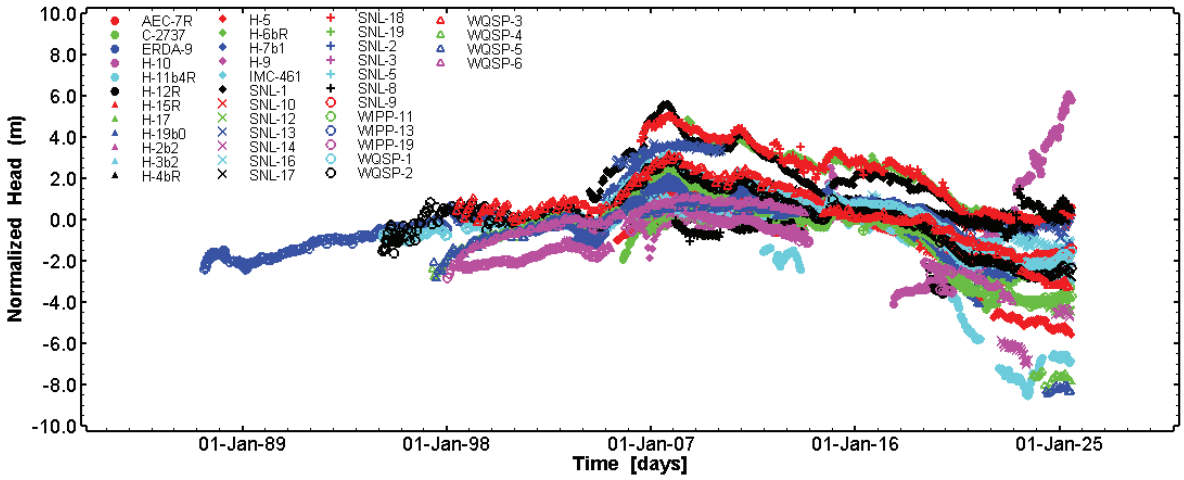

Figure 8. A hydrograph of all current WIPP monitoring network wells.

4. Discussion

The individual scatter and boxplot results provided a comparative visual representation of the data and results of the past and investigatory "full data" set. In a majority of wells, the newly included data are of lower head value than the 2026 data set or the 2014 point representation. These results correspond with the visual inspection of the WIPP monitoring well hydrograph, where water levels in the Culebra monitoring network have been steadily decreasing since 2008. Figure 9 provides a contour map of the differences between calibration targets for CRA-2026 and calibration targets using the full data set. Generally, the differences are minimal but favor a lower average water level. Three wells, H-6bR, SNL-13, and SNL-18 showed the largest water level changes. Well SNL-13 has had a fairly stable, though lower, water level since the Mills Ranch pumping event. Wells H-6bR and SNL-18 have had a steadily decreasing water level since 2008.

With respect to the steady-state representation, these results endorse that the CRA-2026 calibration target calculations may be overzealous. Considering the full time span of the monitoring well network history (1980s), past decades data may not well reflect current hydrologic climates. This would normally not be an issue if well sites persisted, but wells have been plugged and abandoned without replacement, ending the ability to acquire new water level data at that site. Historic wells then become data locked into a representation of Culebra water levels for a set period of time which may disagree with more current data.

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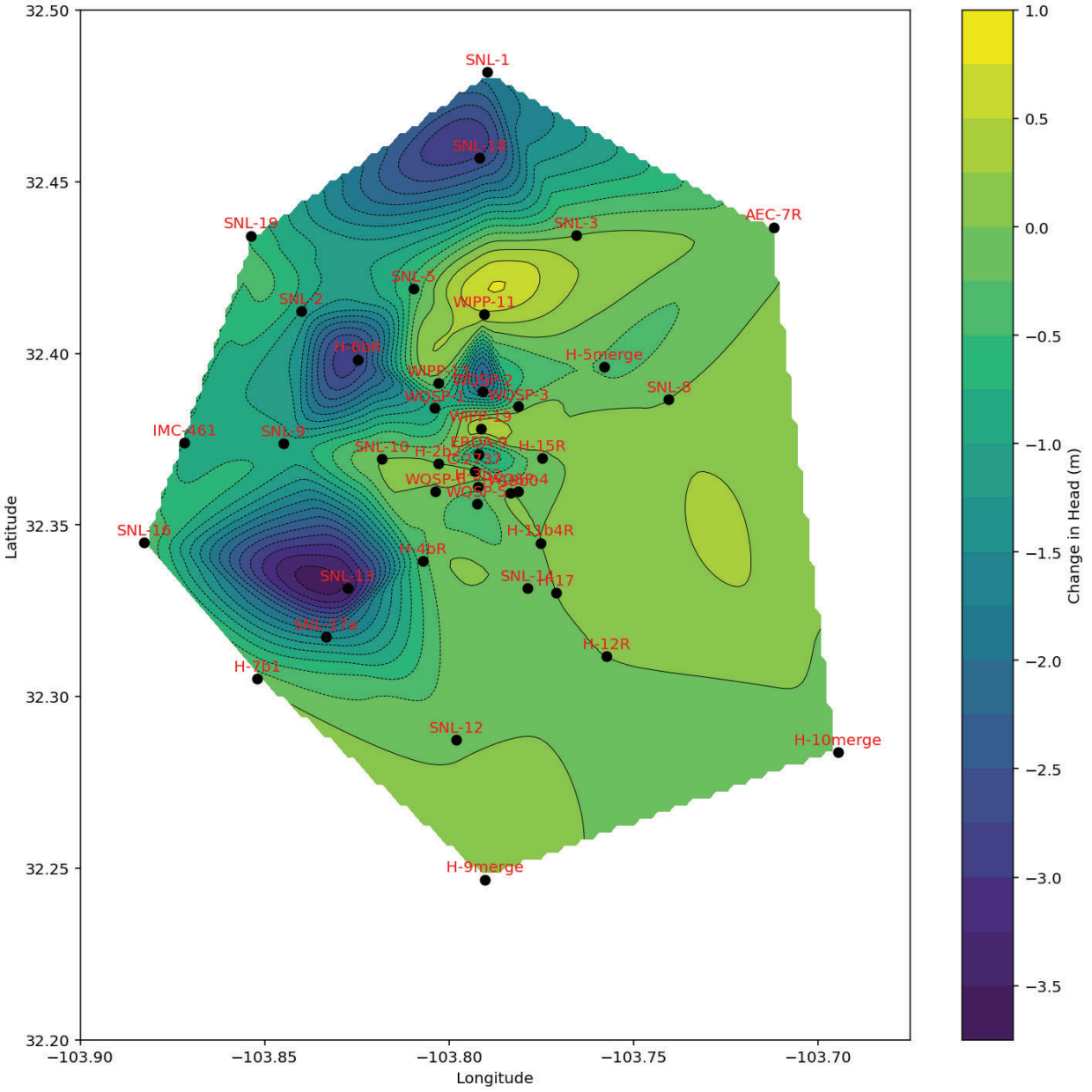

Figure 9. A contour map of the differences between CRA-2026 and full data steady-state calibration targets.

Regression results, as singular analyses, only showed that over the span of the three different sets of calibration targets, the predicted water levels are generally similar. Figure 10 shows a contour map of the differences between the CRA-2026 and Full data models. The model differences show a decrease in head to the north with increases of head in the southeast. The total change in head range between the two modeled surfaces is less than 3 m. This change, coupled with the results discussed for the centrality comparisons, reinforces that future calculations of calibration head targets should be bounded by a more restrictive, and more recent, time interval rather than the complete history of each well.

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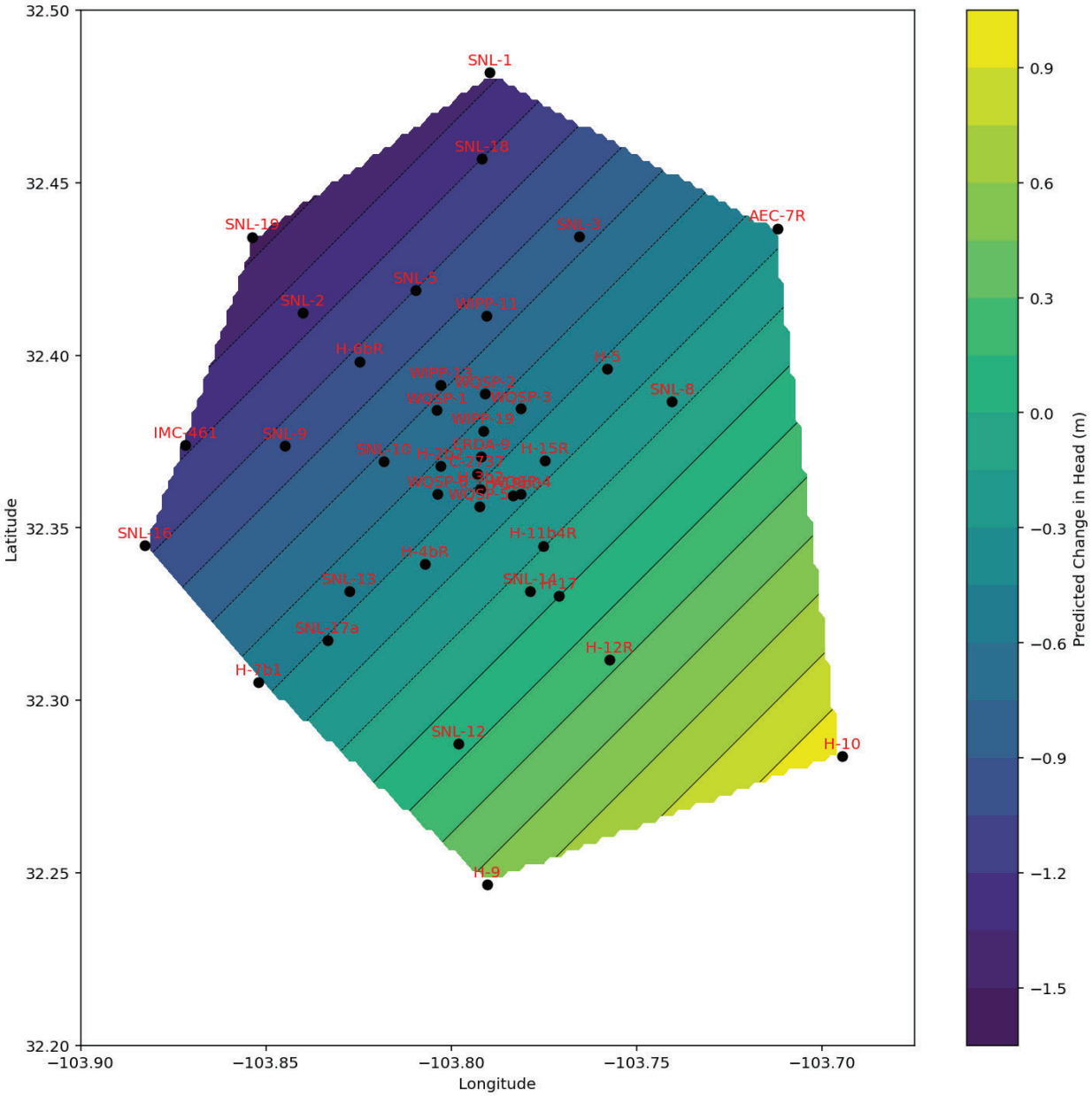

Figure 10. A contour map of the differences between CRA-2026 and full data regression models.

The WIPP monitoring well hydrographs were able to provide a few specific points of information and some useful general aquifer information. The comparative hydrograph showed that a majority of the WIPP monitoring wells generally follow a similar pattern of water level decrease with the exception of well H-10cR. The water level trends in H-10cR are a departure from that measured in the previous H-10c well, where H-10cR has seemingly been recovering to a previously unrecorded higher water level since the well was drilled and developed (Figure 11). This tendency parallels that of wells SNL-6 and SNL-15, which have been recovering for over a decade. H-

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10cR's testing analysis (Bowman 2017) showed the Culebra to be of a relatively low transmissivity at this well. As the recovery pattern is similar to that of the other two wells east of the Culebra flow model constant head boundary, it may be prudent to move the southern portion of the boundary to the west if well H-10cR persists recovering in the future.

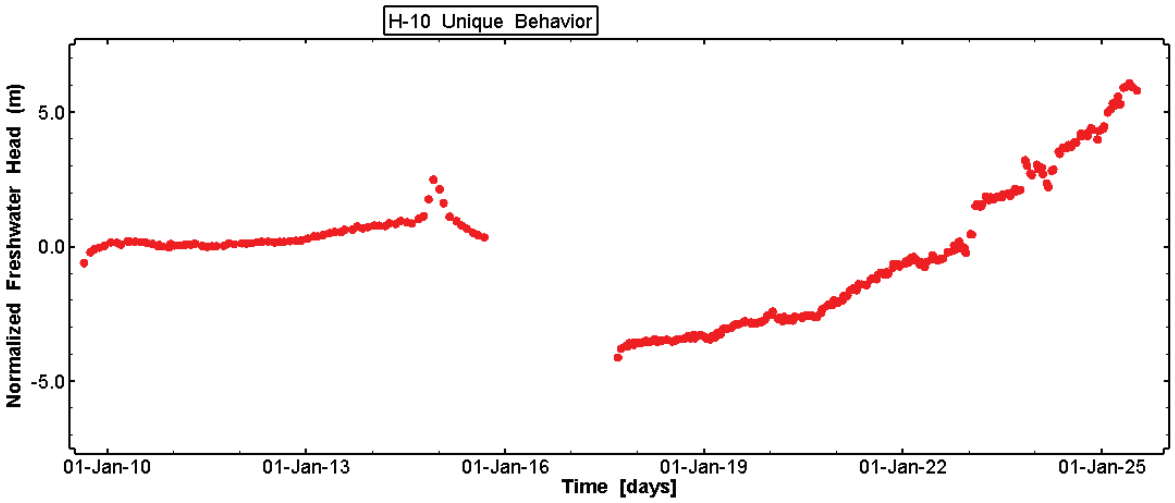

Figure 11. The H-10 hydrograph. The break in data in 2016 distinguished the former H-10c and current H-10cR wells.

Visual inspection of the normalized hydrographs revealed that the overall water levels in the Culebra vary about a general aquifer trend, with exception to well H-10cR (Figure 8). Water levels have decreased over the history of monitoring the Culebra similarly (Figure 8). Three aquifer sub-trends were identified based upon the final values in each well: water levels that stabilize above the normalized mean 0, those that stabilize between 0 and -4 m, and those that stabilize below -4 m. These sets of wells are illustrated in Figure 12, Figure 13, and Figure 14, respectively. Those wells that have water levels that stabilize above mean 0 tend to be those to the northeast and southwest of the WIPP Land Withdrawal boundary. A water level stabilization begins in approximately 2021 and persists. Wells with water levels that stabilized below -4 m of normalized freshwater head are located inside and south of the LWB. As these representations of head are normalized based upon an idealized model over a heterogeneous aquifer, their exact values are probably of little use, but this normalization approach does give a good sense of the overall aquifer water level trend and magnitude of water level variability. With respect to the steady-state representation of water levels, the inclusion of new data supports the continued representation of the Culebra as steady-state for model calibration. Though there is a general persisting decrease in heads for many years, since 2022, the water levels in the Culebra have seemed to stabilize. It is unknown if the recent stabilization in water levels is a short-term (years) hydrologic setting or part of a larger (decades) pattern.

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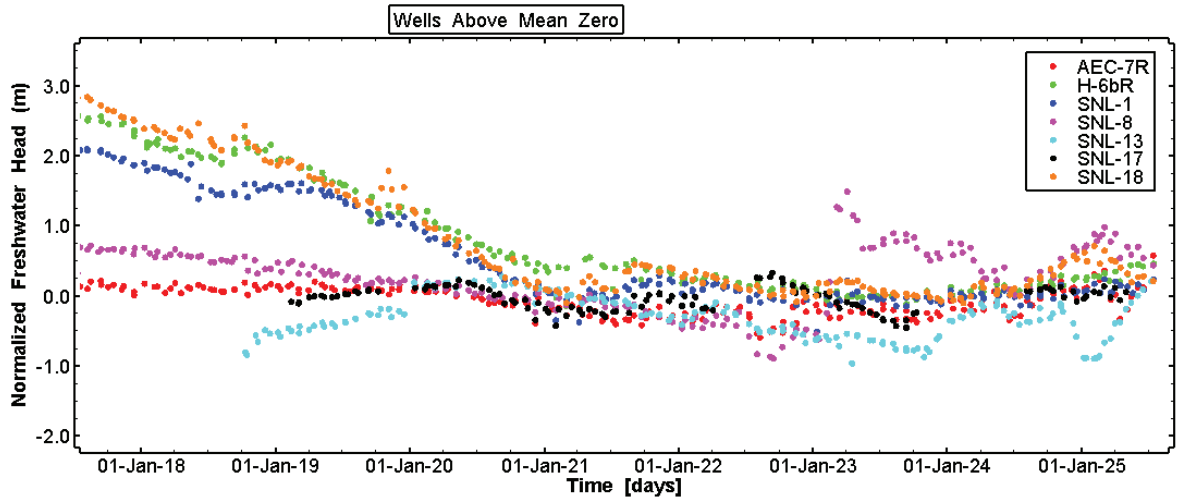

Figure 12. A hydrograph of wells with currently increasing head above normalized mean zero.

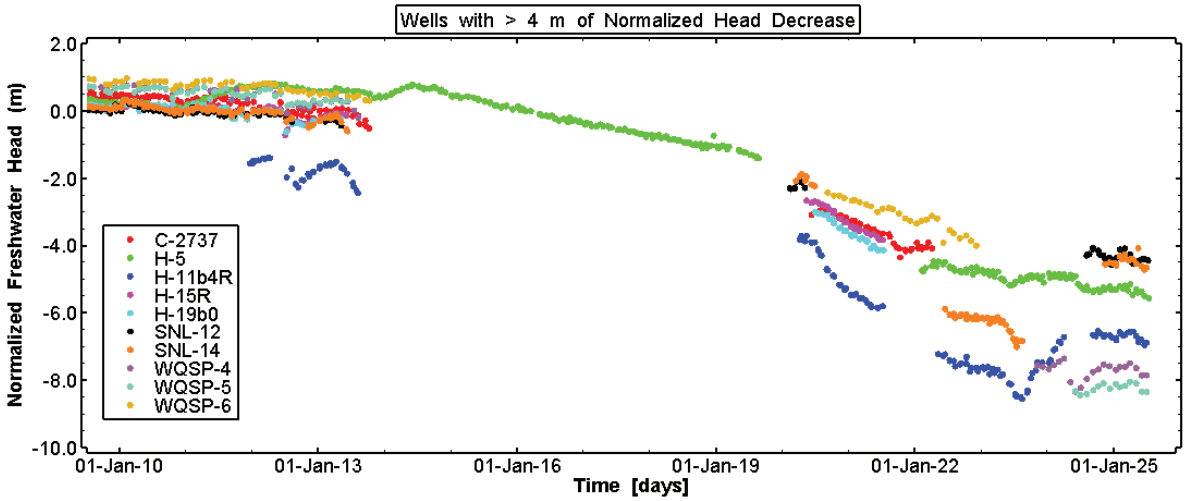

Figure 13. A hydrograph of wells with currently stabilized head below -4 m of normalized head.

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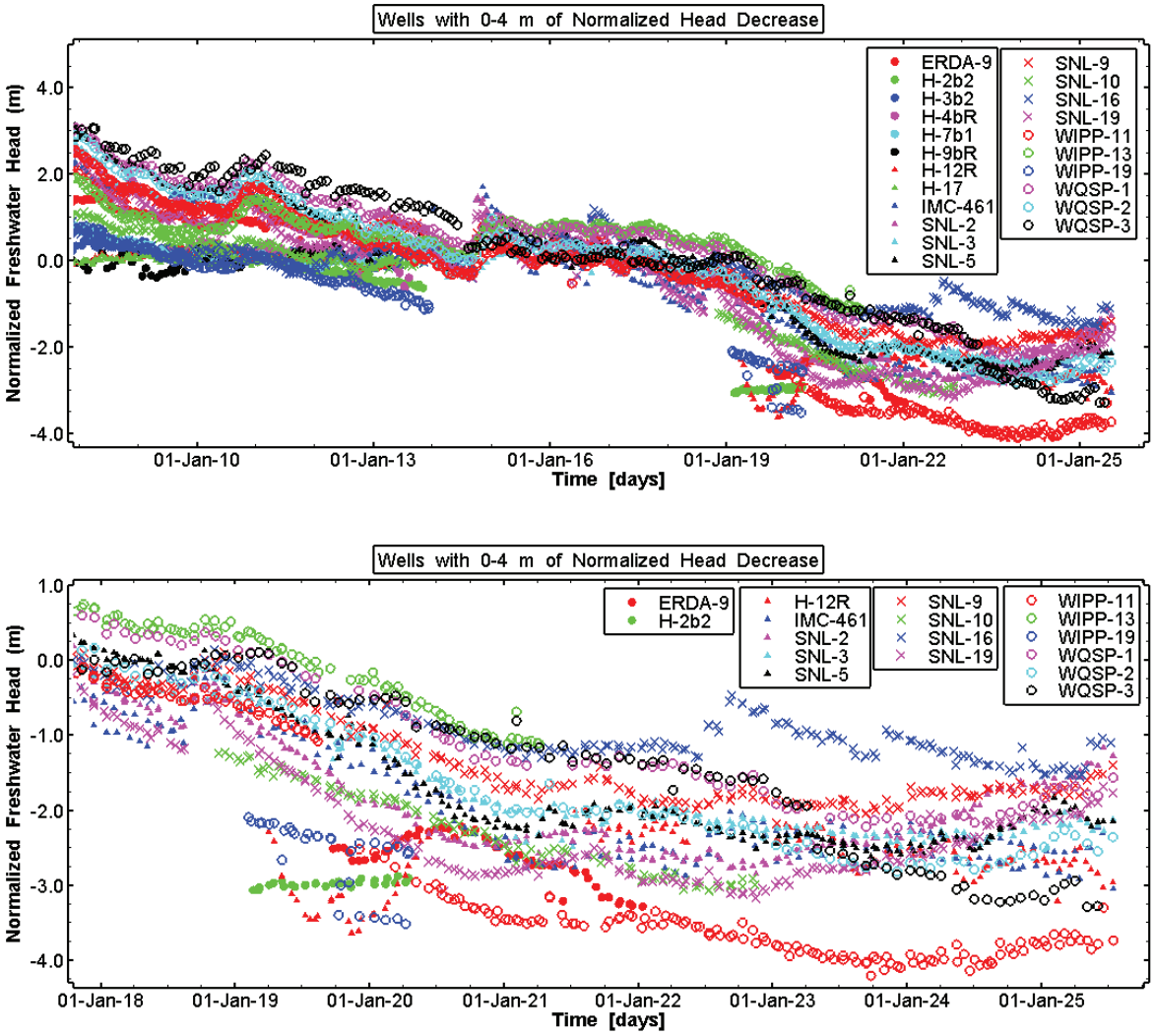

Figure 14. Hydrographs of wells with currently stabilized head between 0 and -4 m of normalized head over two time periods.

5. Summary and Conclusions

This Analysis Report investigates the incorporation of new data as applied to the conceptualization of components of the Culebra flow model. Water level data recorded since 2018 was included by way of existing methodologies to generate an updated set of transmissivity field calibration targets to emulate steady-state aquifer conditions. These new targets were compared against previous iterations of calibration targets used in previous compliance recertification applications.

Several insights can be taken from the water levels as analyzed in this report and applied to the conceptualization of the Culebra flow model. Calculation of the steady-state calibration targets showed that water levels since 2018 have generally decreased in most wells. Comparisons over the three target data sets indicate that a compromise between the 2014 and 2026 steady-state calculation approaches is likely appropriate where targets can be statistically calculated but over a

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smaller timespan. Regression models indicated that the inclusion of new data will likely change the gradient of the potentiometric surface of the aquifer, but the changes were minimal. This endorses the concept of linearly variable boundary conditions for constant head boundaries, though it did not endorse that constant head boundaries are specifically appropriate in all cases. Finally, the normalized hydrographs provided insight into the general water level trends of the Culebra and that they are more similar than described in previous reports. As the variability of the Culebra, as a whole, follows a predominant trend, conceptualization of a steady-state representation of the aquifer still appears to be a valid approach.

6. References

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7. Appendix A – Evaluated Data

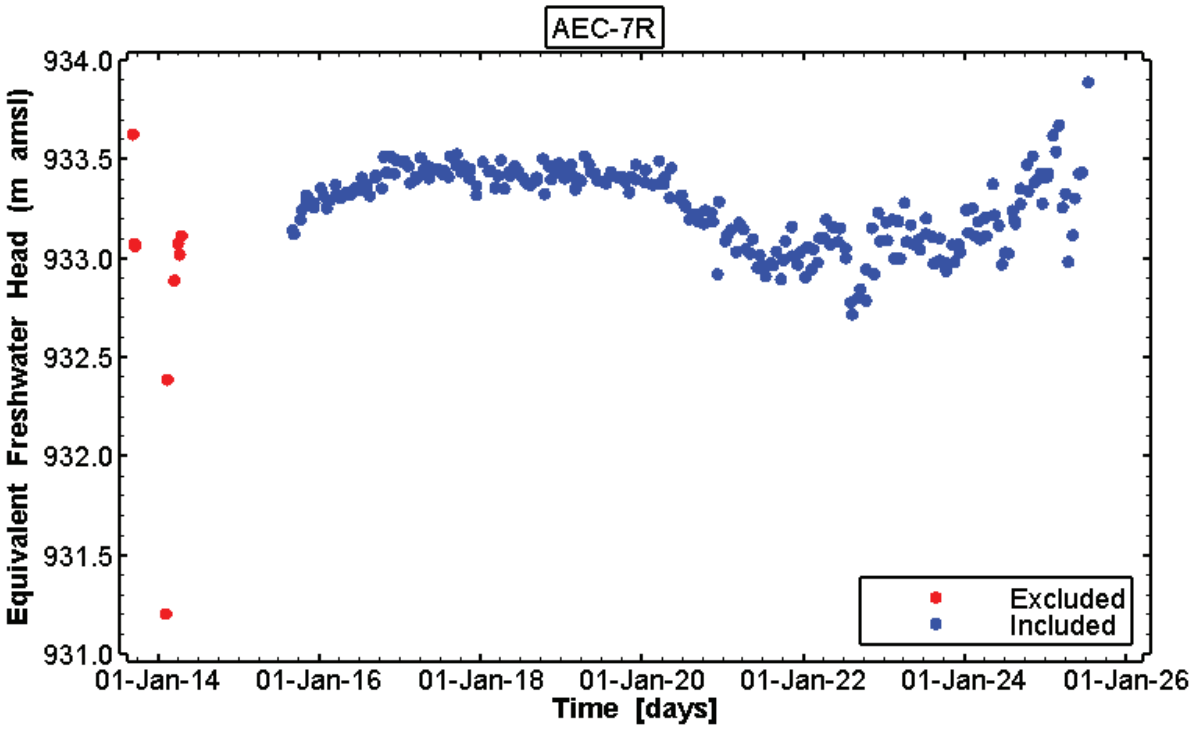

Figure A1. Data included and excluded from the AEC-7R analysis.

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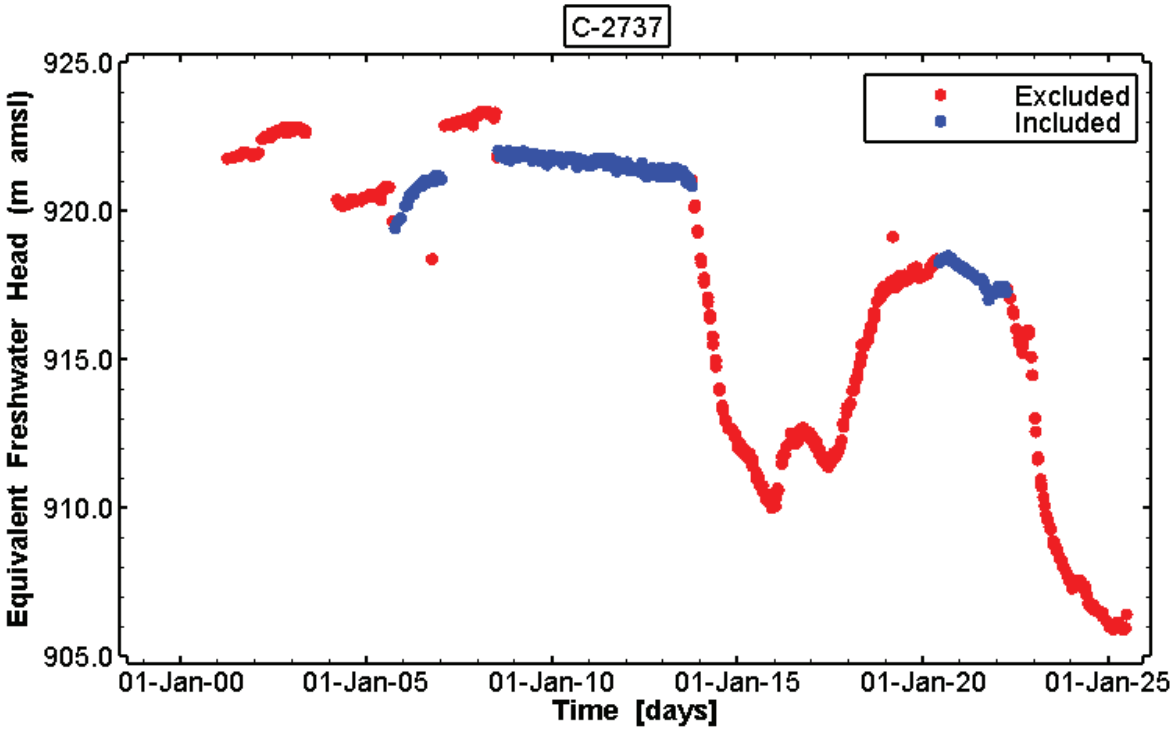

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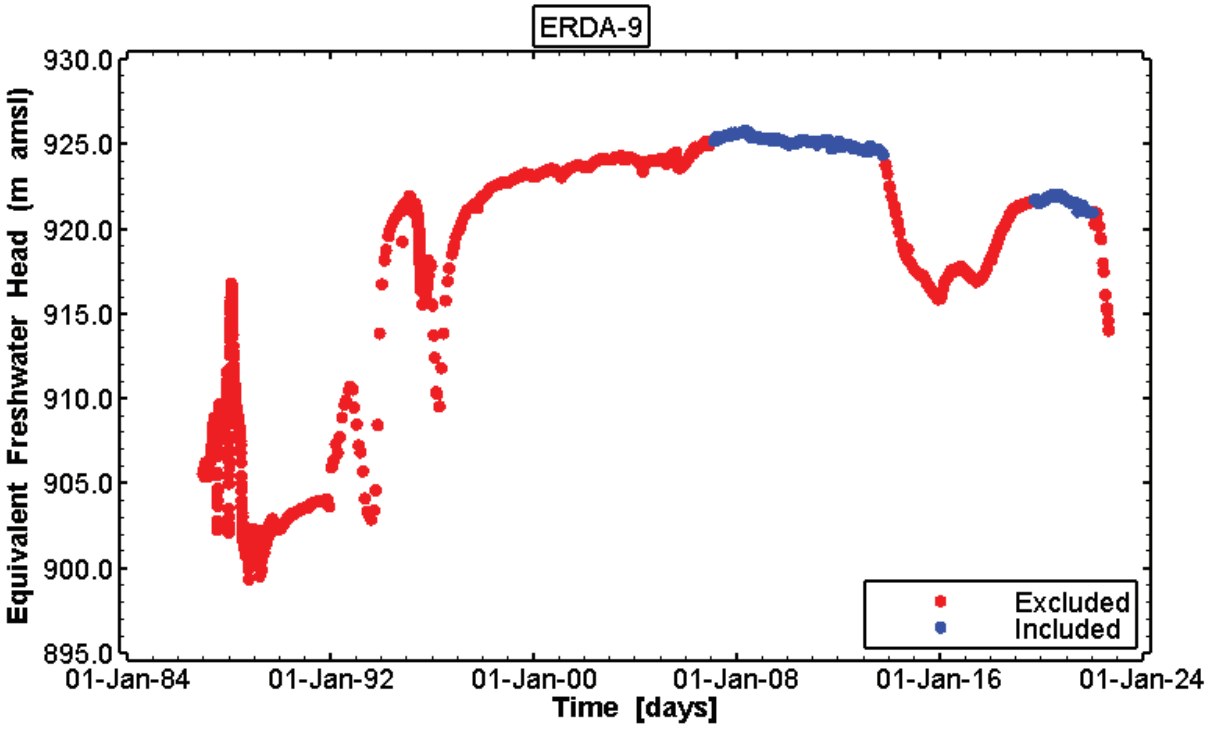

Figure A3. Data included and excluded from the ERDA-9 analysis.

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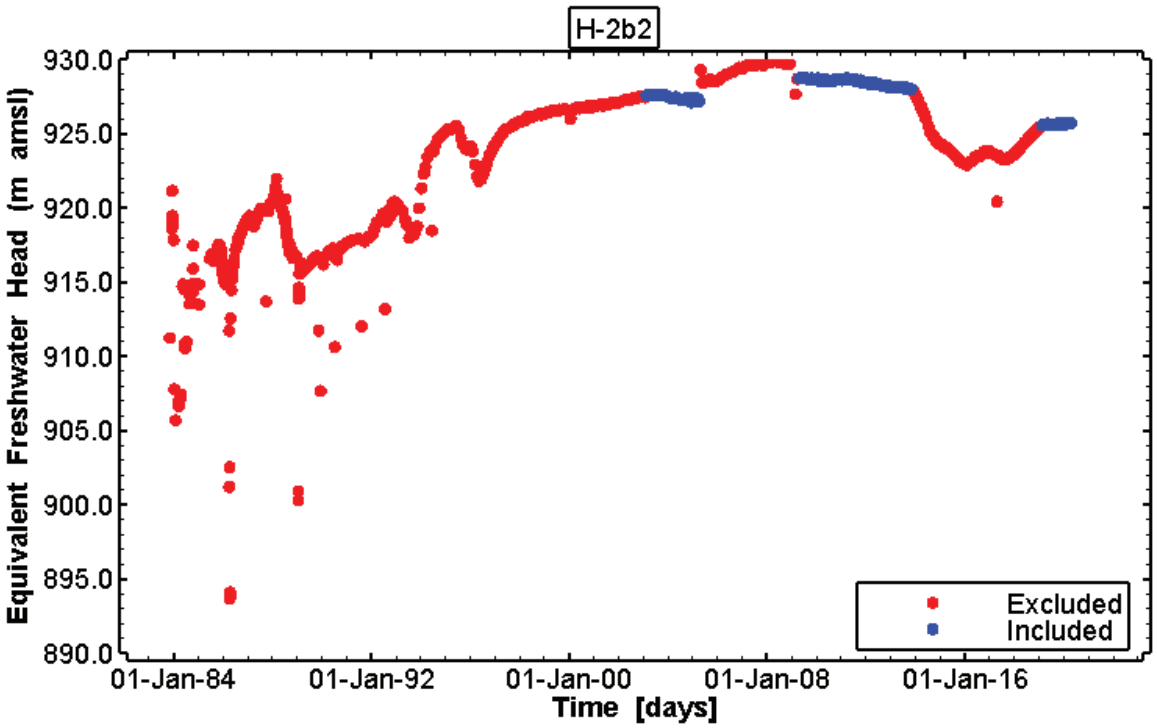

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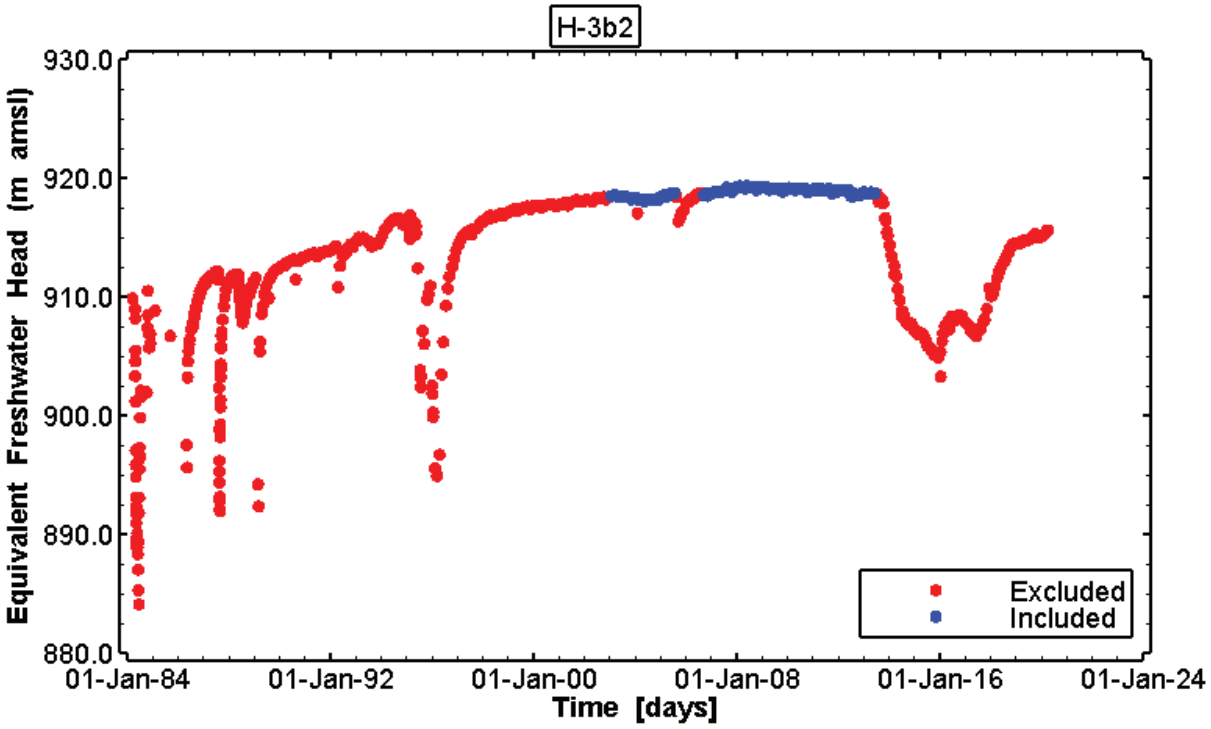

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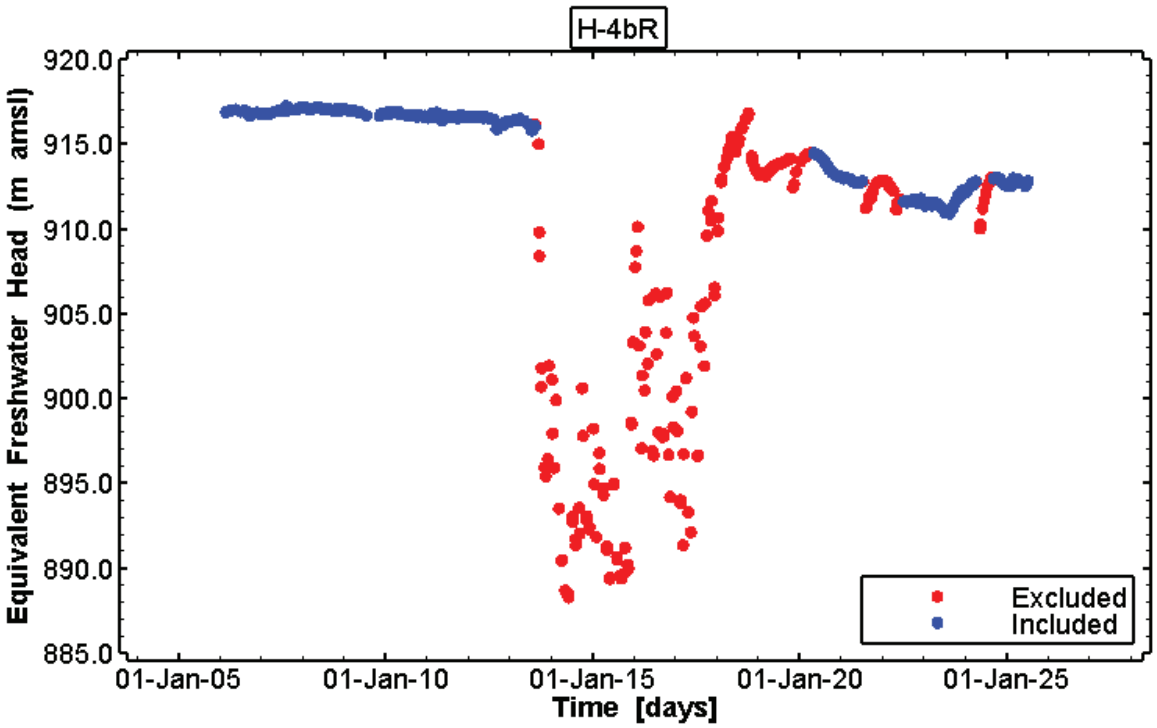

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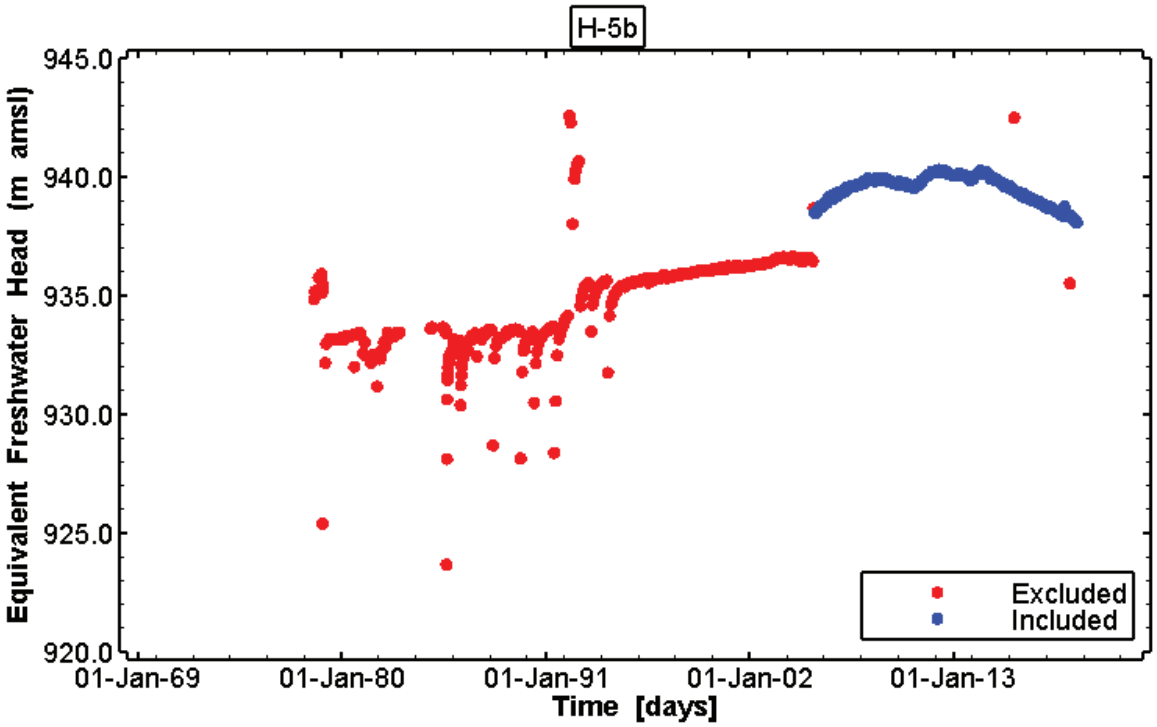

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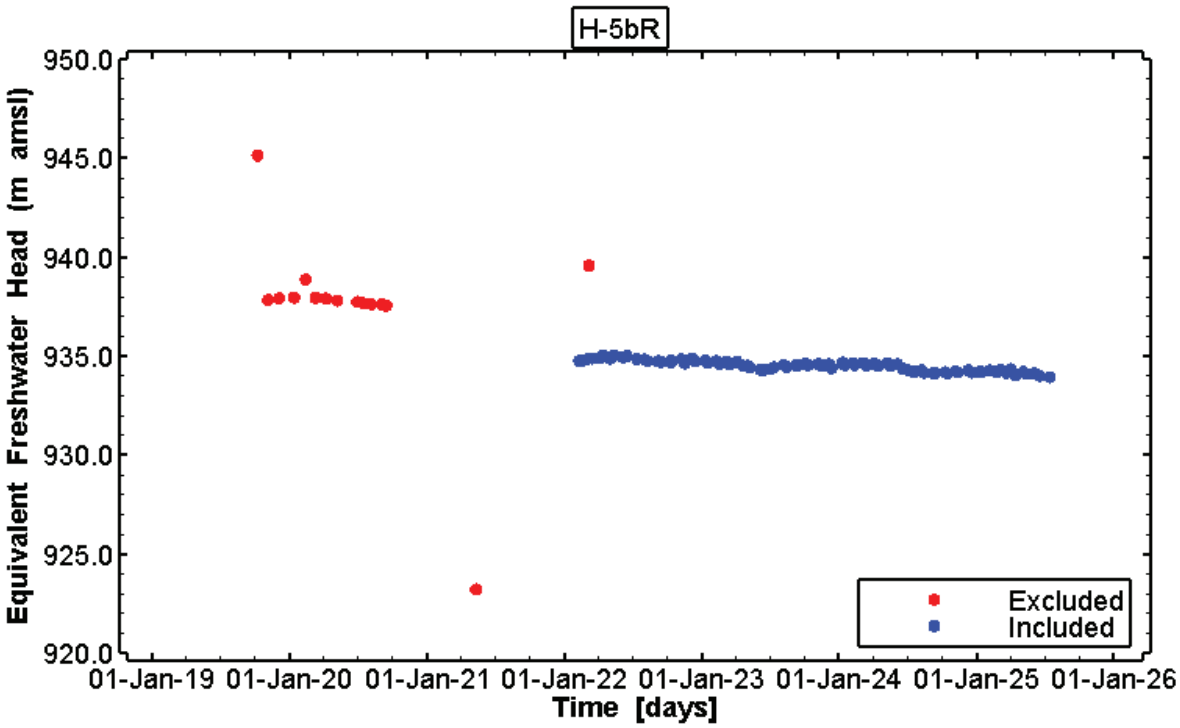

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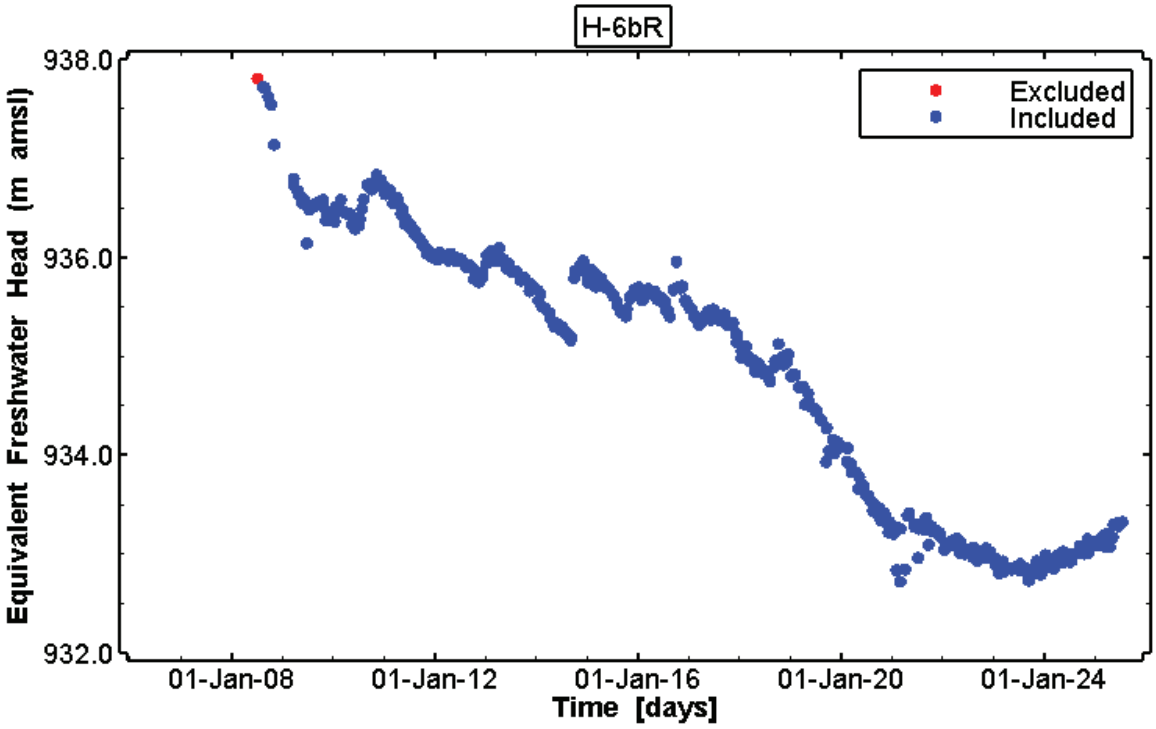

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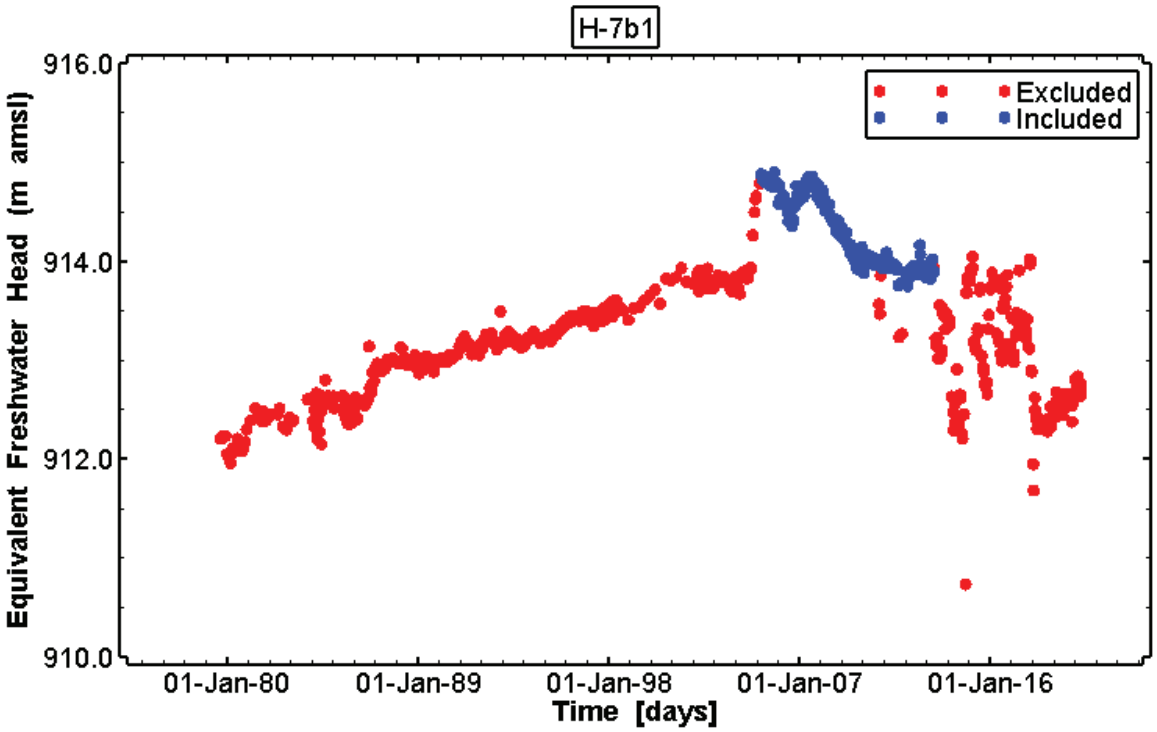

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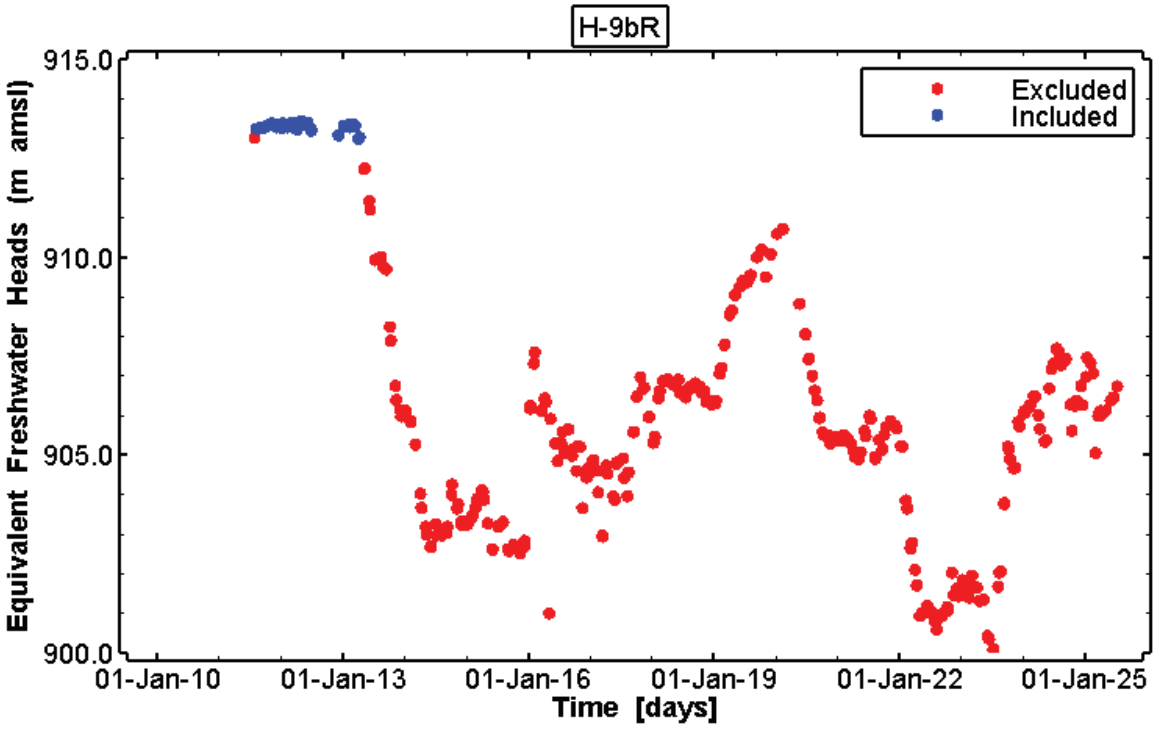

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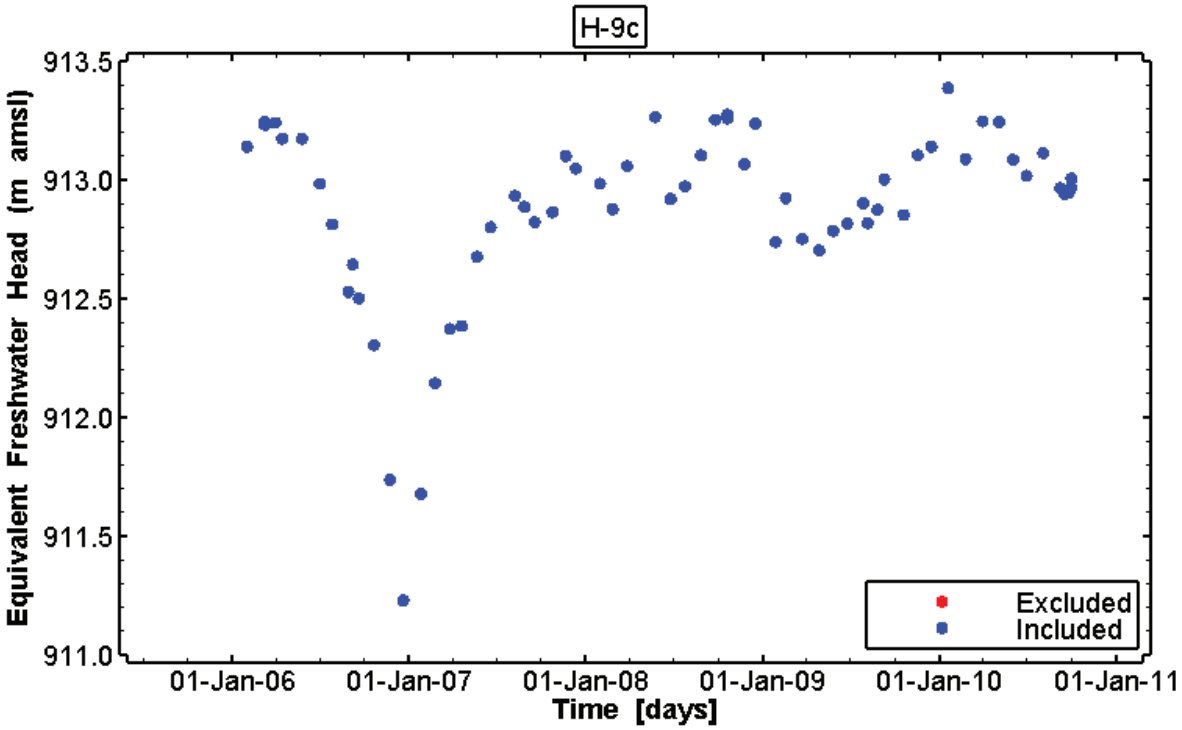

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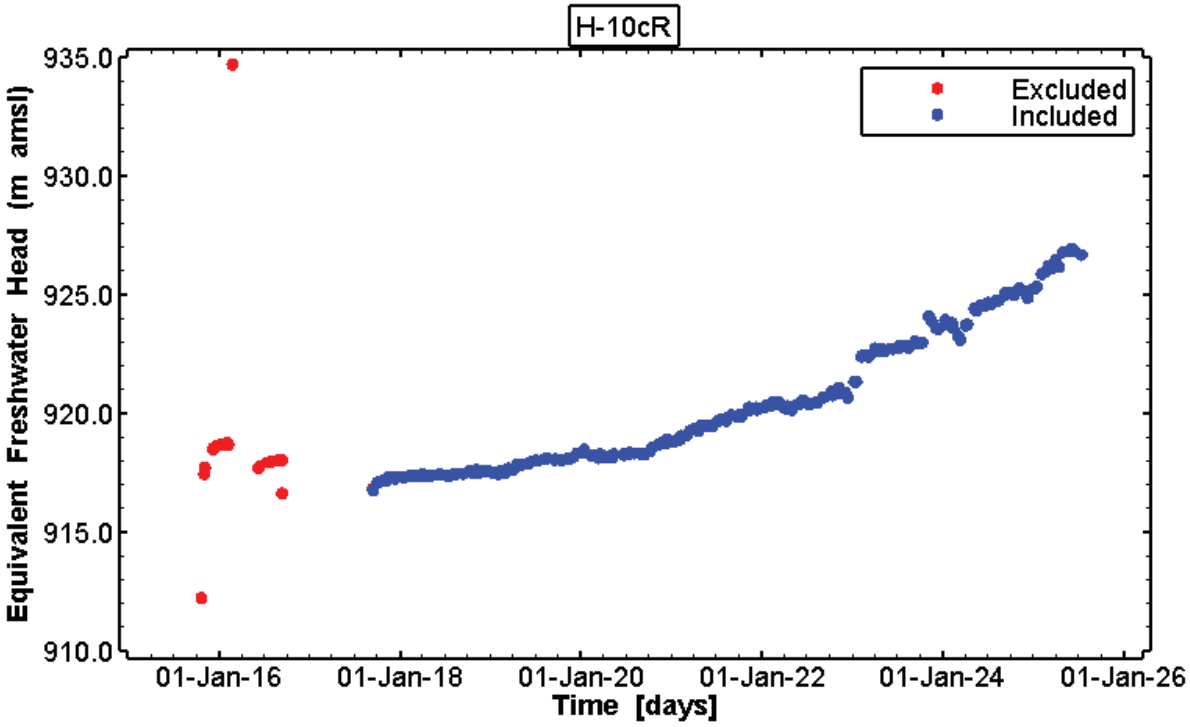

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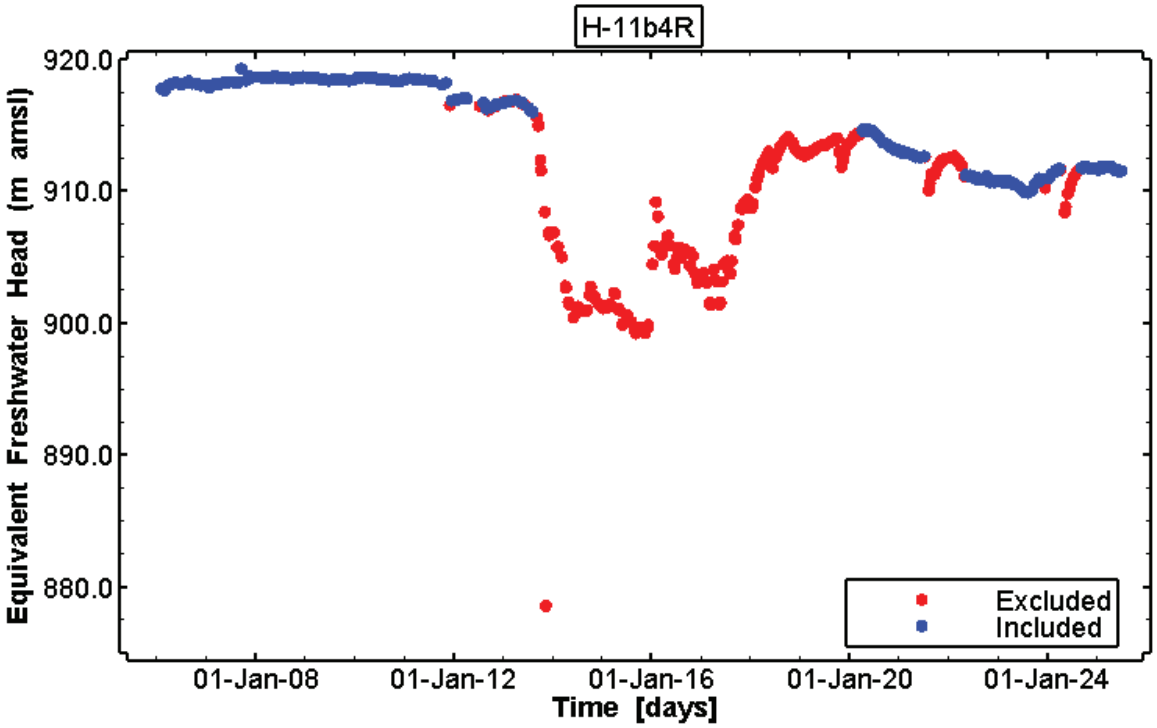

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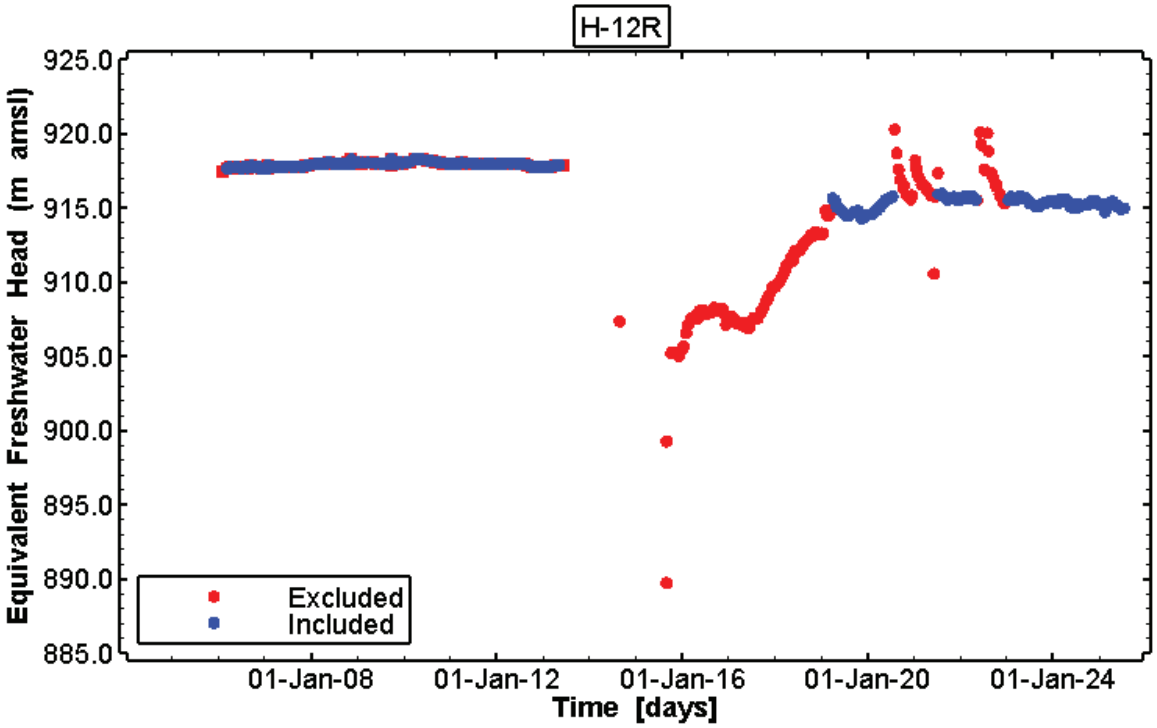

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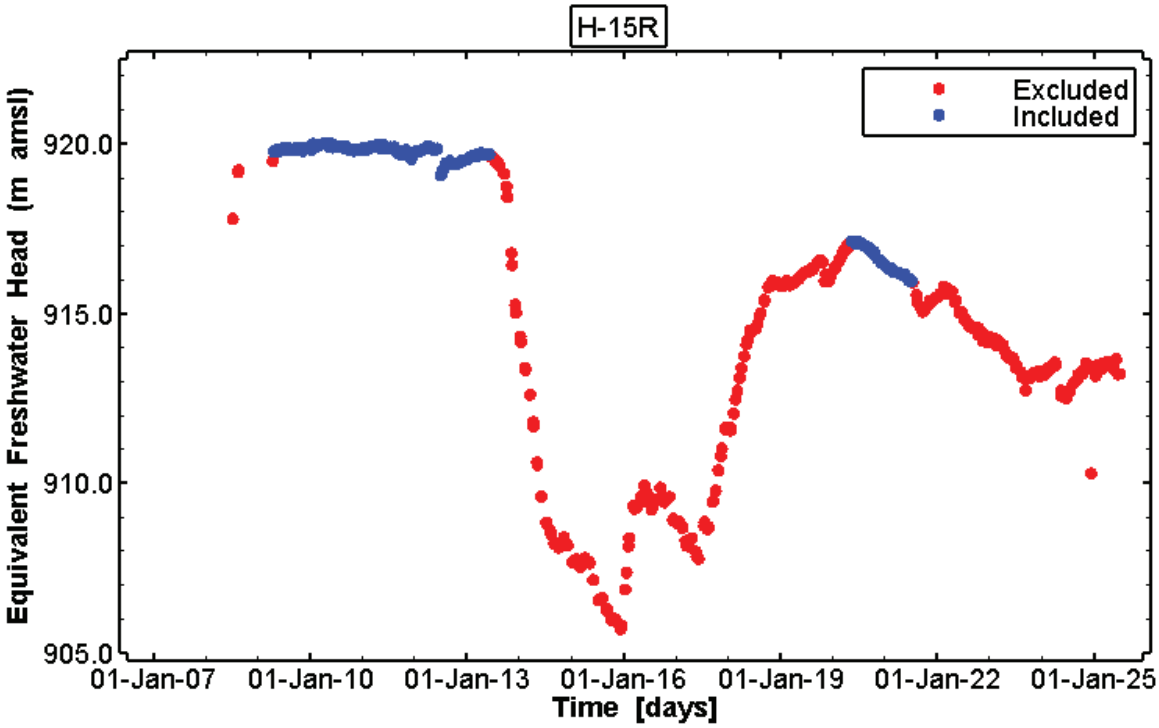

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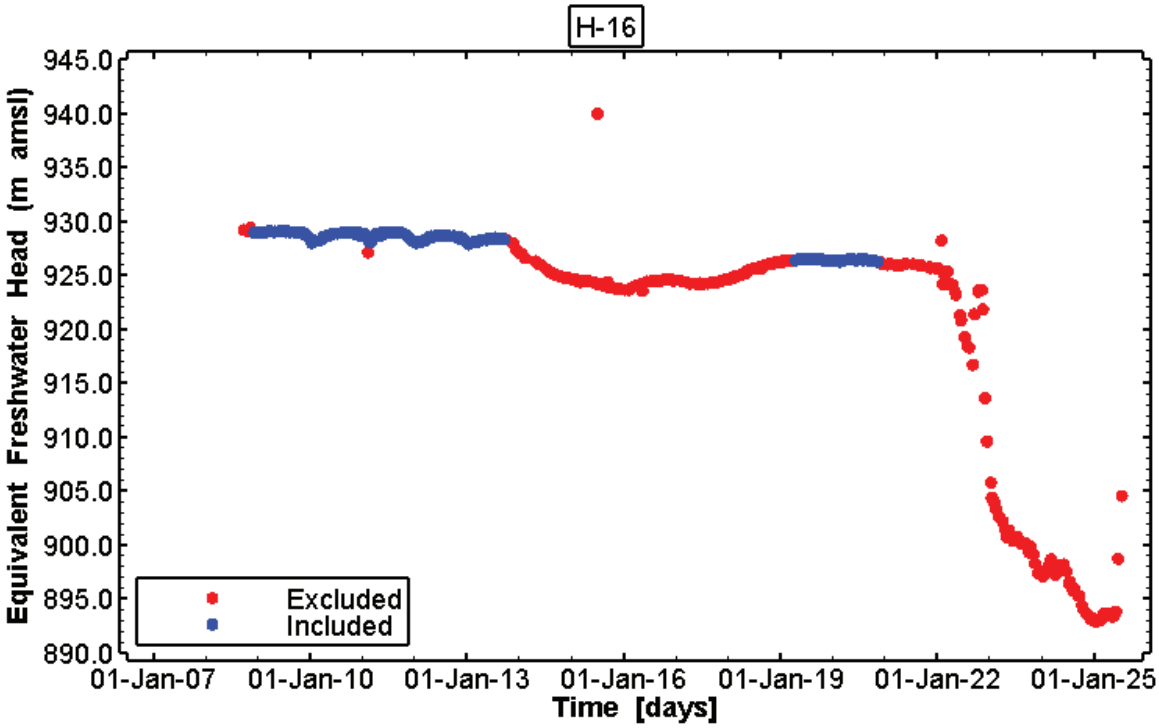

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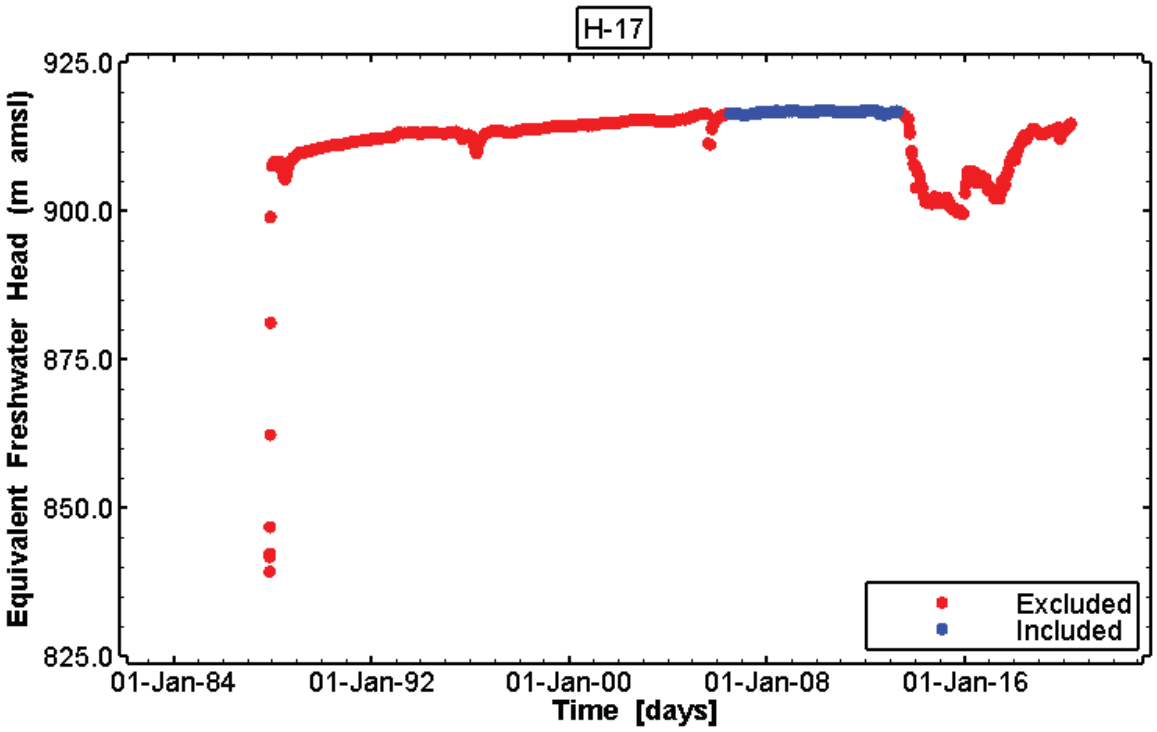

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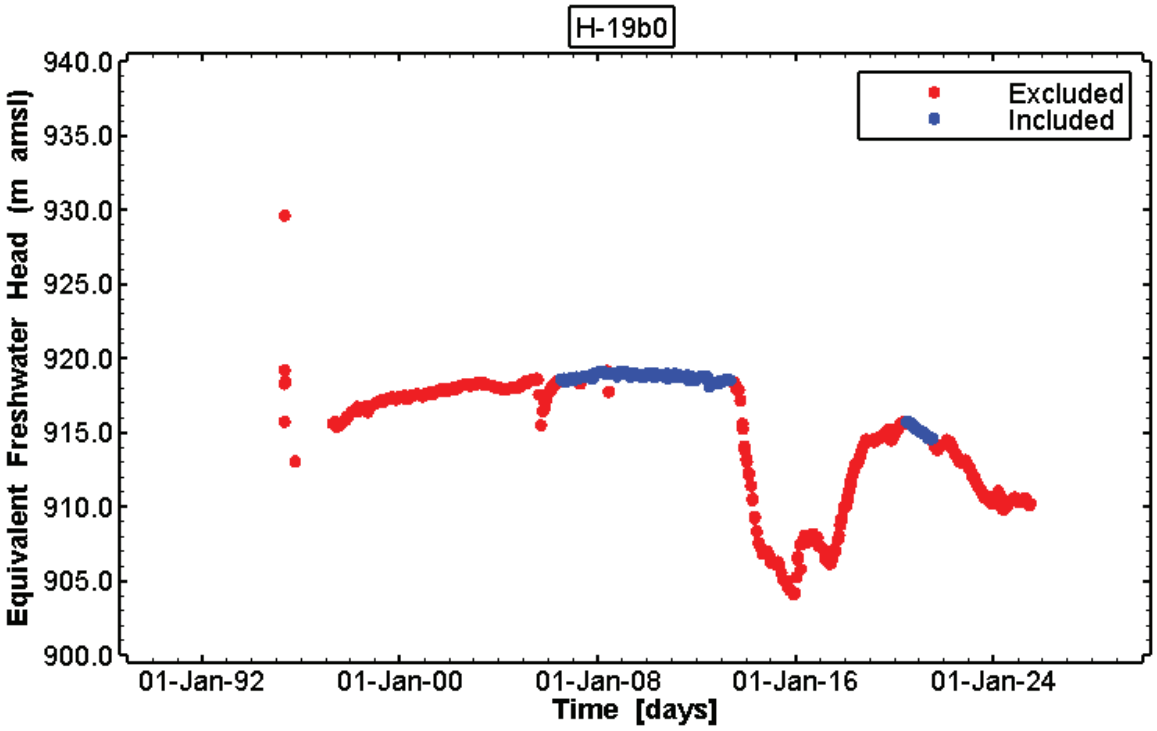

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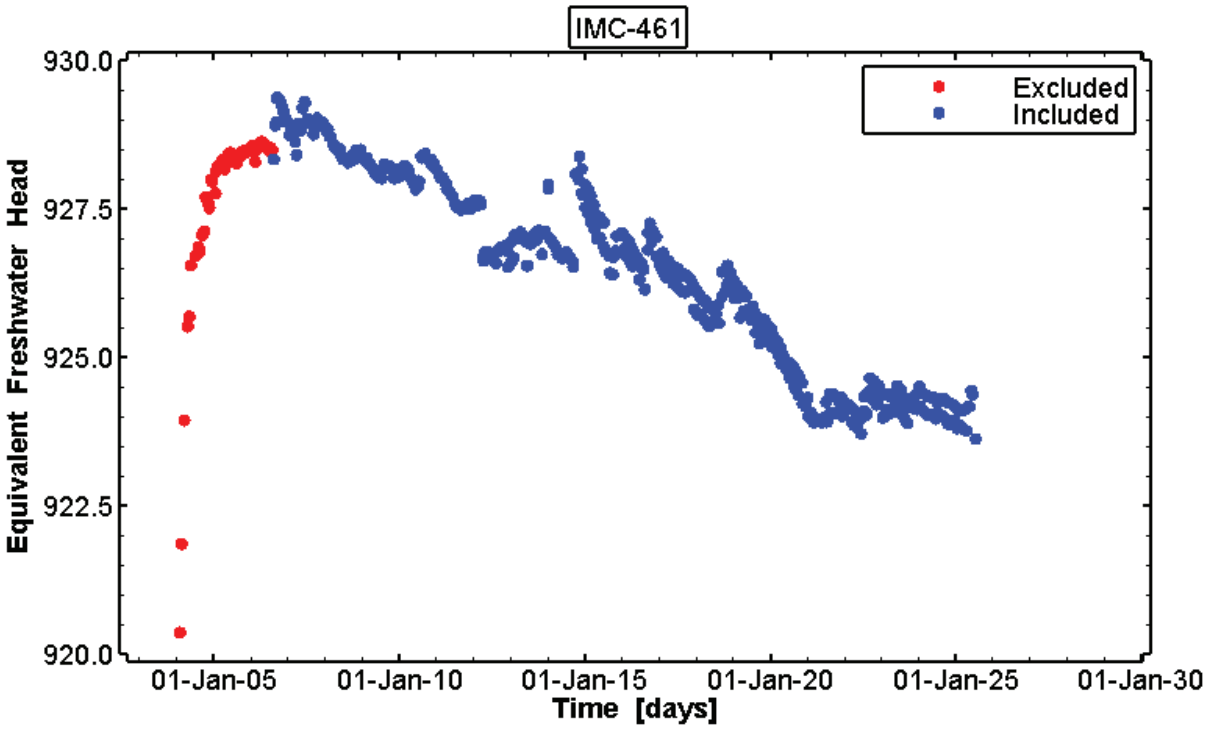

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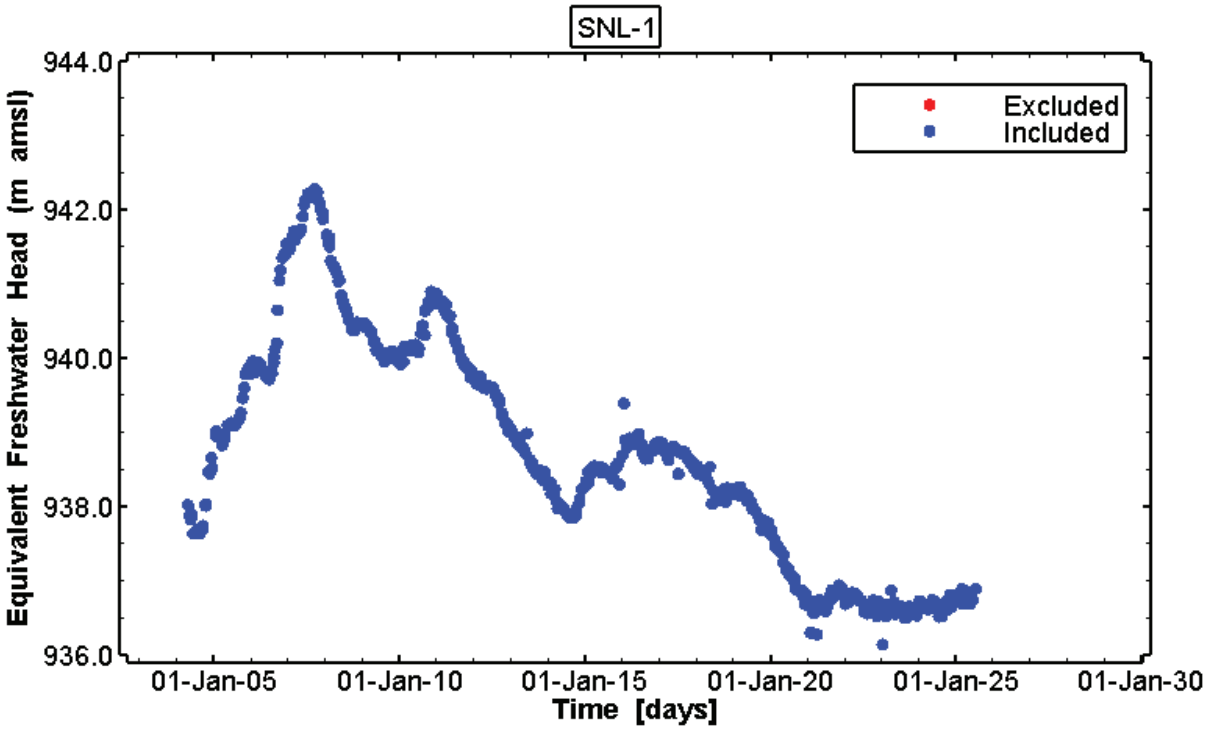

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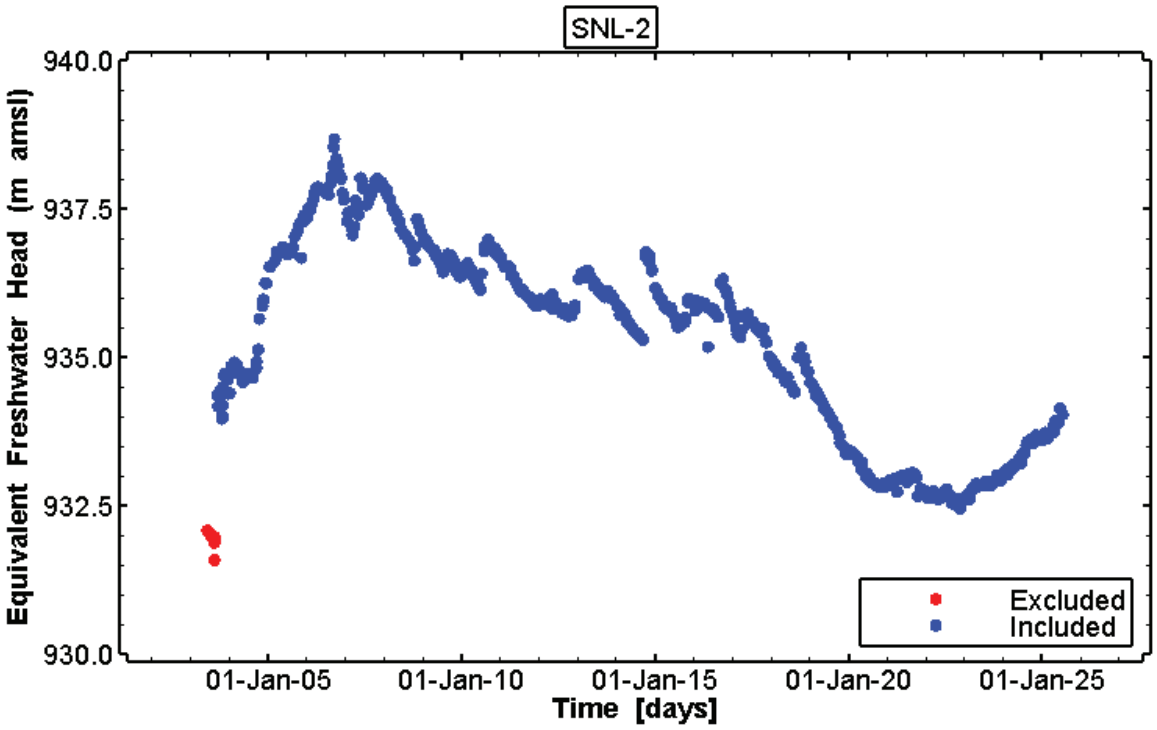

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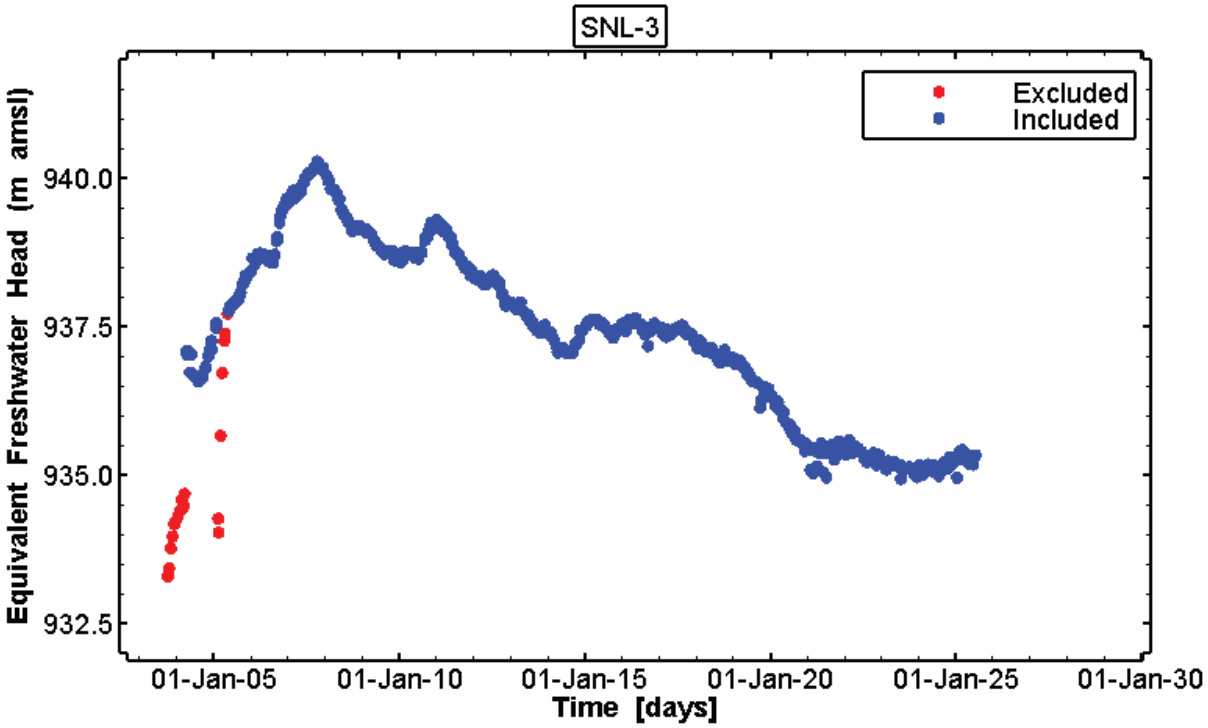

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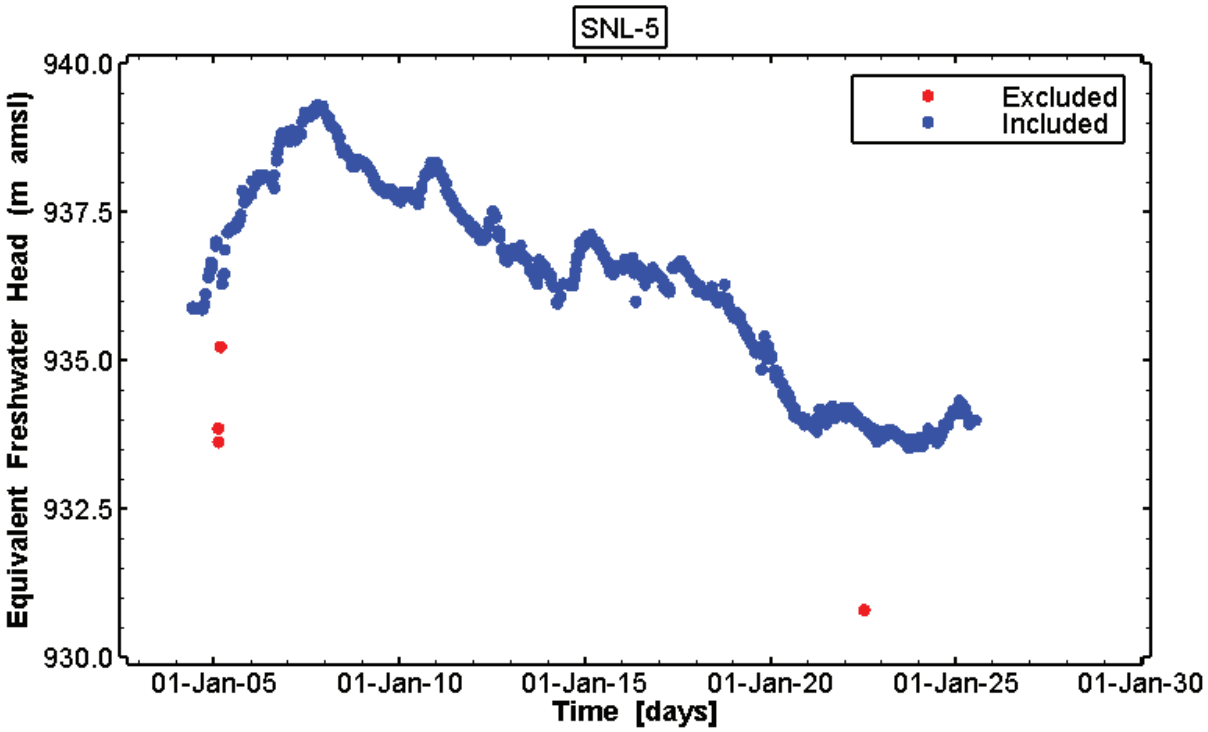

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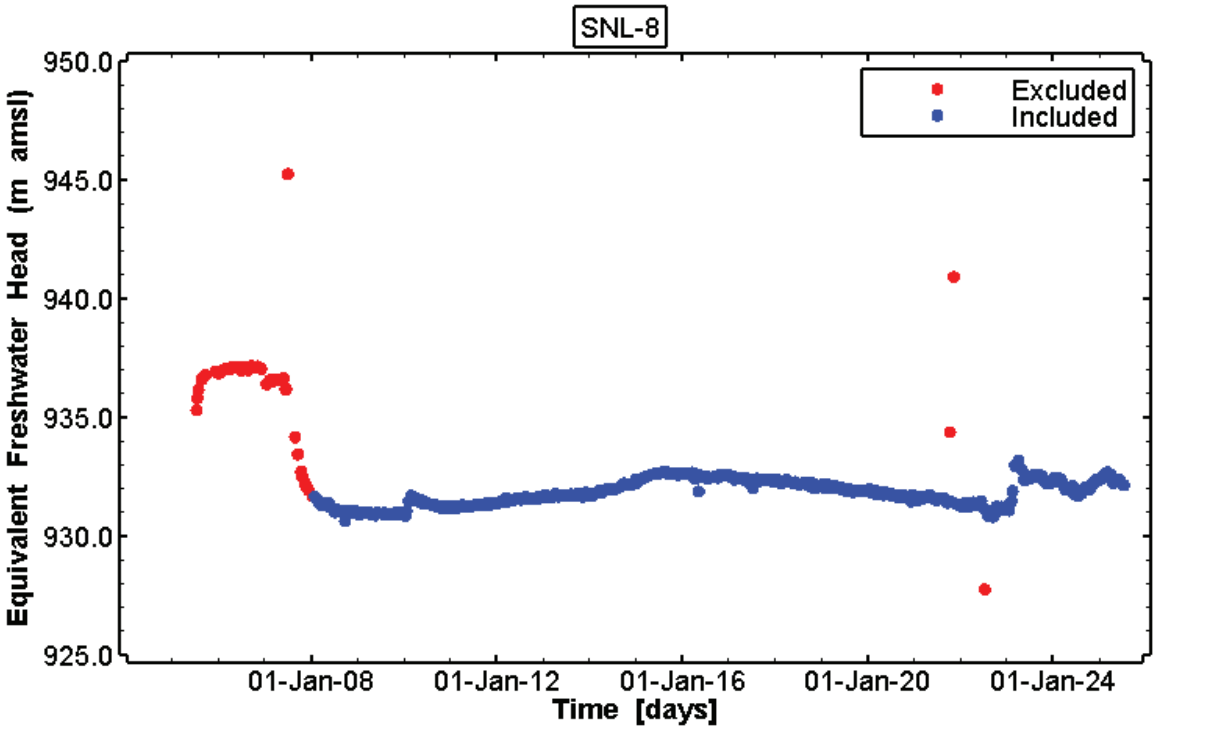

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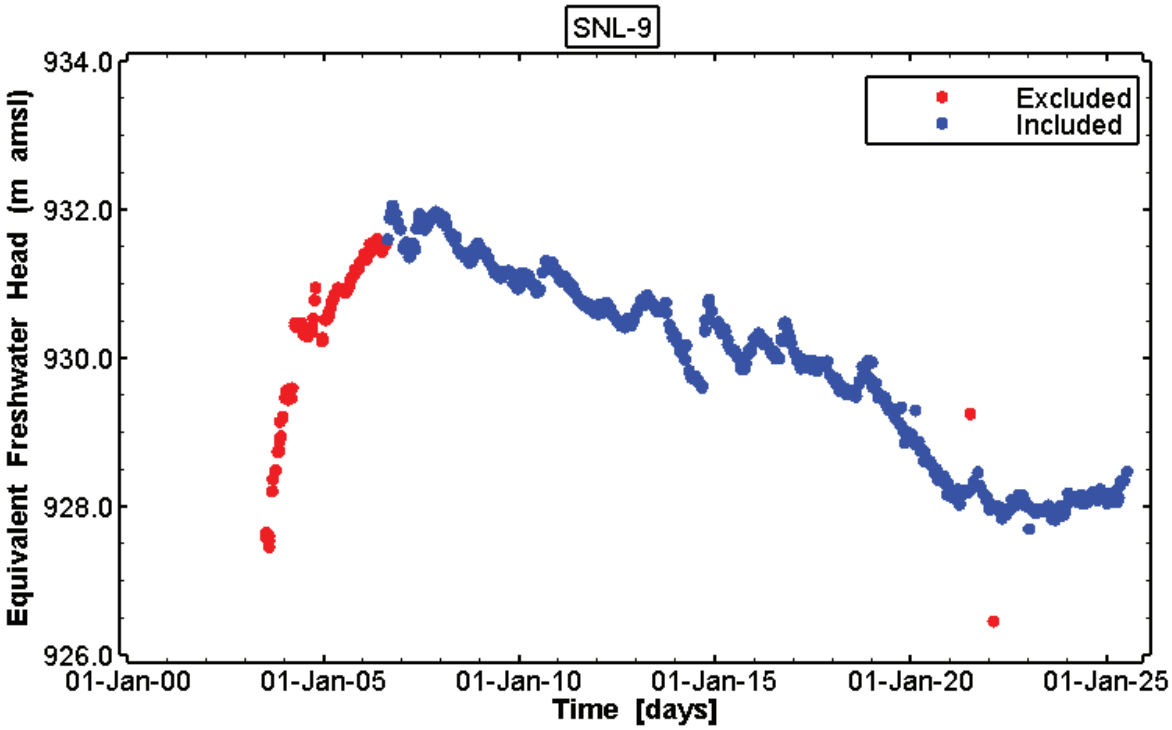

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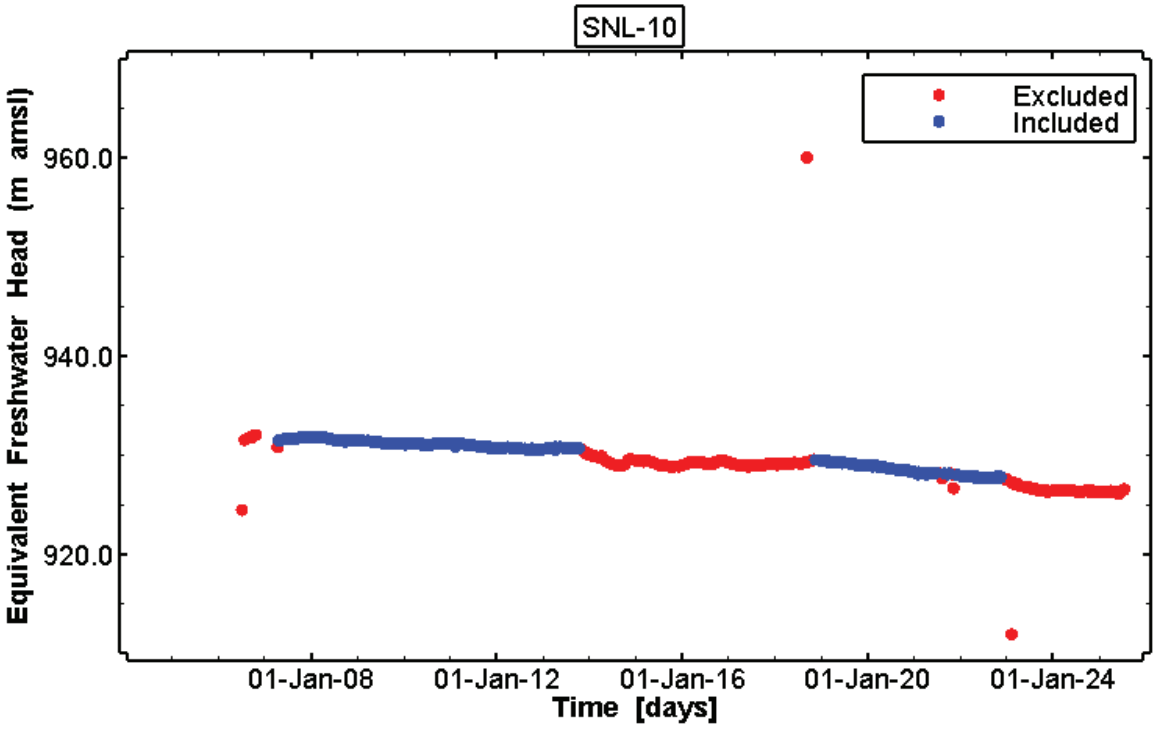

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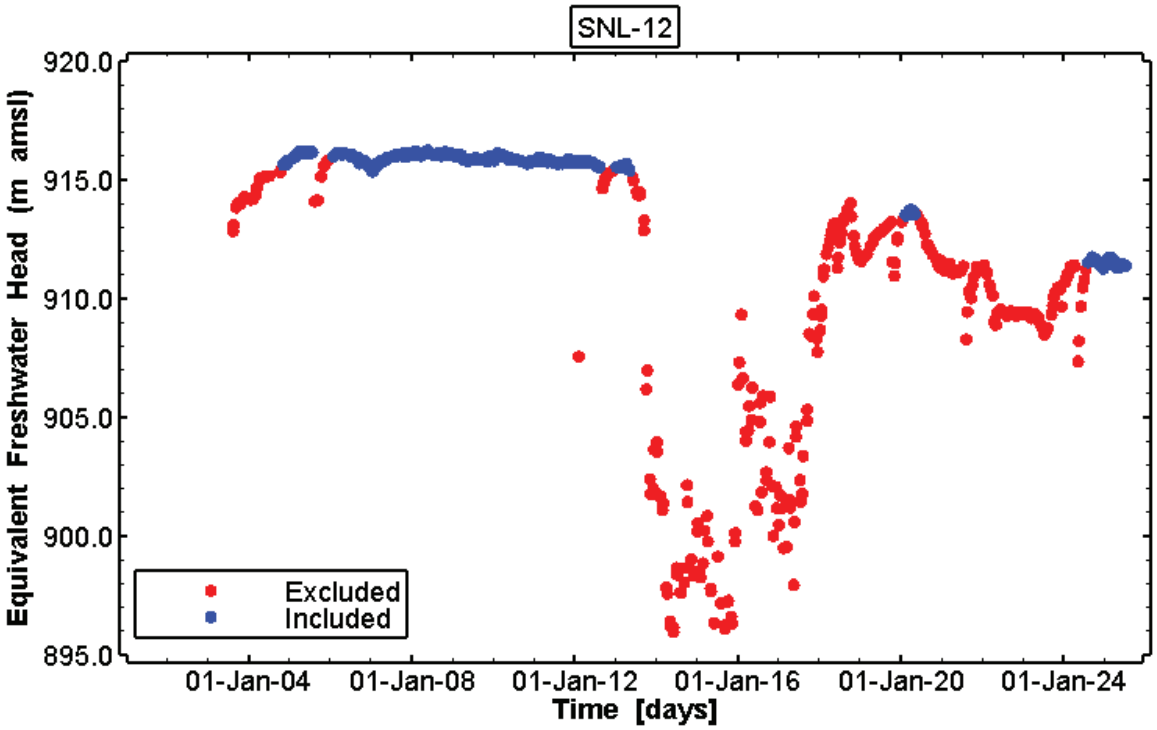

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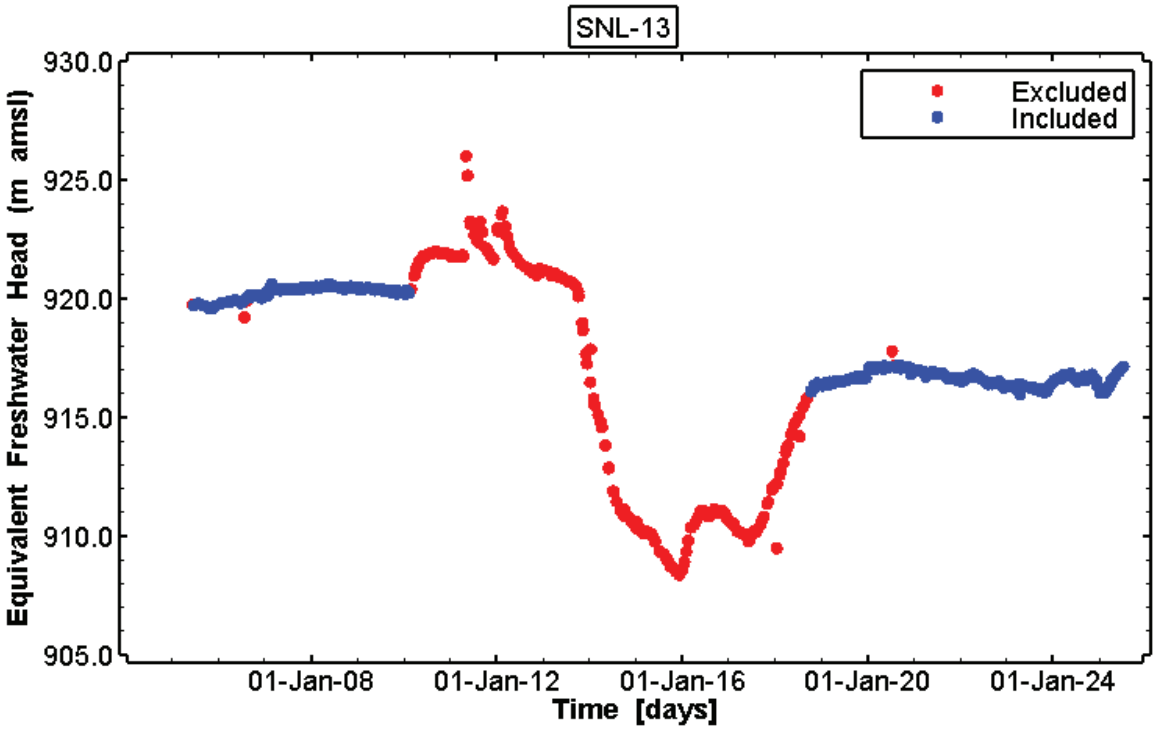

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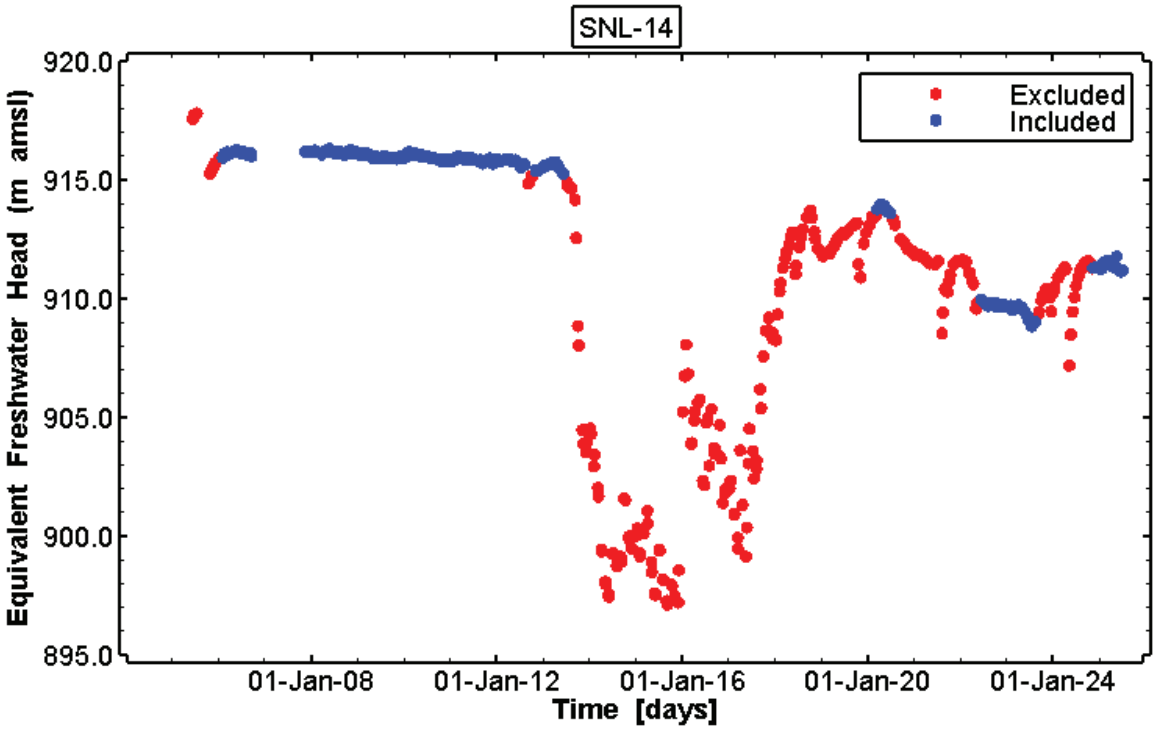

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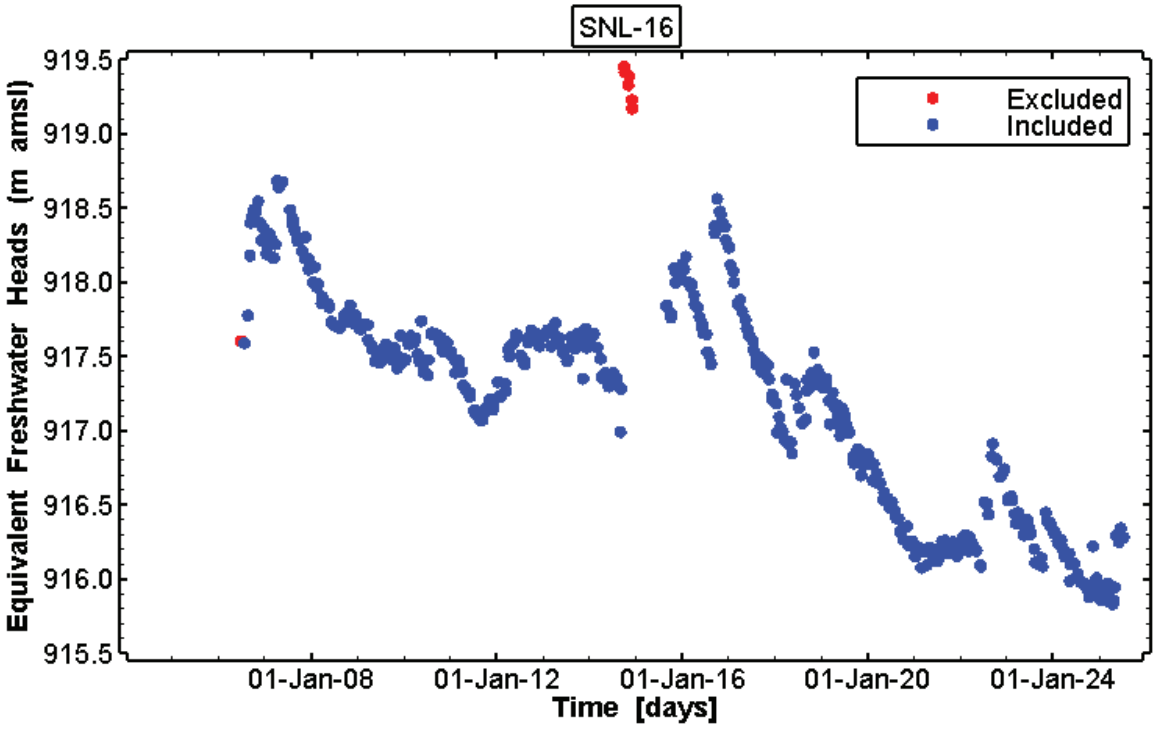

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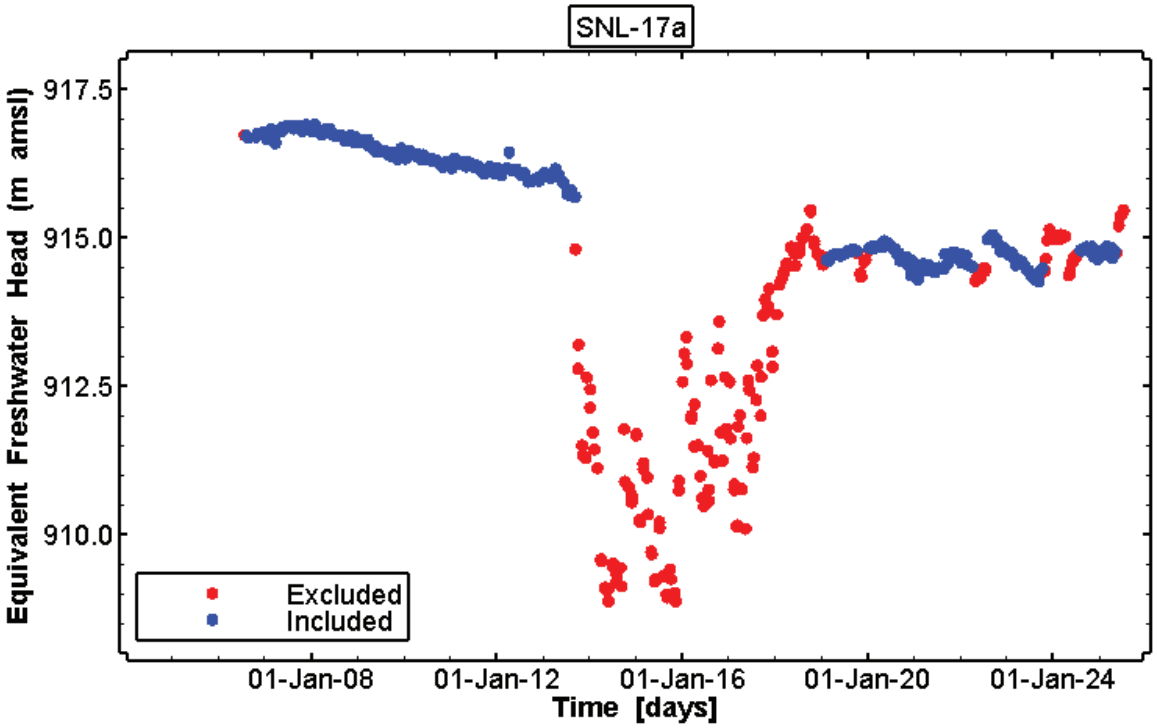

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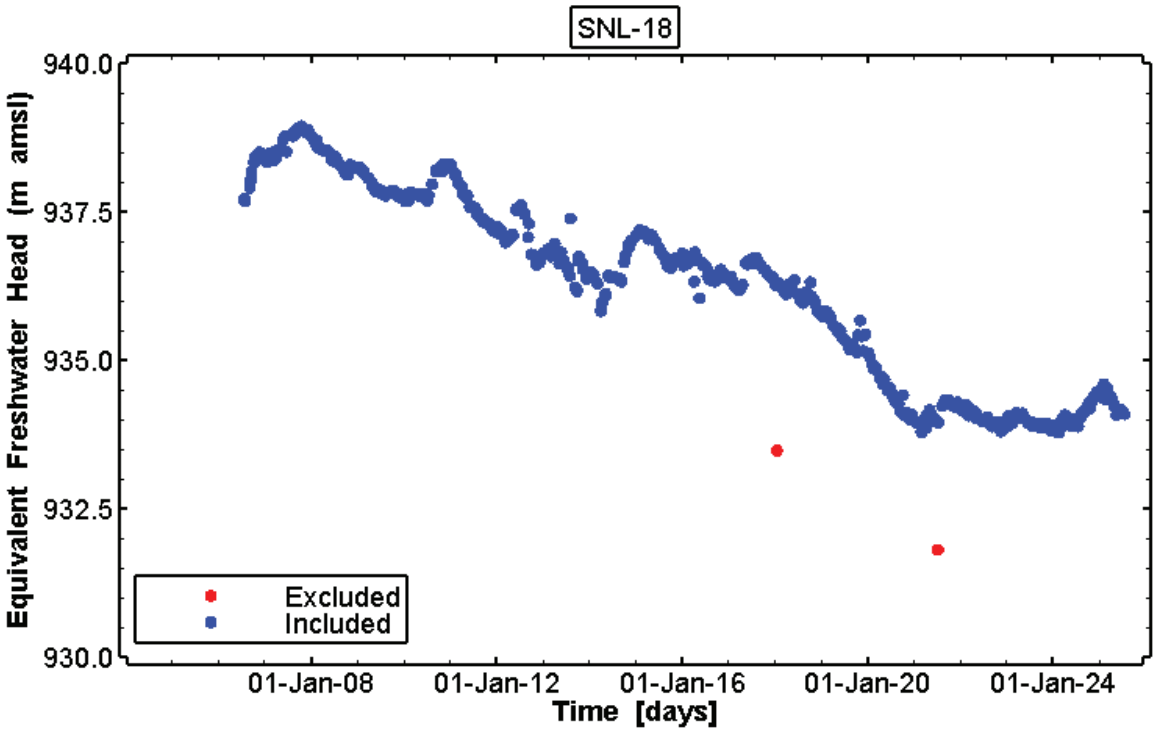

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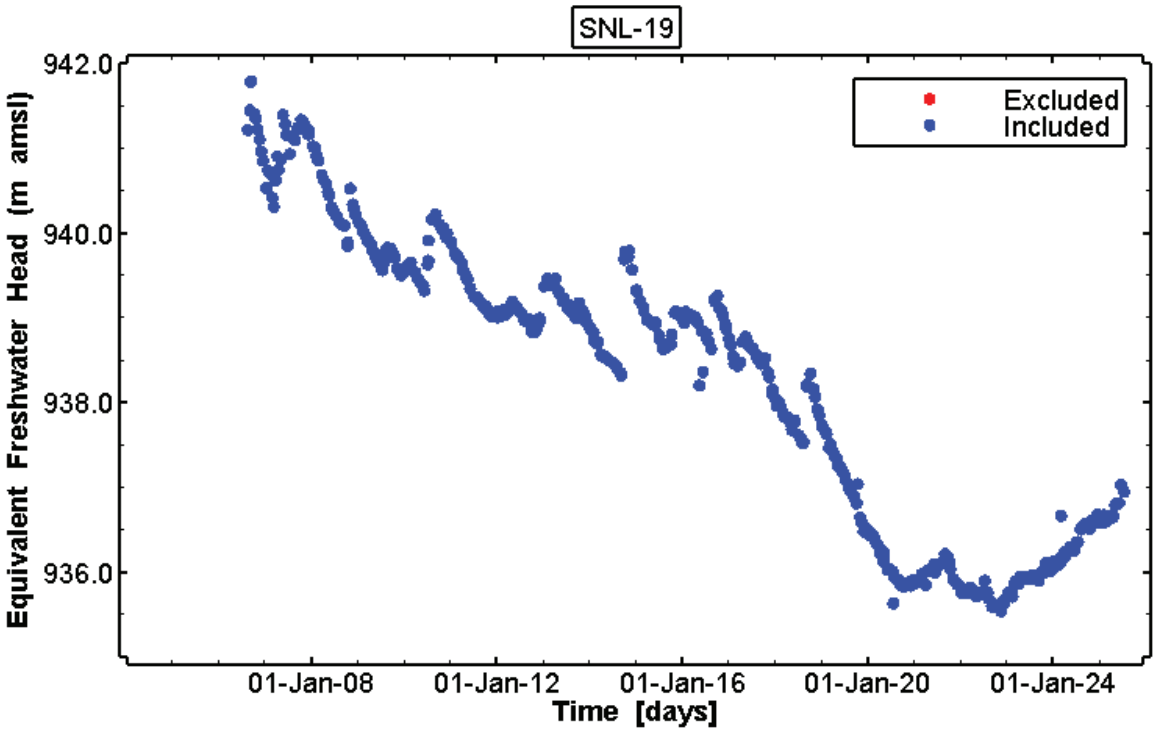

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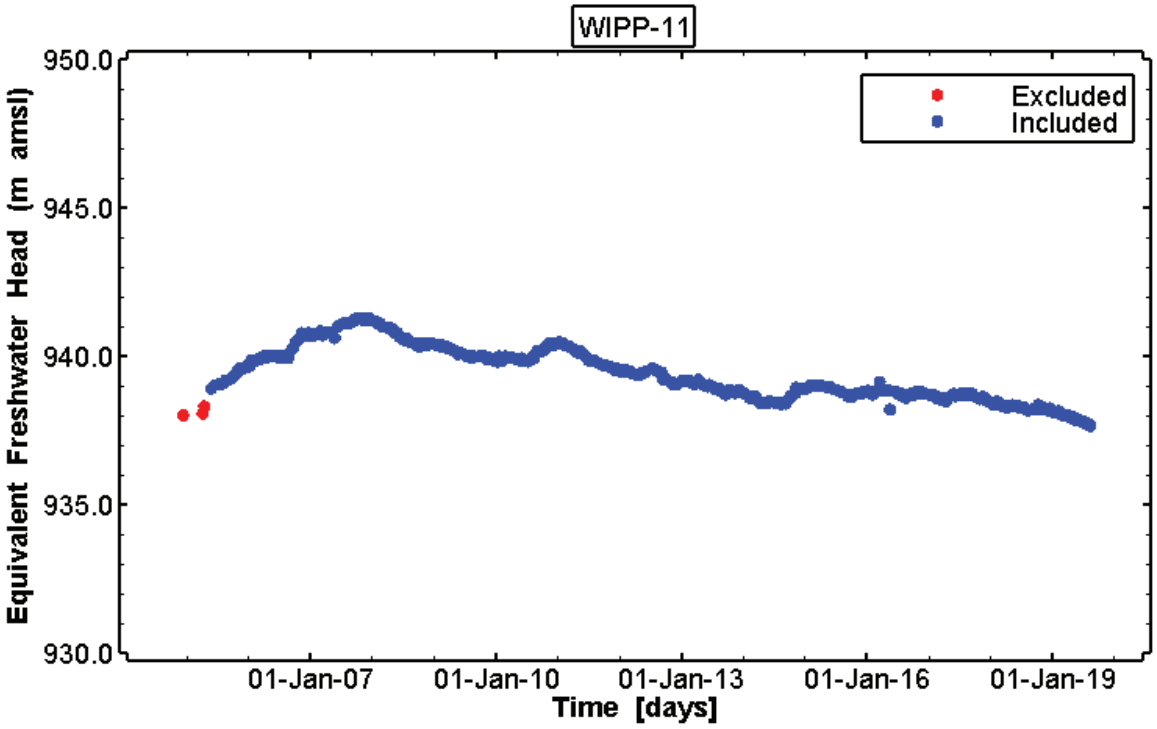

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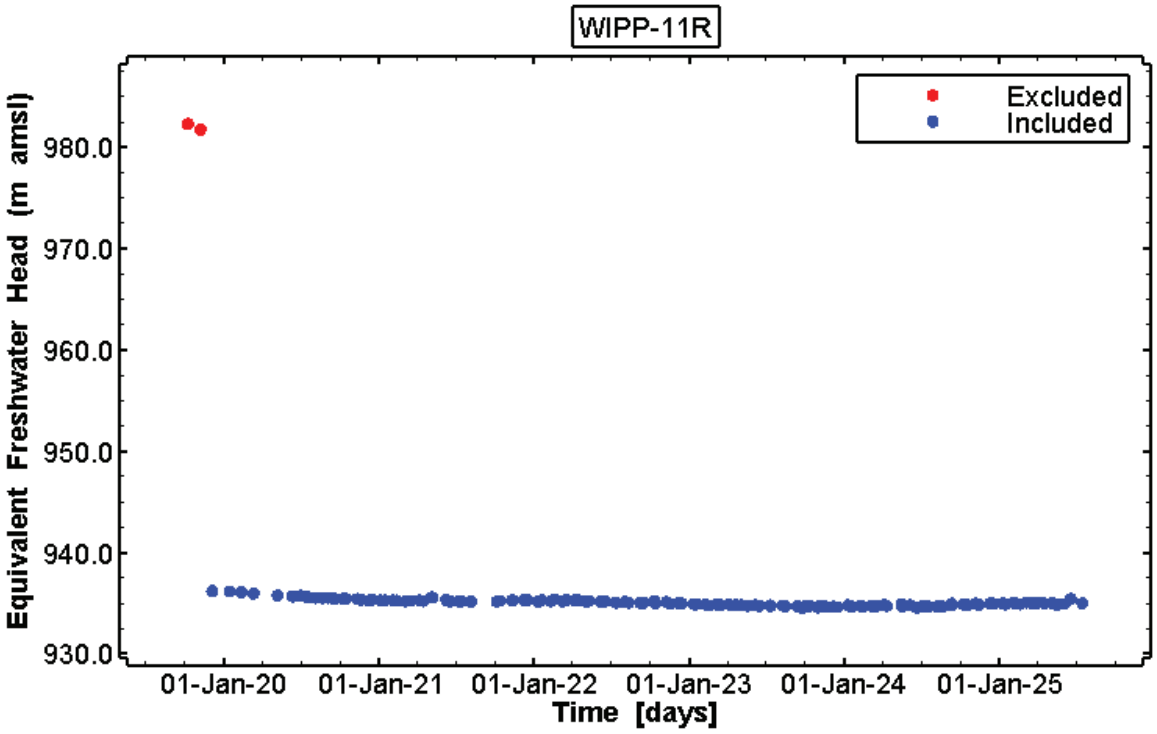

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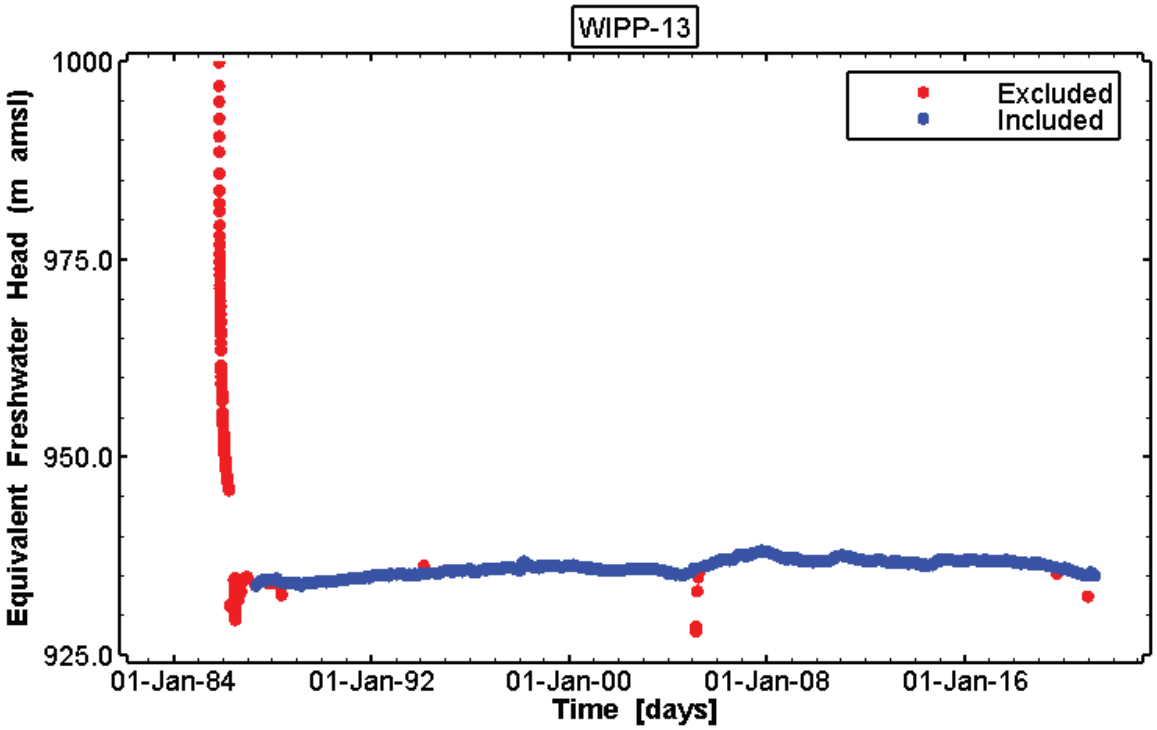

Figure A37. Data included and excluded from the WIPP-13 analysis.

Information Only

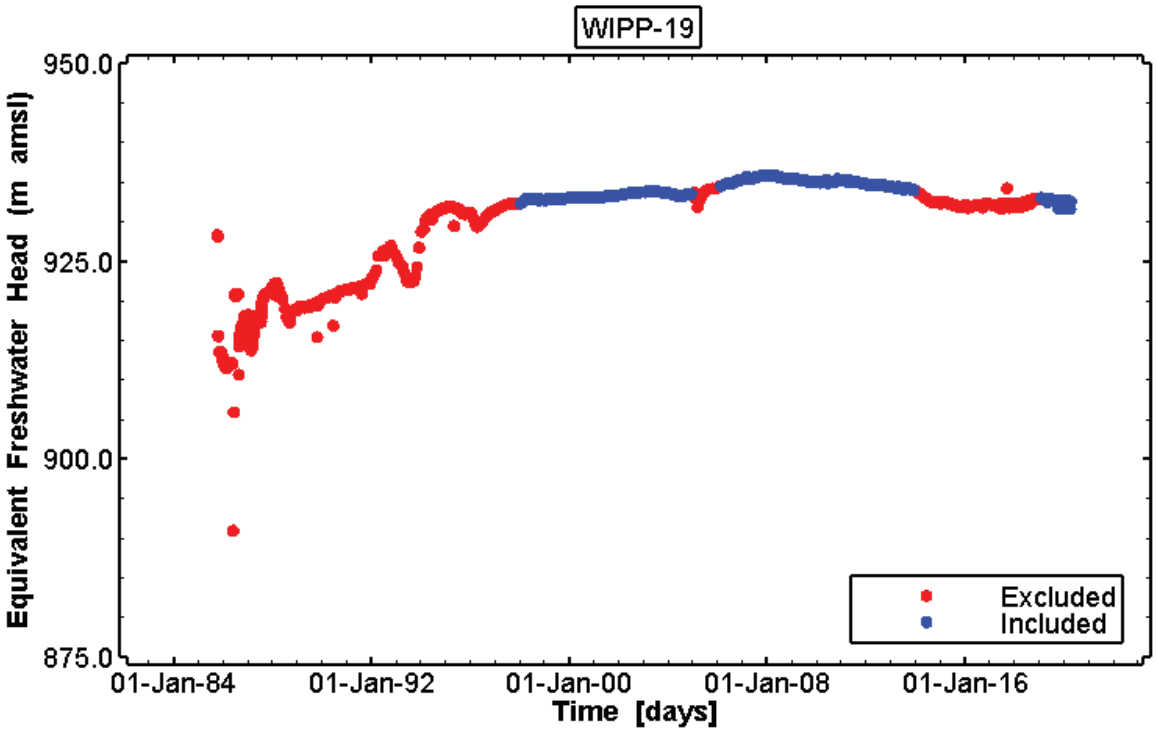

Figure A38. Data included and excluded from the WIPP-19 analysis.

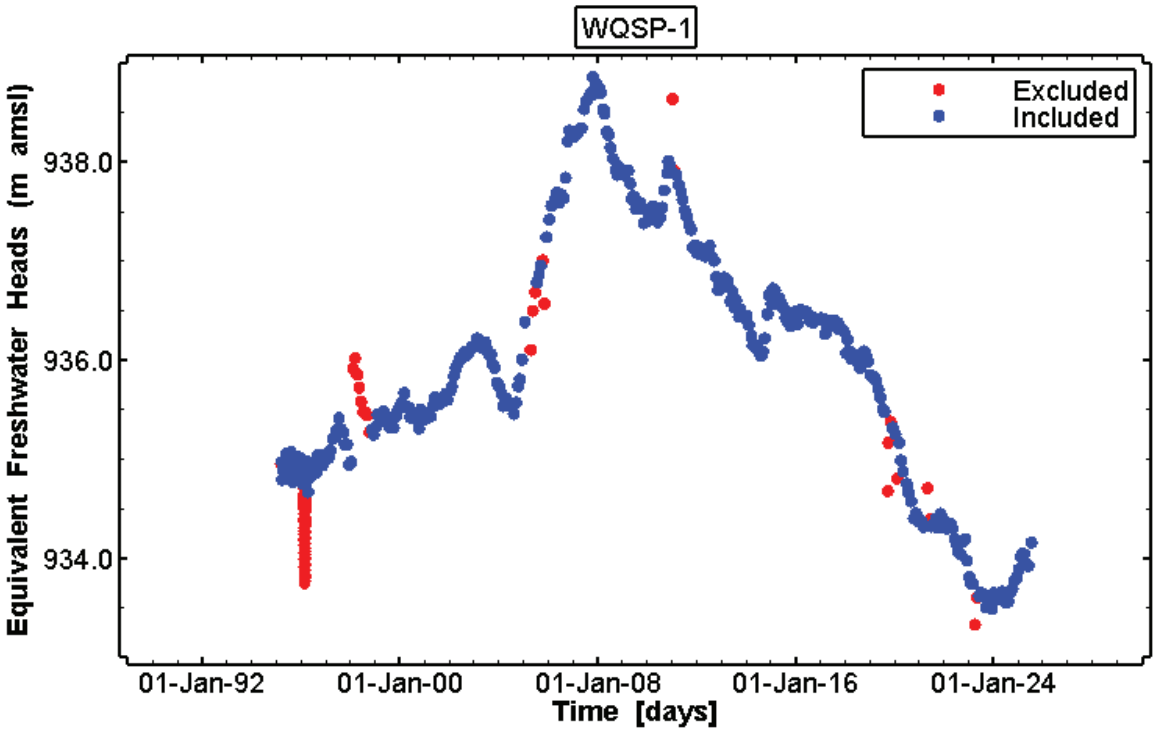

Figure A39. Data included and excluded from the WIQSP-1 analysis.

Information Only

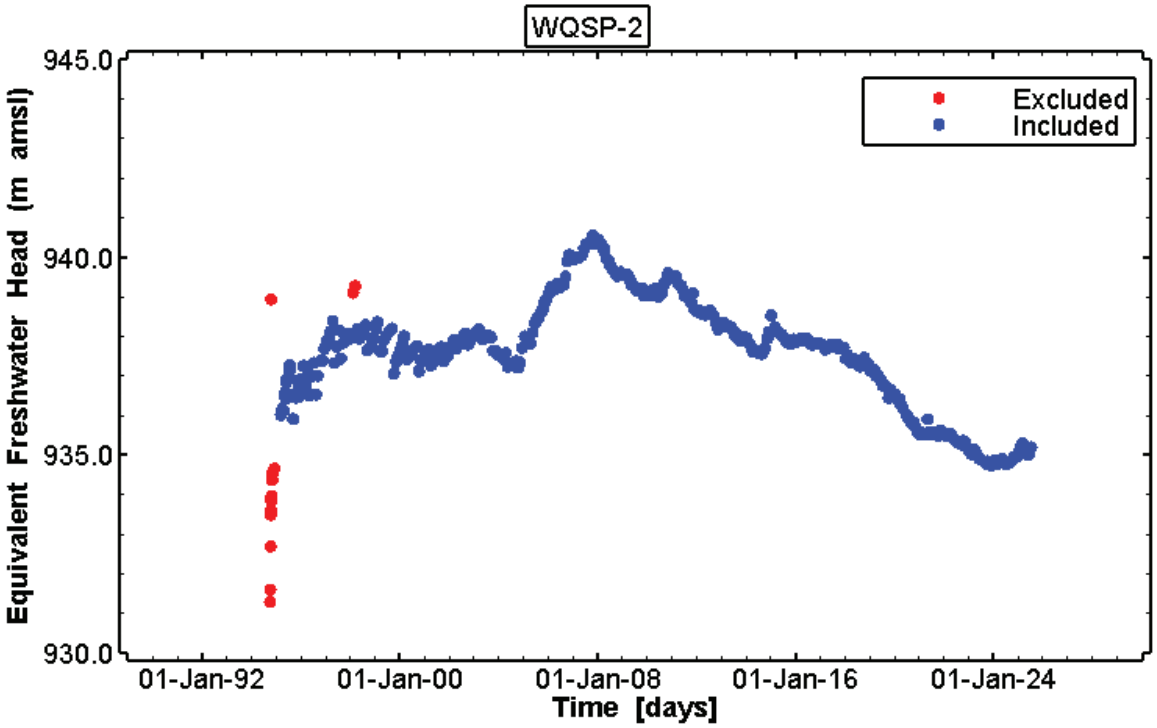

Figure A40. Data included and excluded from the WQSP-2 analysis.

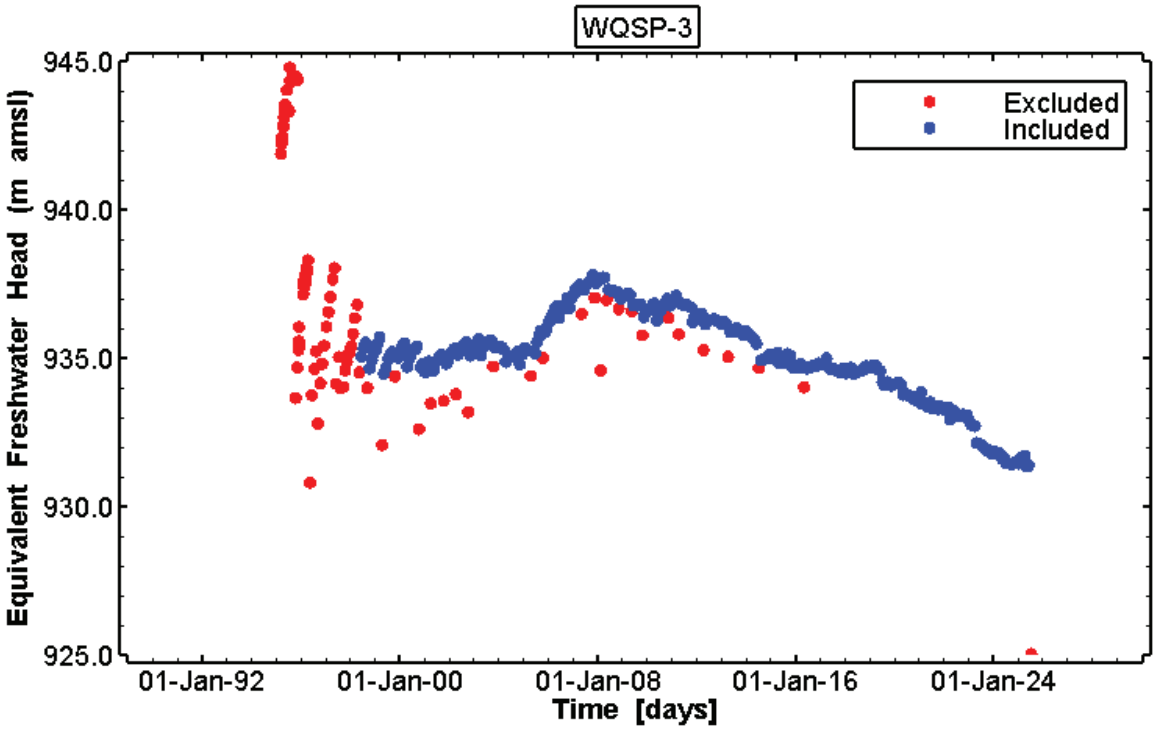

Figure A41. Data included and excluded from the WQSP-3 analysis.

Information Only

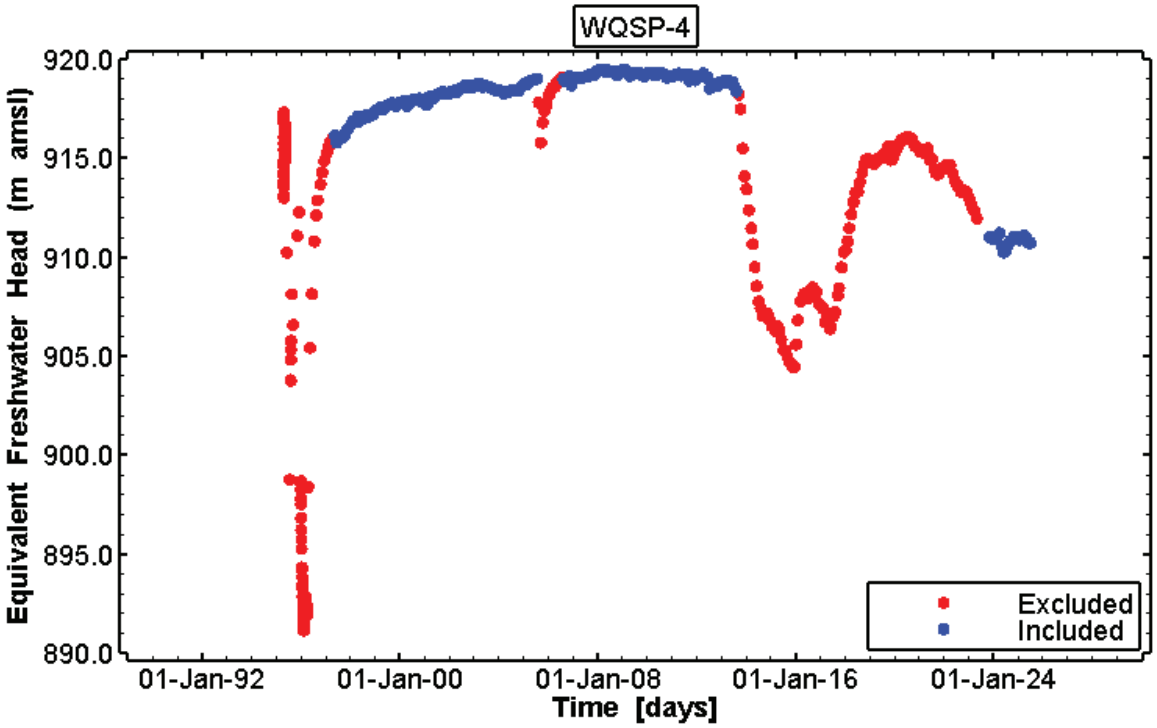

Figure A42. Data included and excluded from the WQSP-4 analysis.

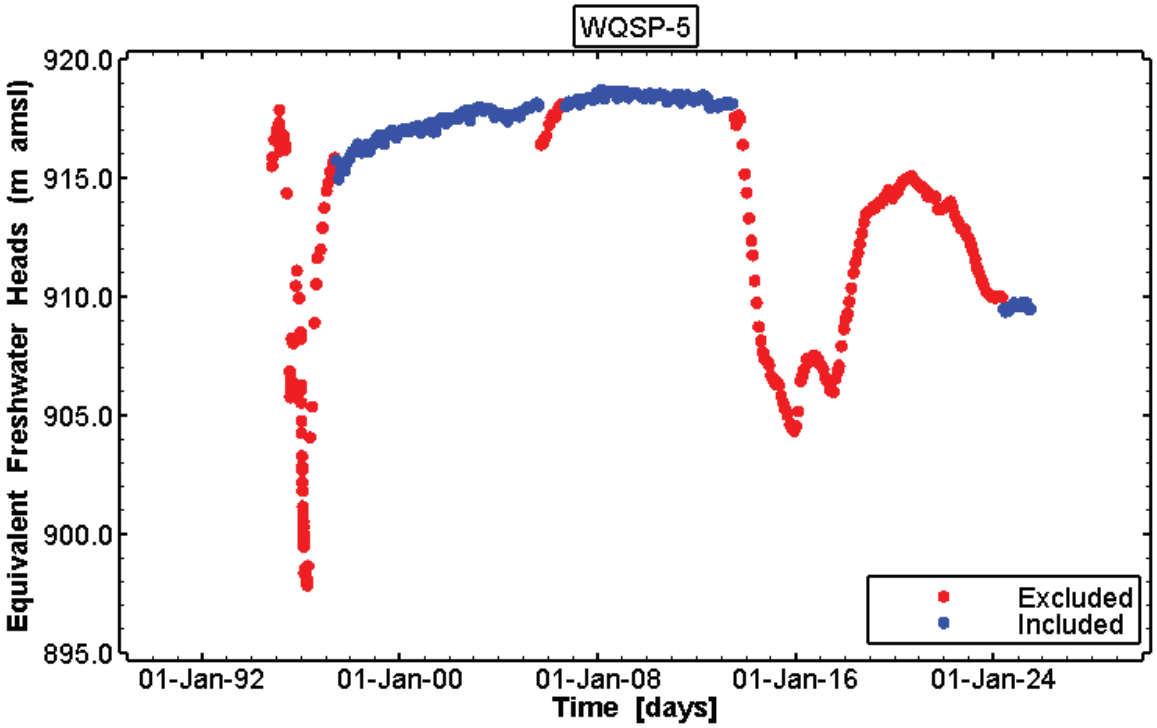

Figure A43. Data included and excluded from the WQSP-5 analysis.

Information Only

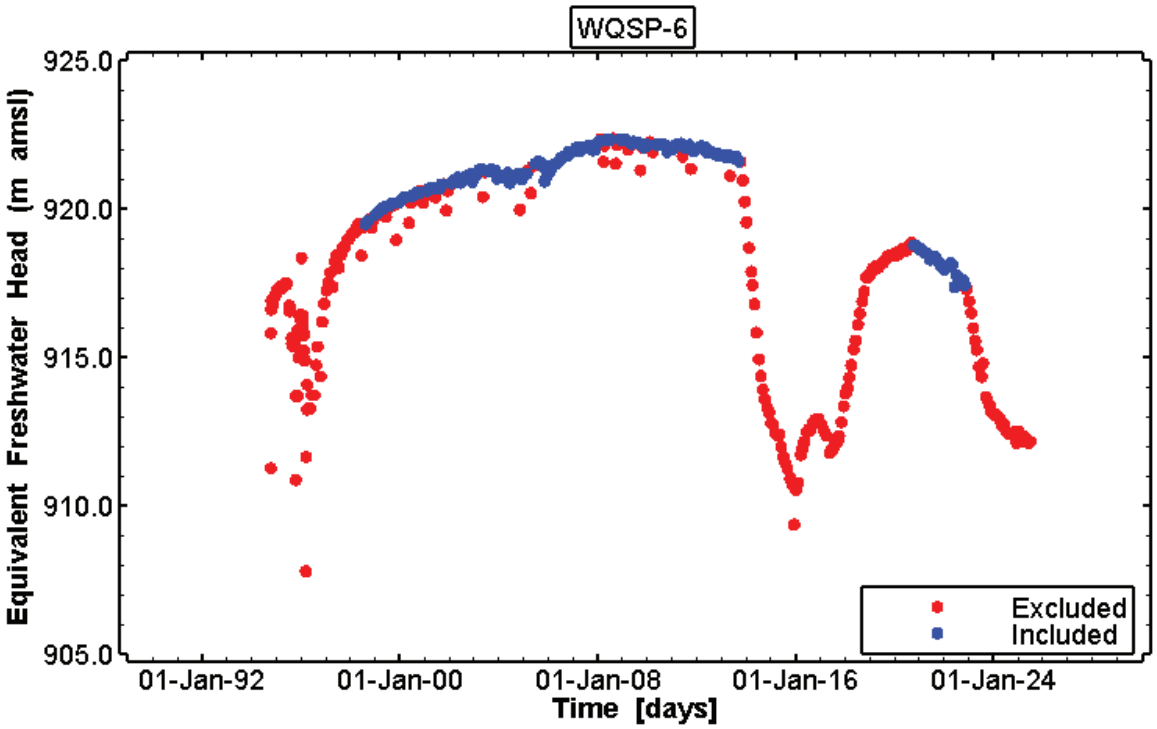

Figure A44. Data included and excluded from the WQSP-6 analysis.

Information Only

8. Appendix B – Scatter and Box Plots

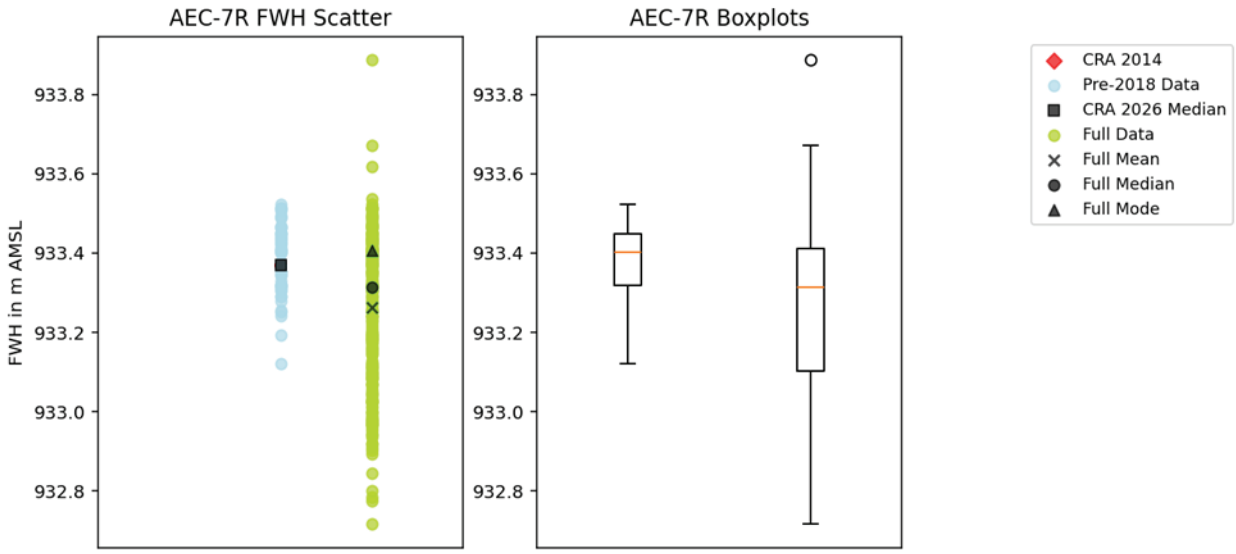

Figure B1. AEC-7R freshwater head scatter and box plots. A CRA 2014 value does not exist for this well as there was no target used in that calibration.

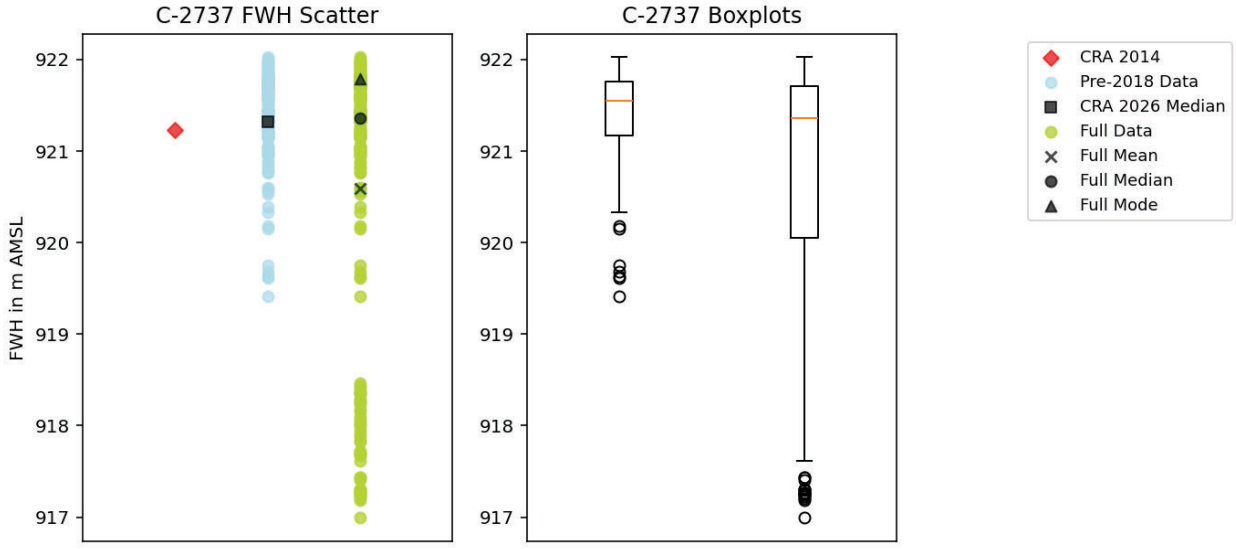

Figure B2. C-2737 freshwater head scatter and box plots.

Information Only

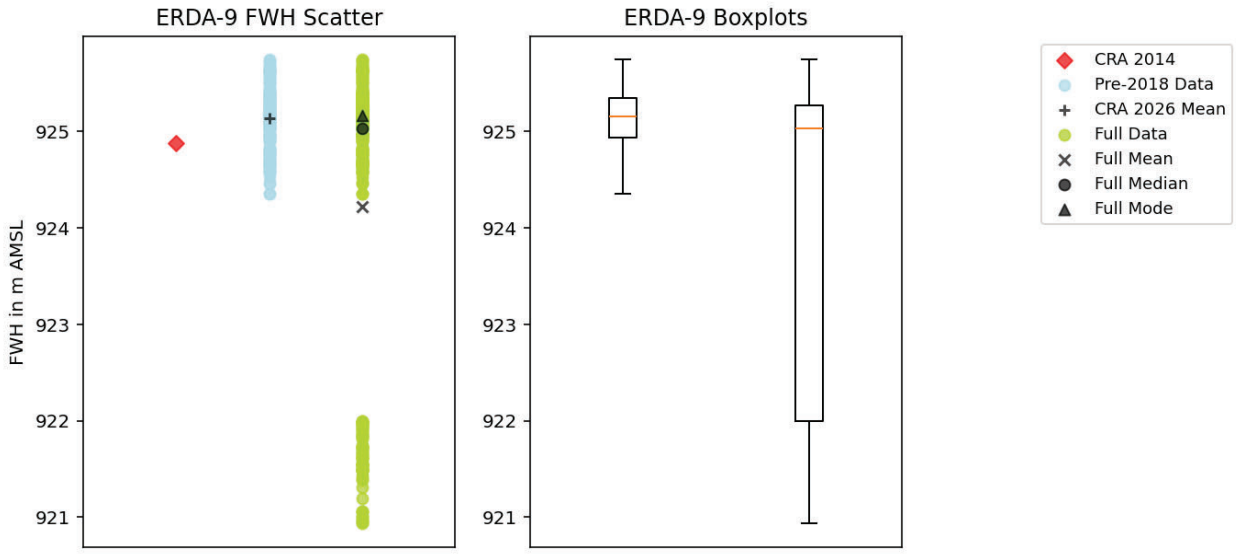

Figure B3. ERDA-9 freshwater head scatter and box plots.

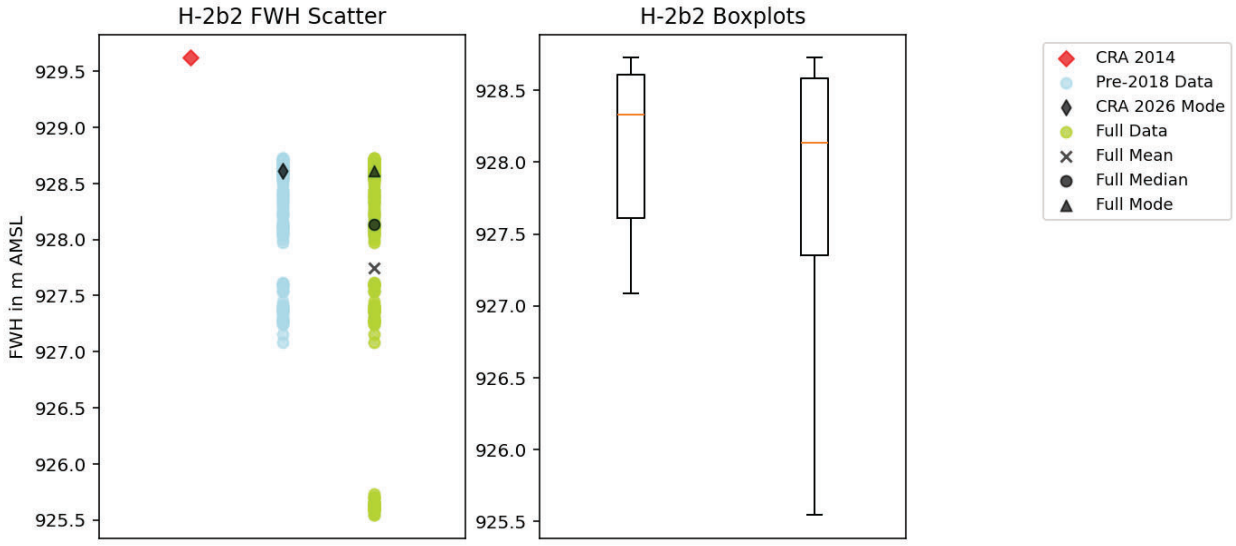

Figure B4. H-2b2 freshwater head scatter and box plots.

Information Only

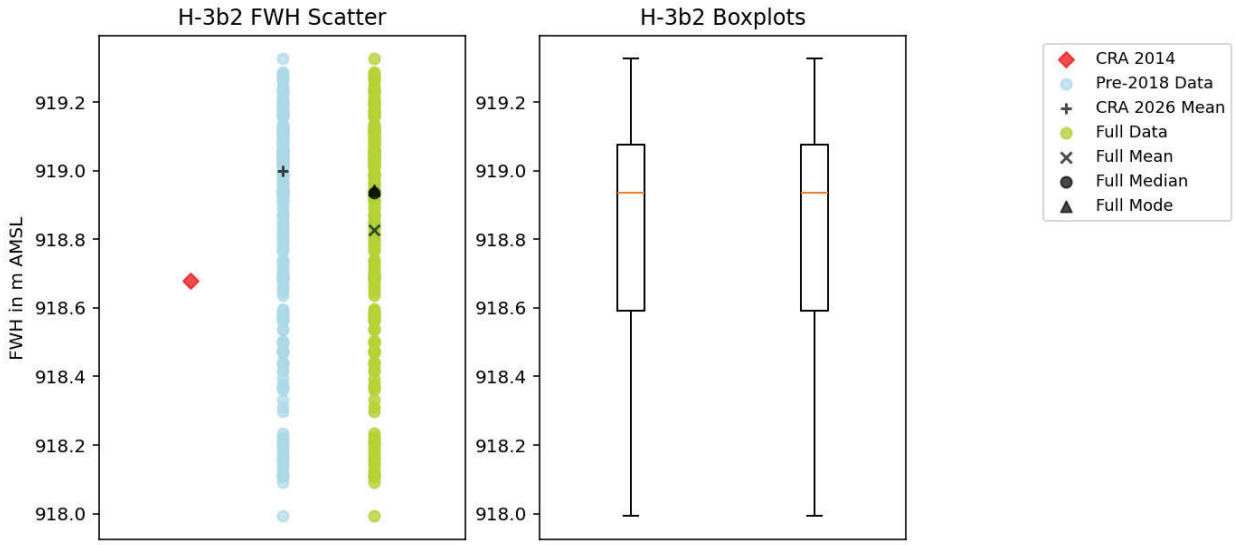

Figure B5. H-3b2 freshwater head scatter and box plots.

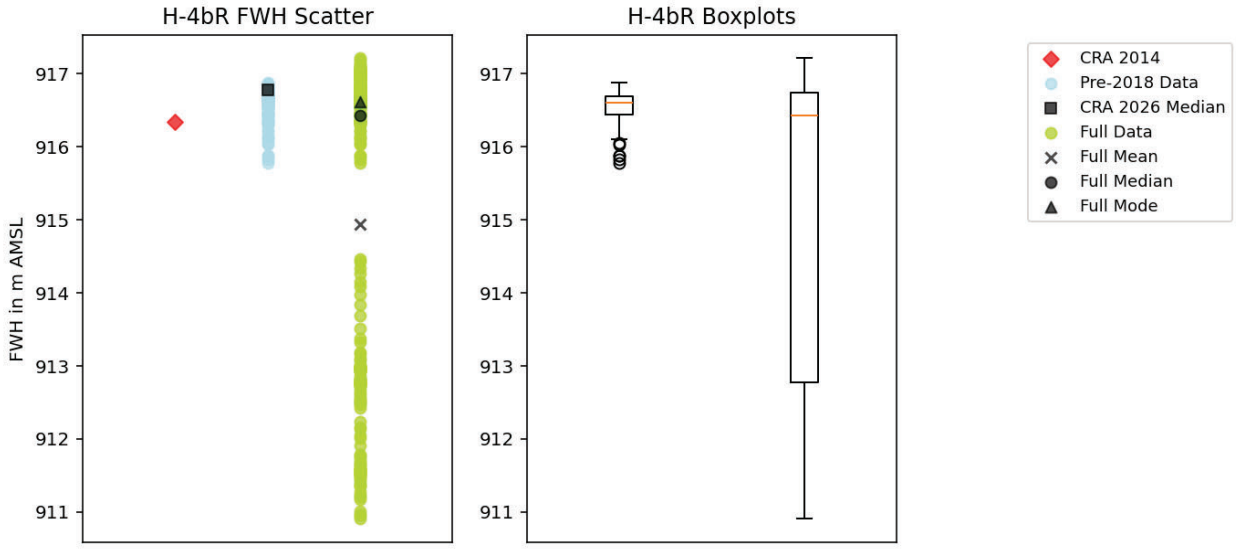

Figure B6. H-4bR freshwater head scatter and box plots.

Information Only

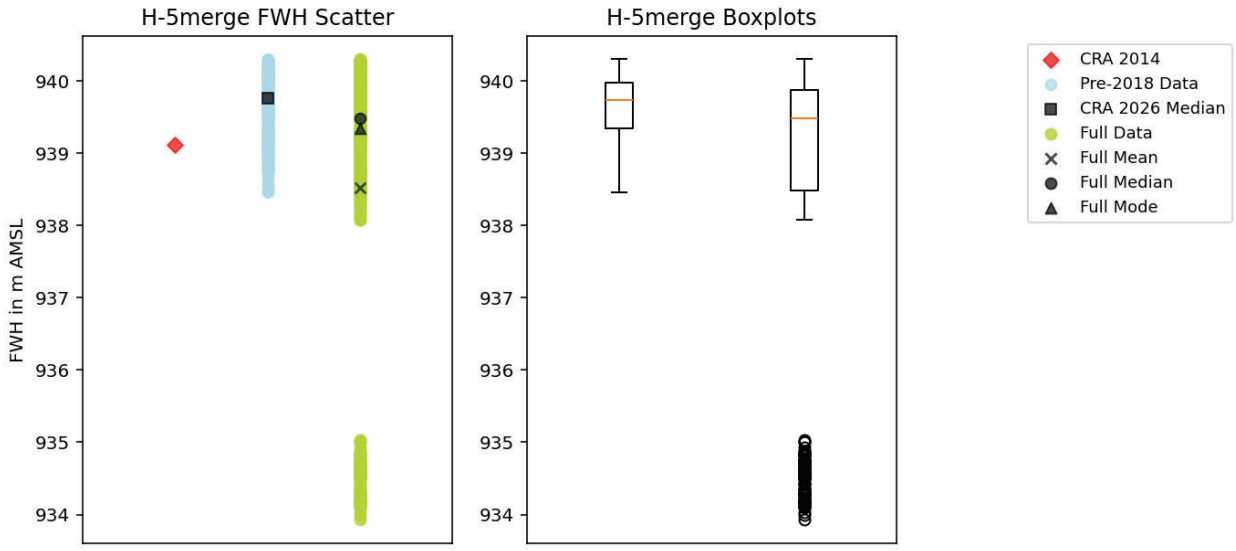

Figure B7. H-5bmerge freshwater head scatter and box plots.

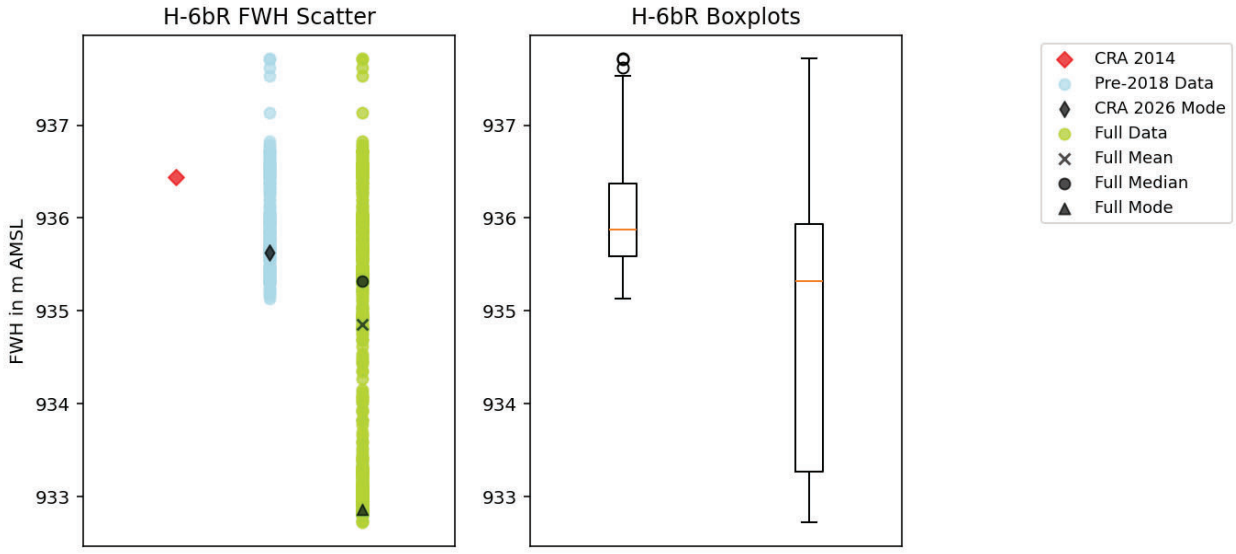

Figure B8. H-6bR freshwater head scatter and box plots.

Information Only

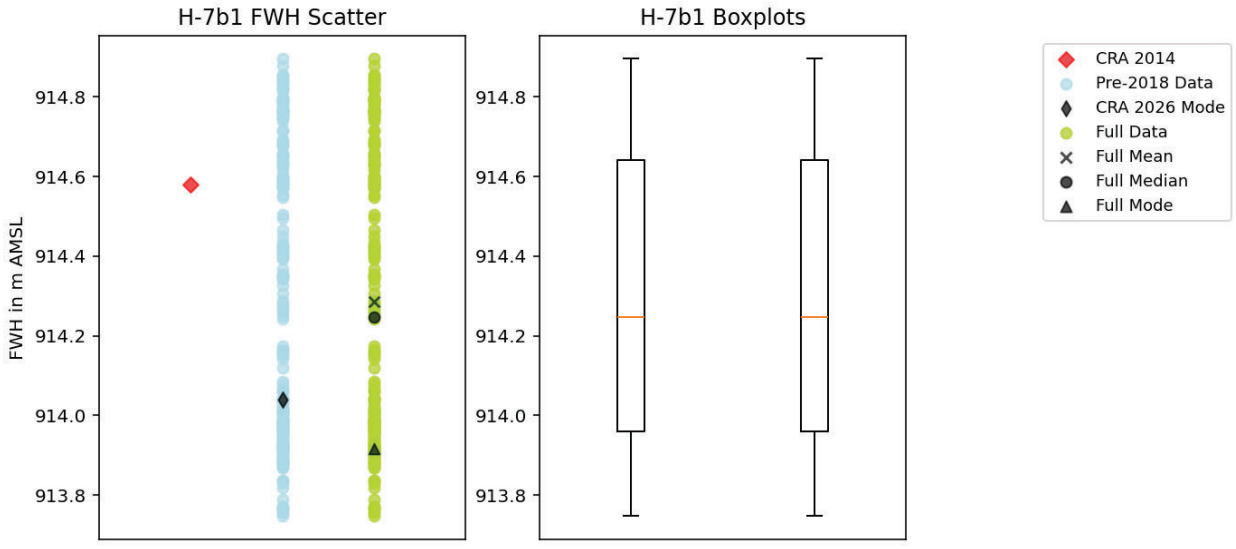

Figure B9. H-7b1 freshwater head scatter and box plots.

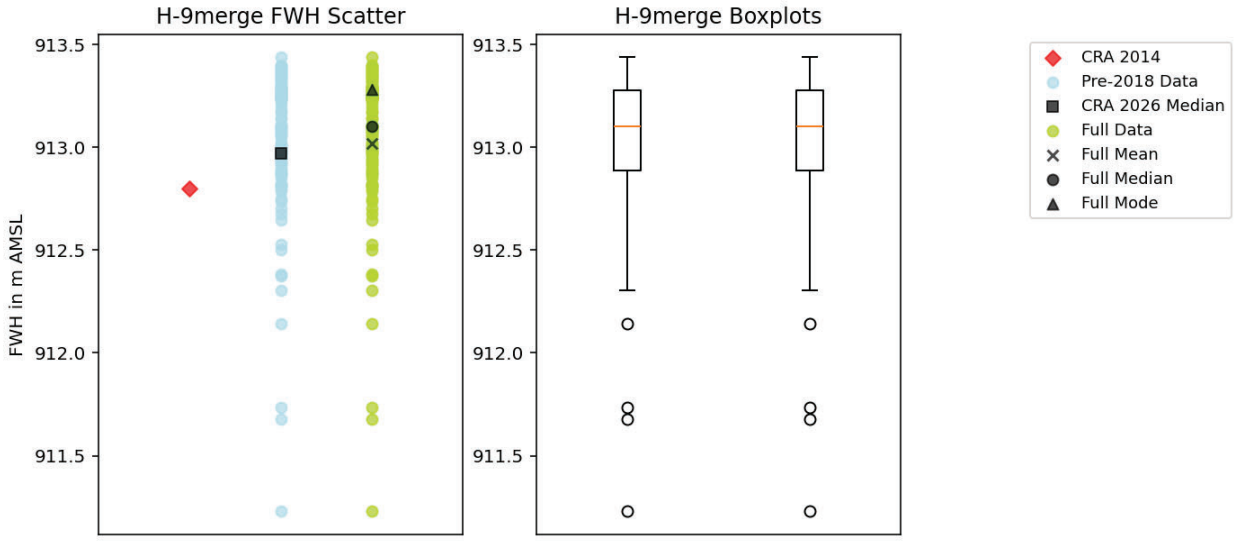

Figure B10. H-9merge freshwater head scatter and box plots.

Information Only

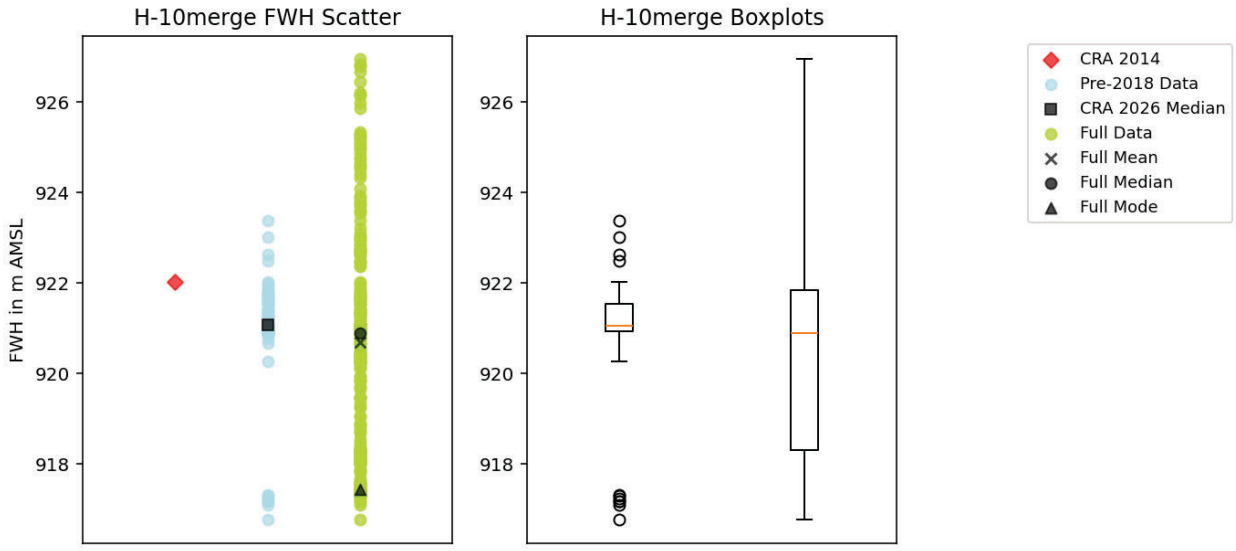

Figure B11. H-10merge freshwater head scatter and box plots.

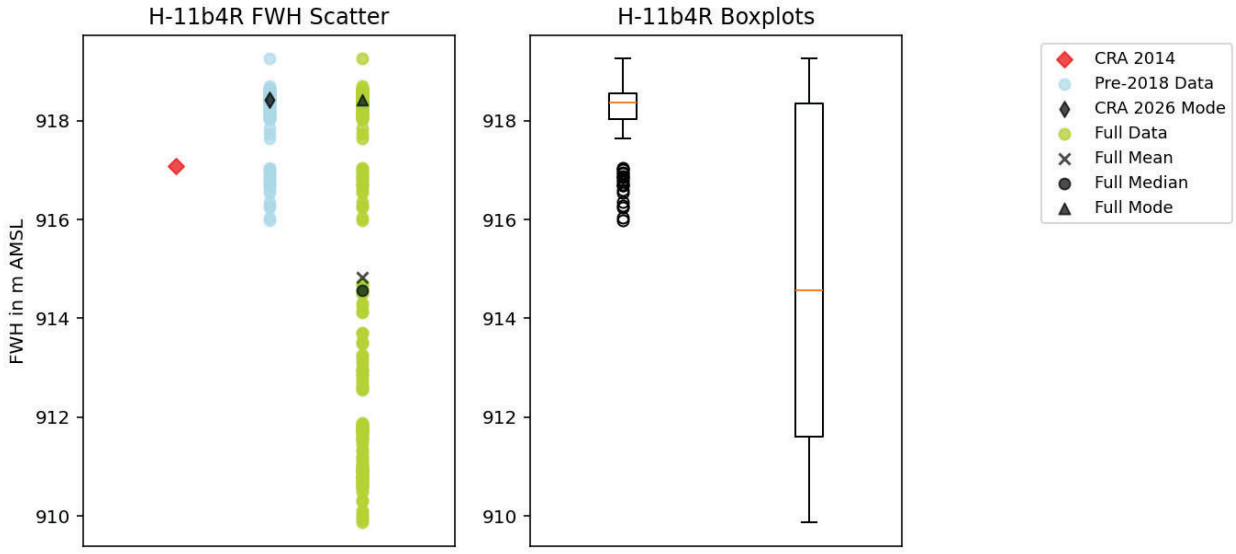

Figure B12. H-11b4R freshwater head scatter and box plots.

Information Only

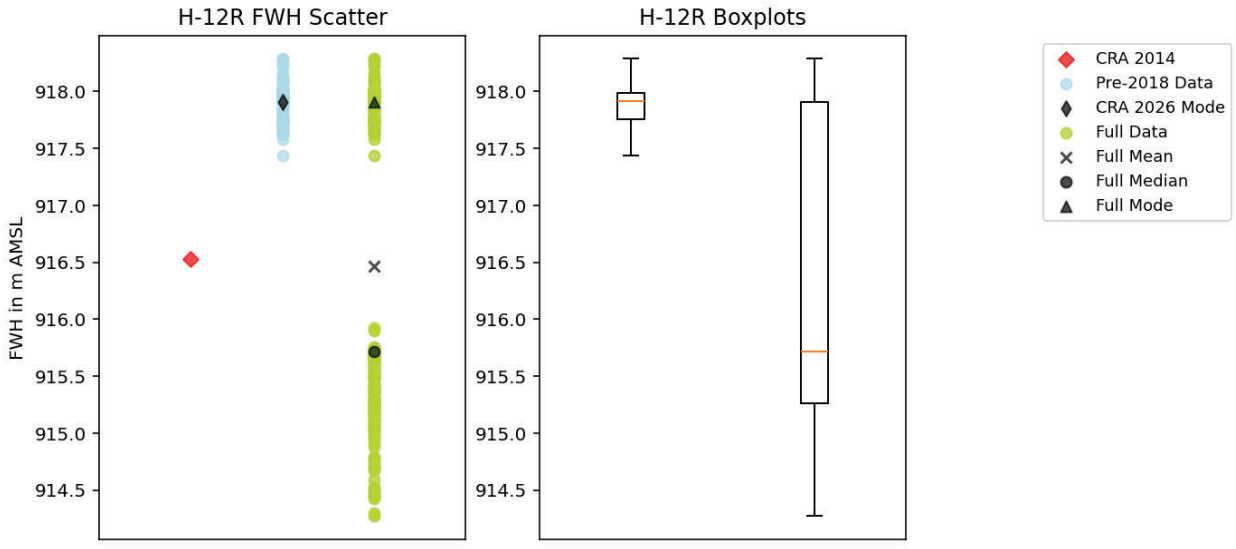

Figure B13. H-12R freshwater head scatter and box plots.

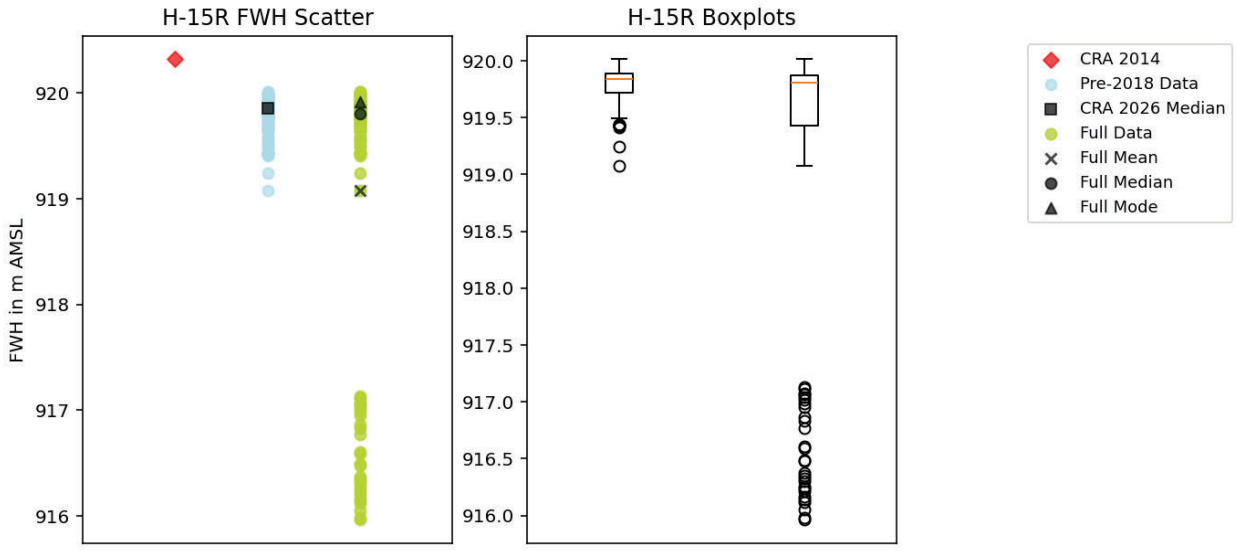

Figure B14. H-15R freshwater head scatter and box plots.

Information Only

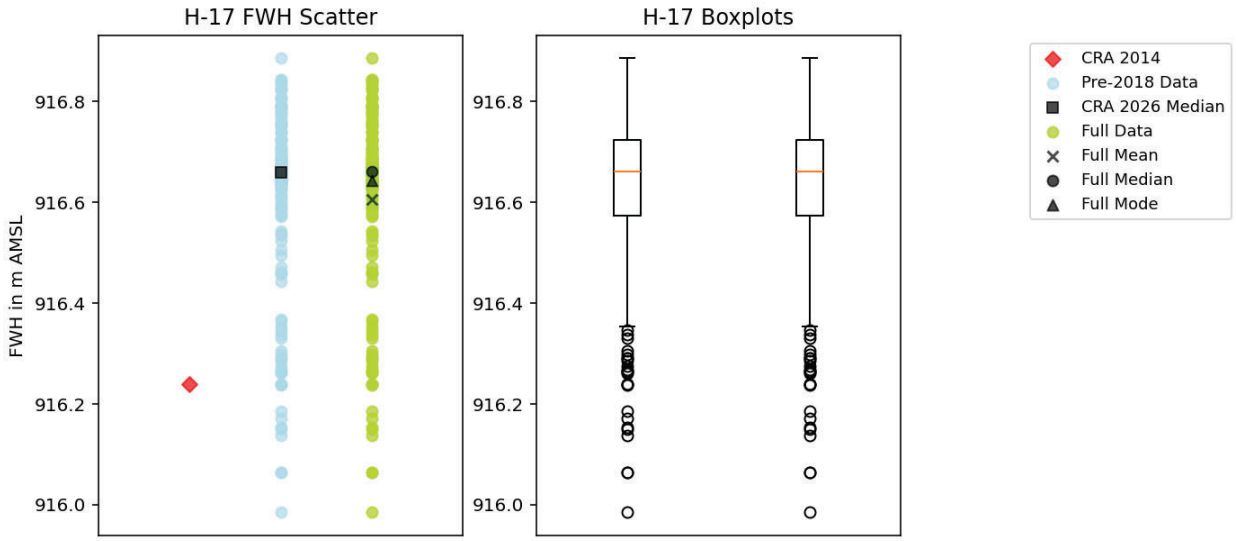

Figure B15. H-17 freshwater head scatter and box plots.

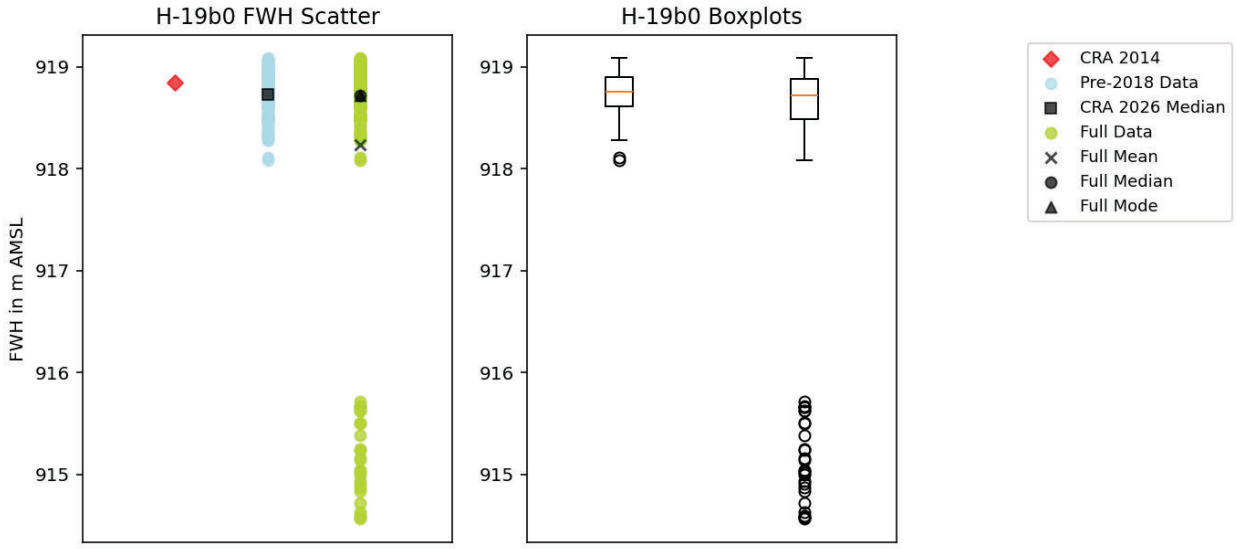

Figure B16. H-19b0 freshwater head scatter and box plots.

Information Only

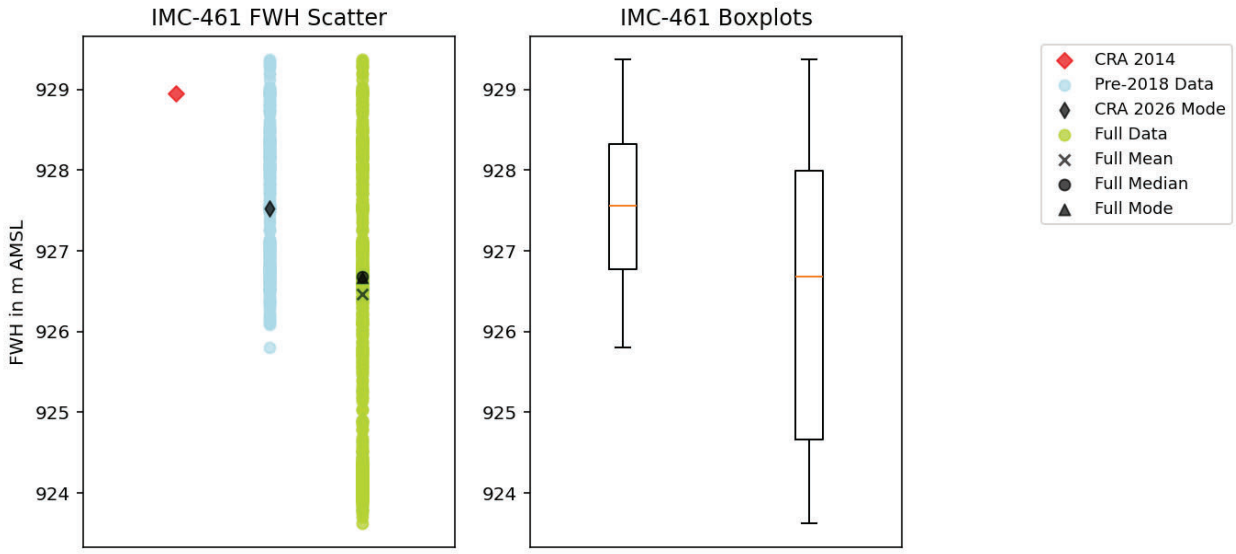

Figure B17. IMC-461 freshwater head scatter and box plots.

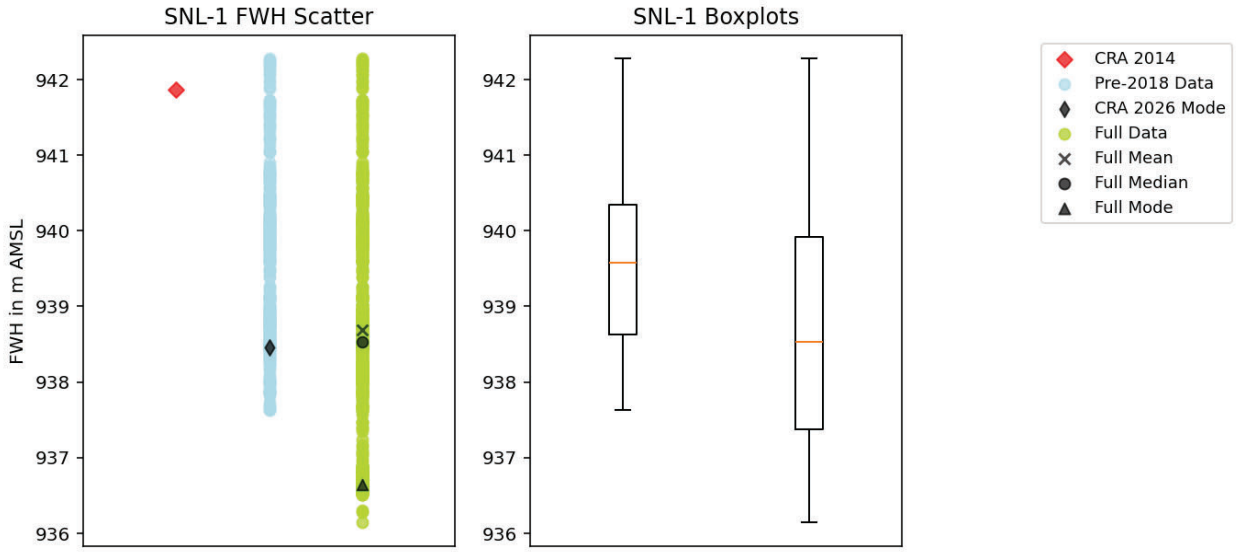

Figure B18. SNL-1 freshwater head scatter and box plots.

Information Only

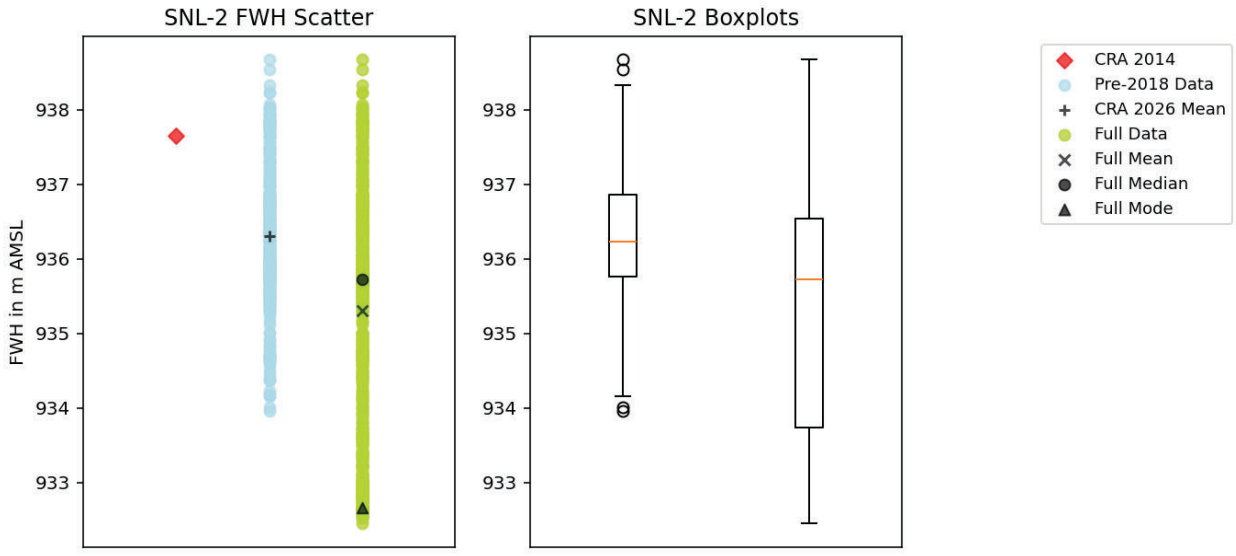

Figure B19. SNL-2 freshwater head scatter and box plots.

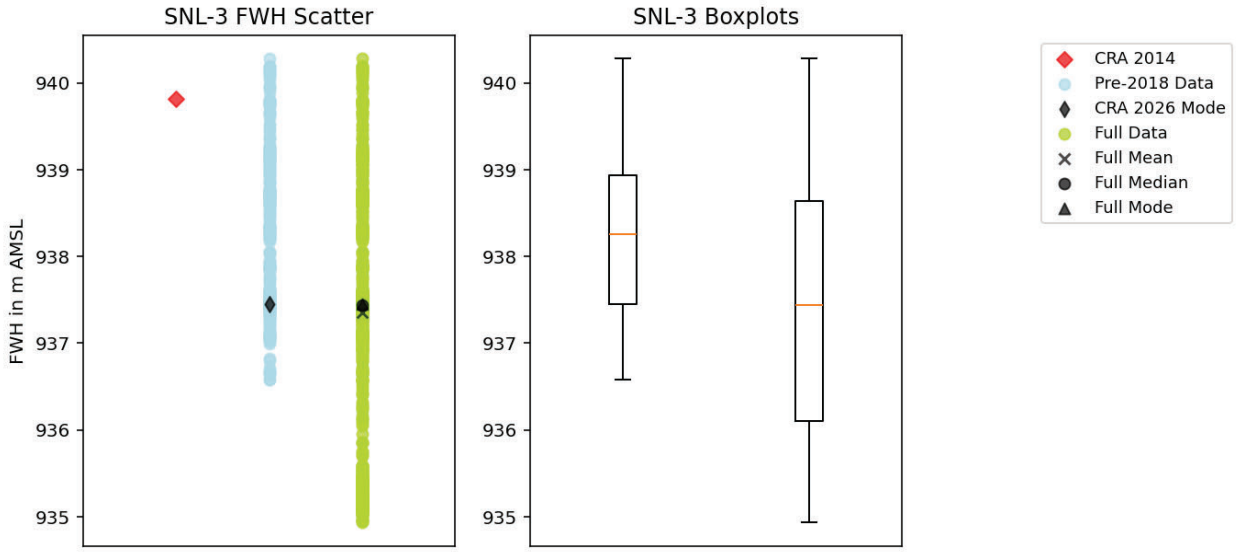

Figure B20. SNL-3 freshwater head scatter and box plots.

Information Only

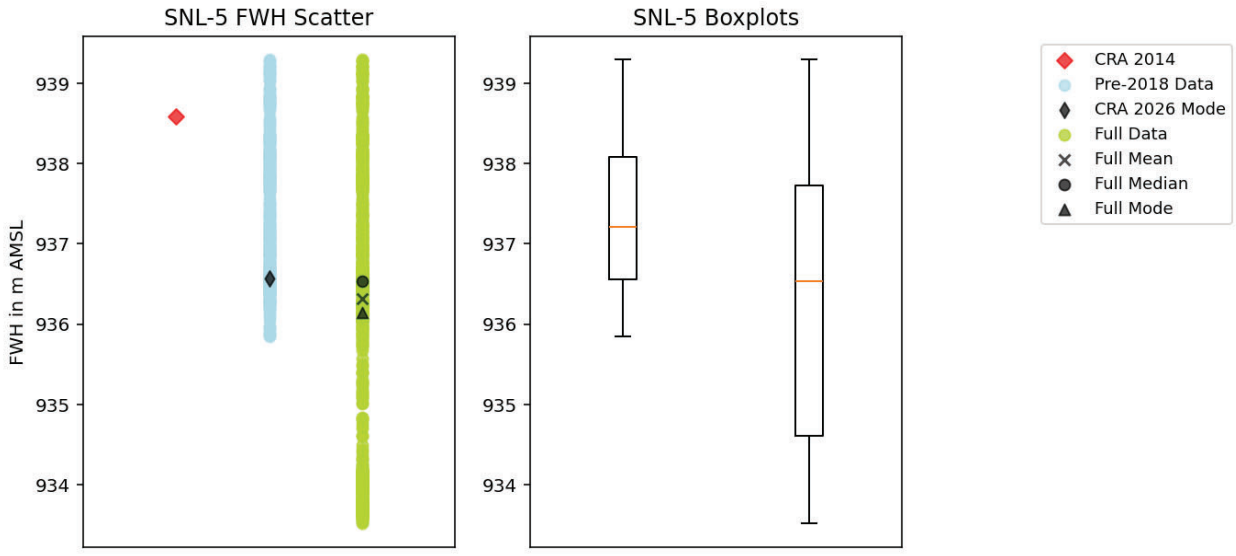

Figure B21. SNL-5 freshwater head scatter and box plots.

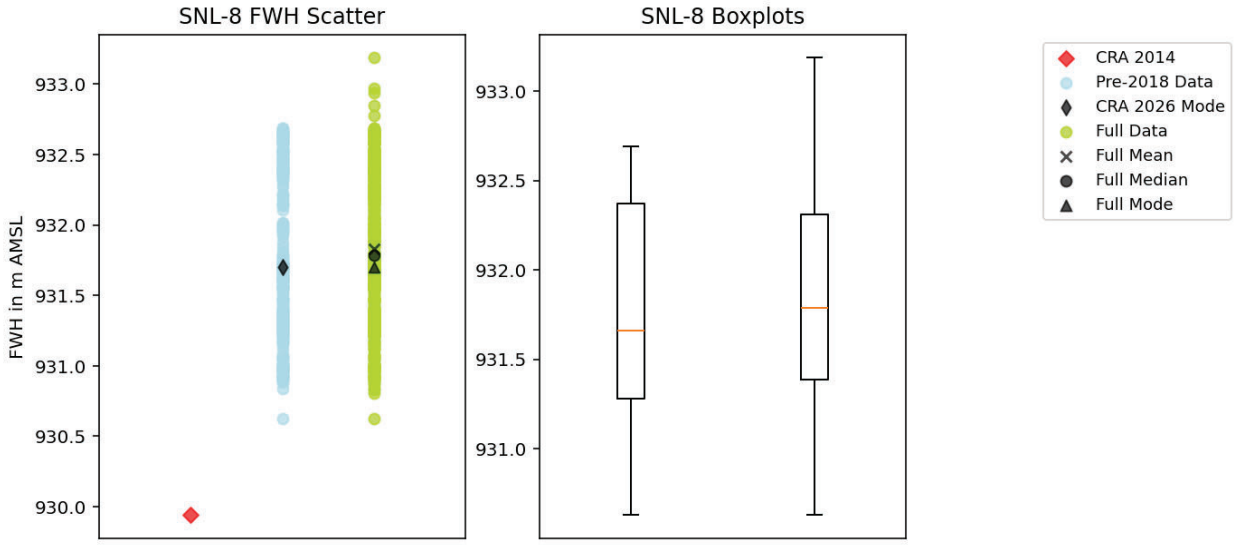

Figure B22. SNL-8 freshwater head scatter and box plots.

Information Only

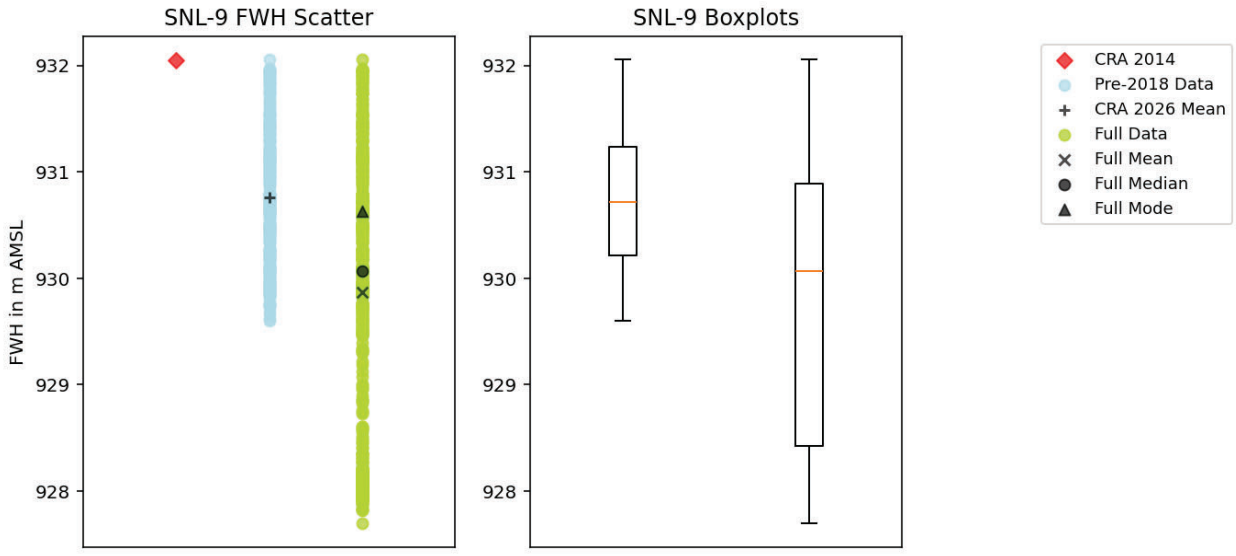

Figure B23. SNL-9 freshwater head scatter and box plots.

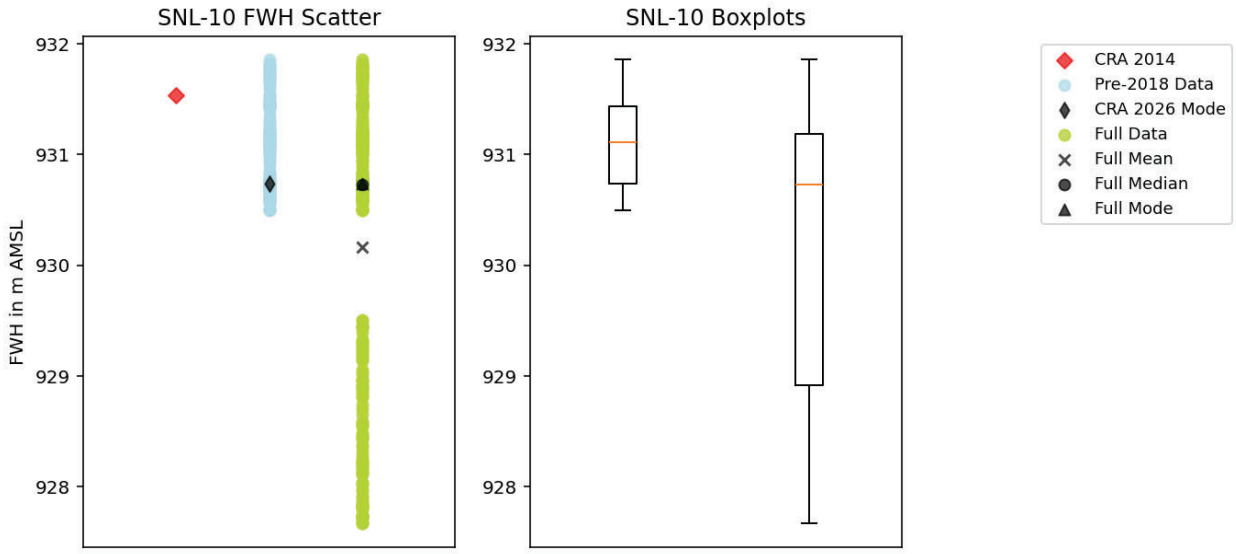

Figure B24. SNL-10 freshwater head scatter and box plots.

Information Only

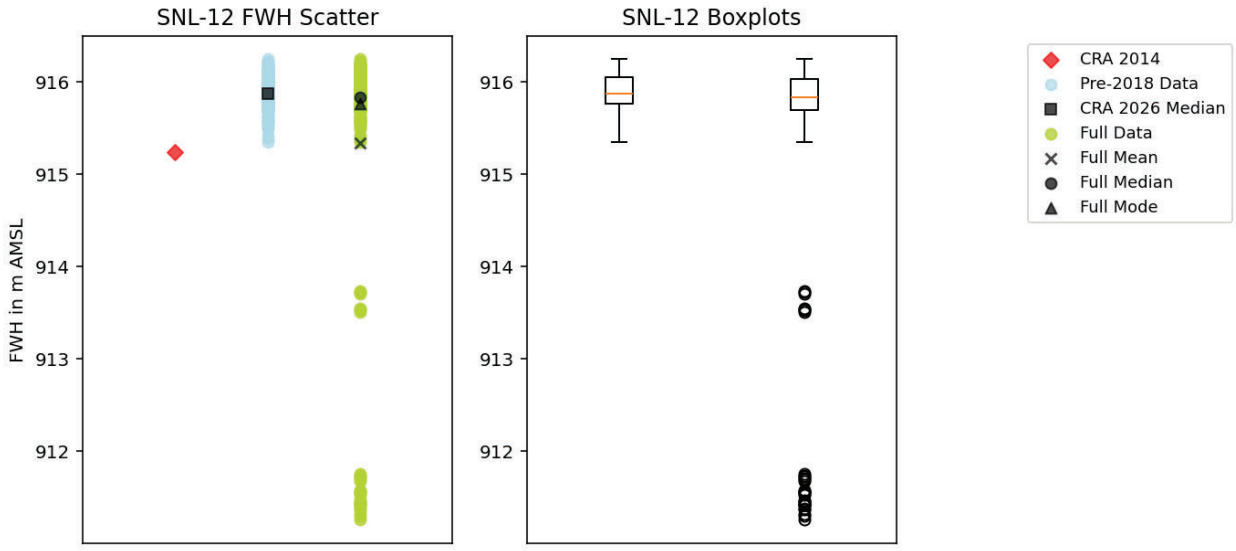

Figure B25. SNL-12 freshwater head scatter and box plots.

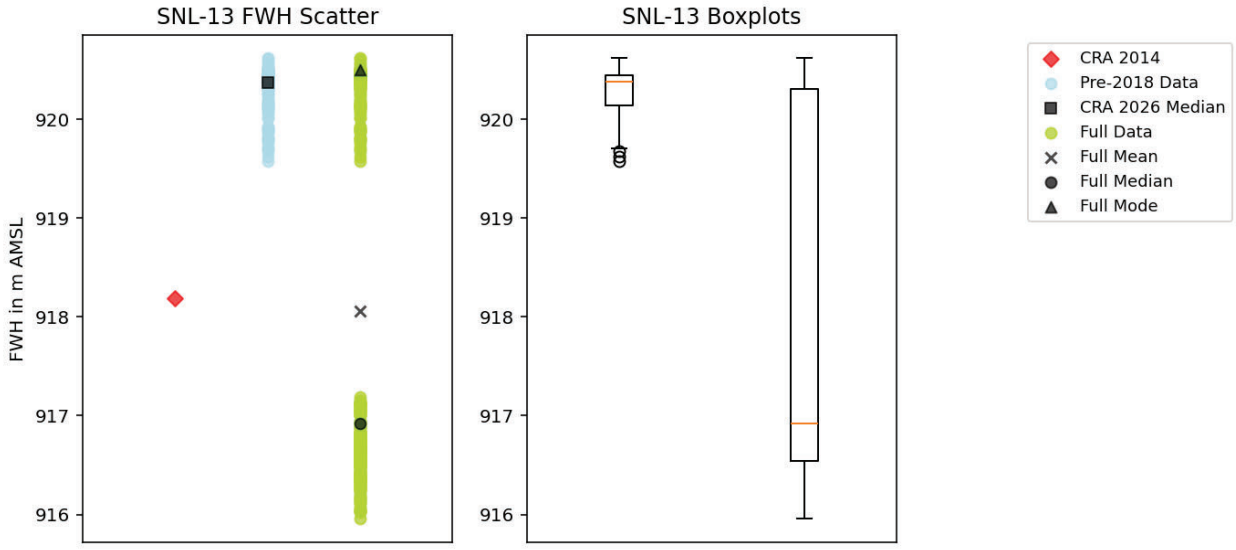

Figure B26. SNL-13 freshwater head scatter and box plots.

Information Only

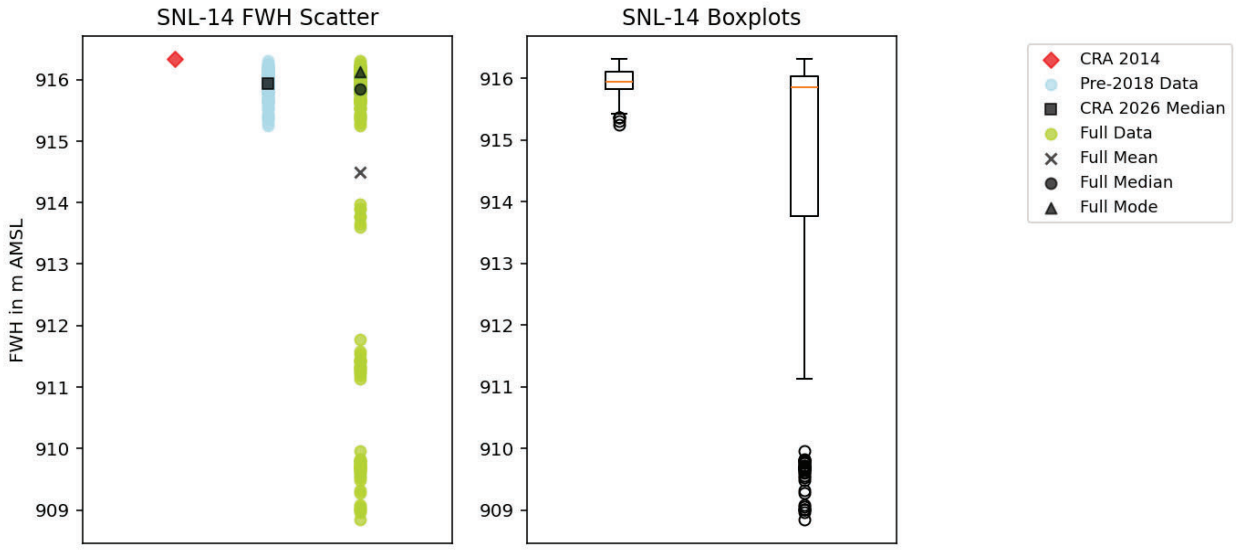

Figure B27. SNL-14 freshwater head scatter and box plots.

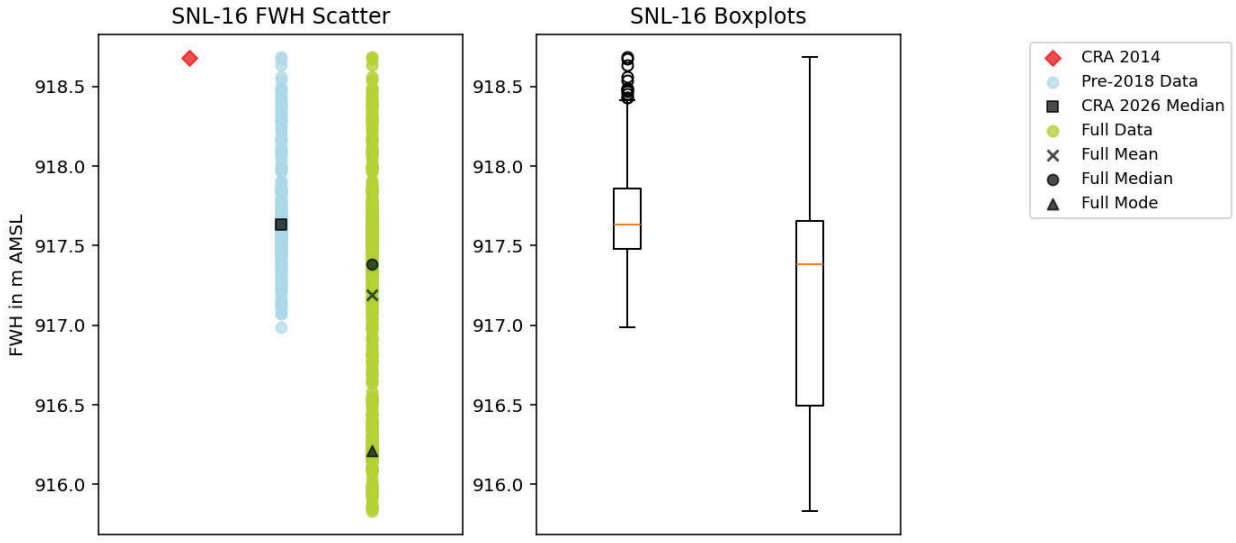

Figure B28. SNL-16 freshwater head scatter and box plots.

Information Only

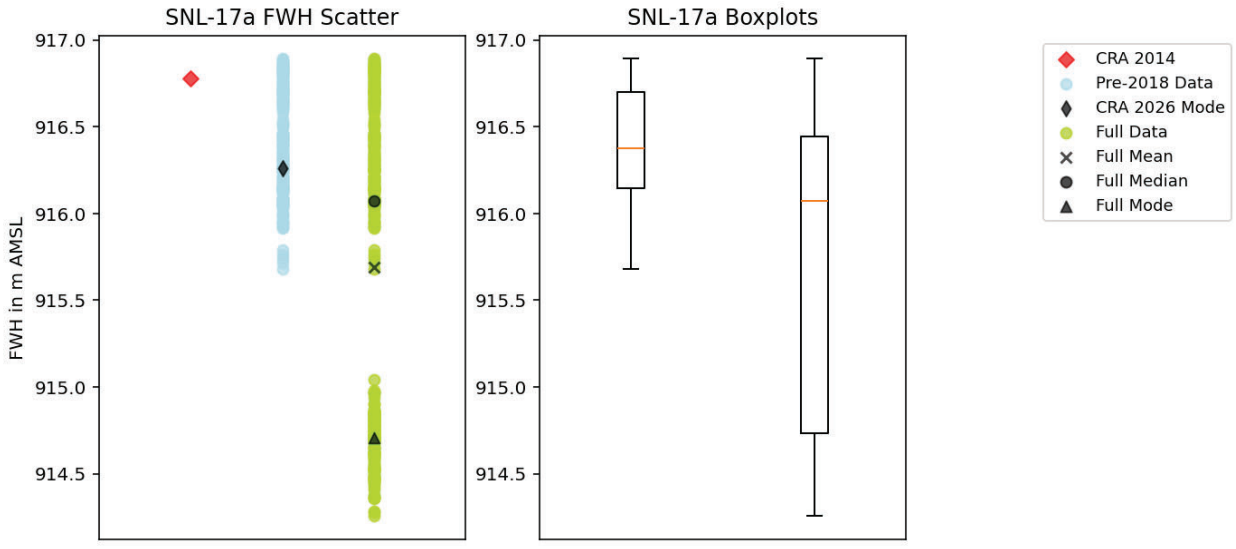

Figure B29. SNL-17a freshwater head scatter and box plots.

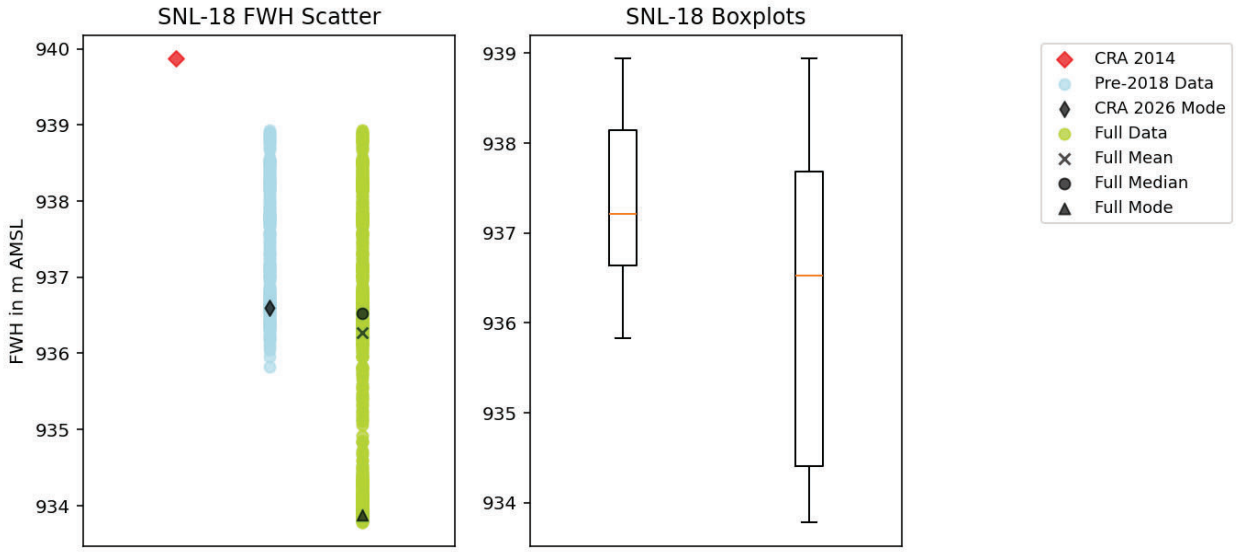

Figure B30. SNL-18 freshwater head scatter and box plots.

Information Only

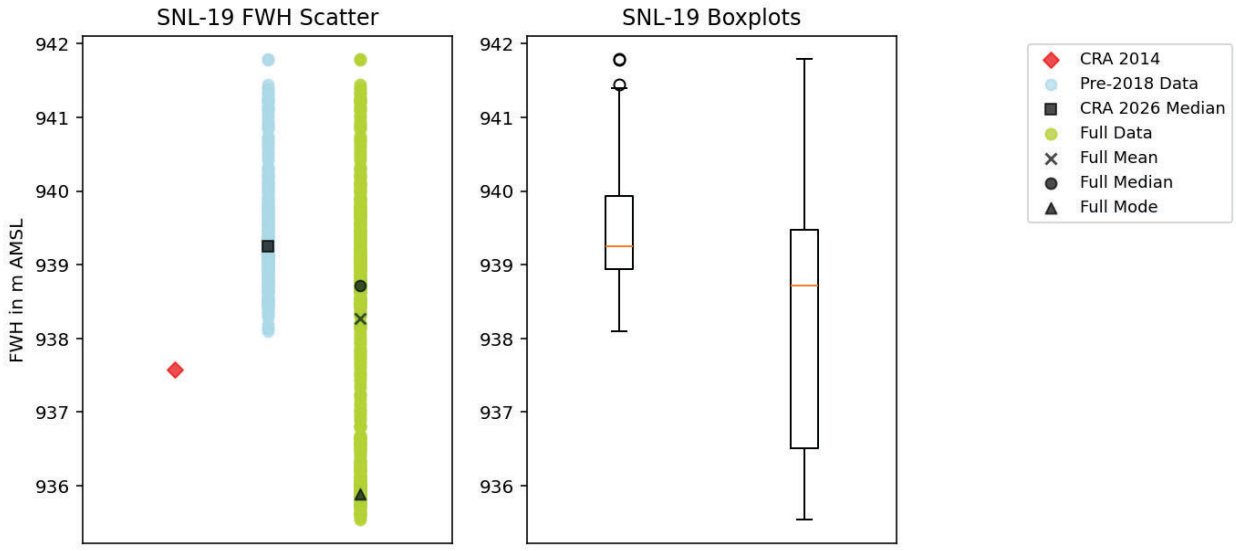

Figure B31. SNL-19 freshwater head scatter and box plots.

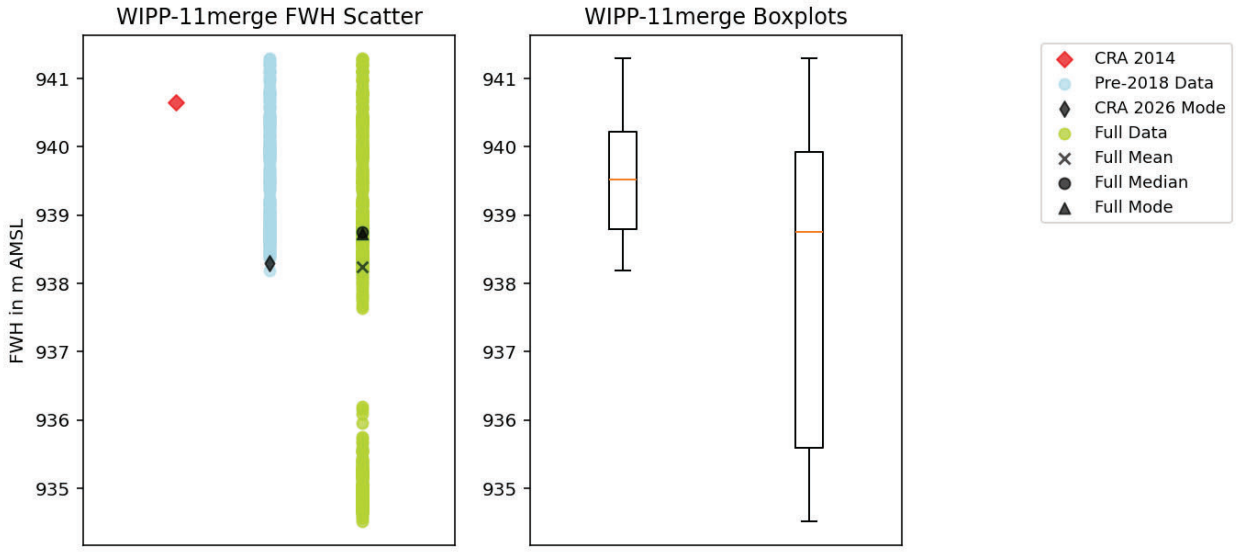

Figure B32. WIPP-11merge freshwater head scatter and box plots.

Information Only

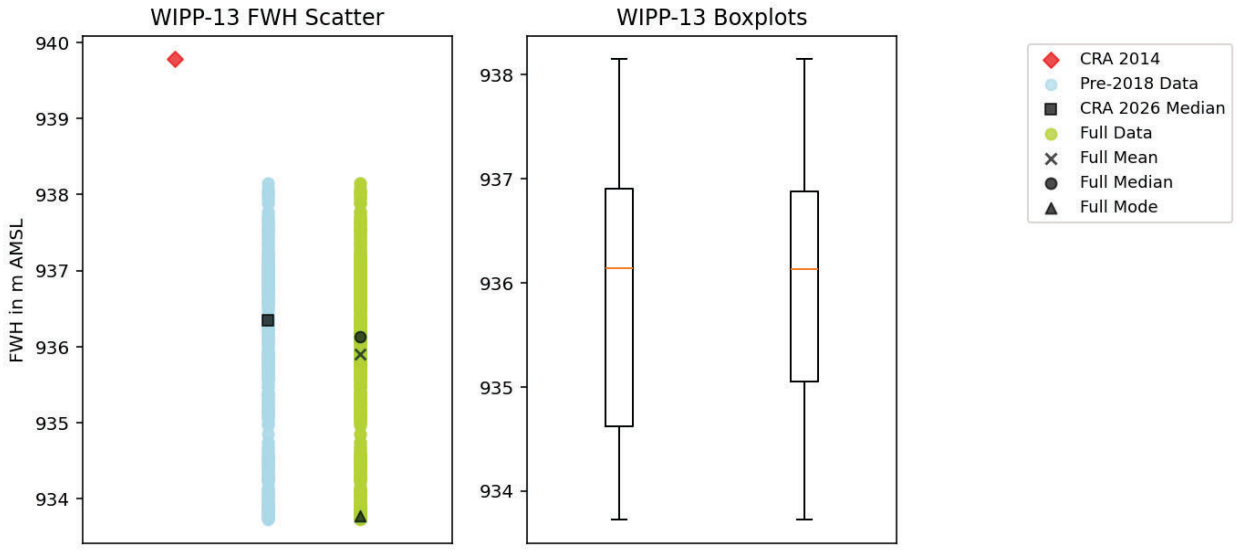

Figure B33. WIPP-13 freshwater head scatter and box plots.

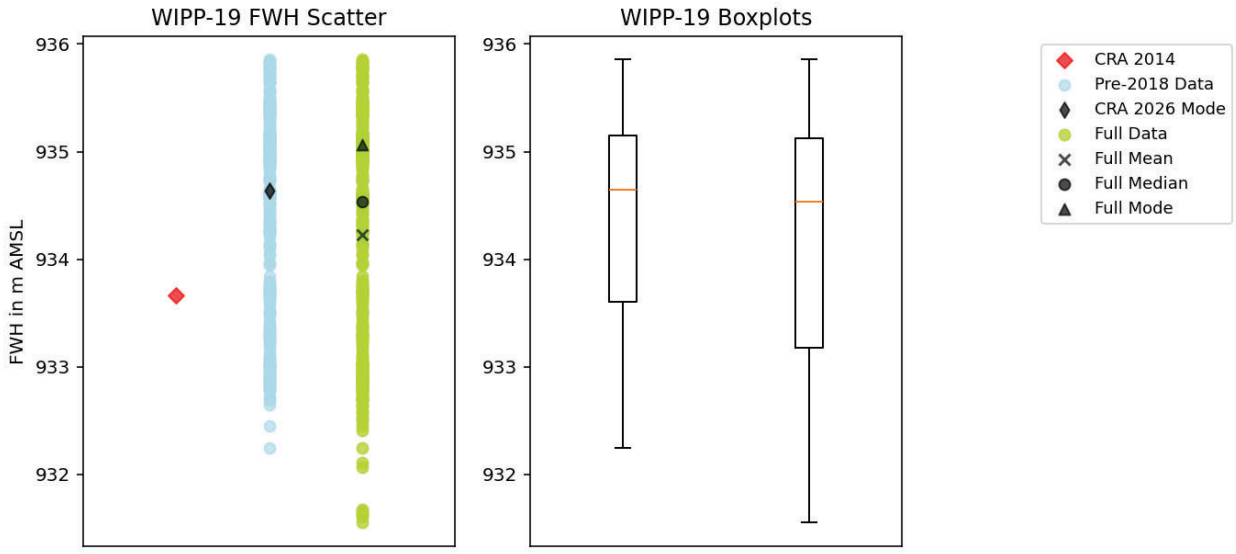

Figure B34. WIPP-19 freshwater head scatter and box plots.

Information Only

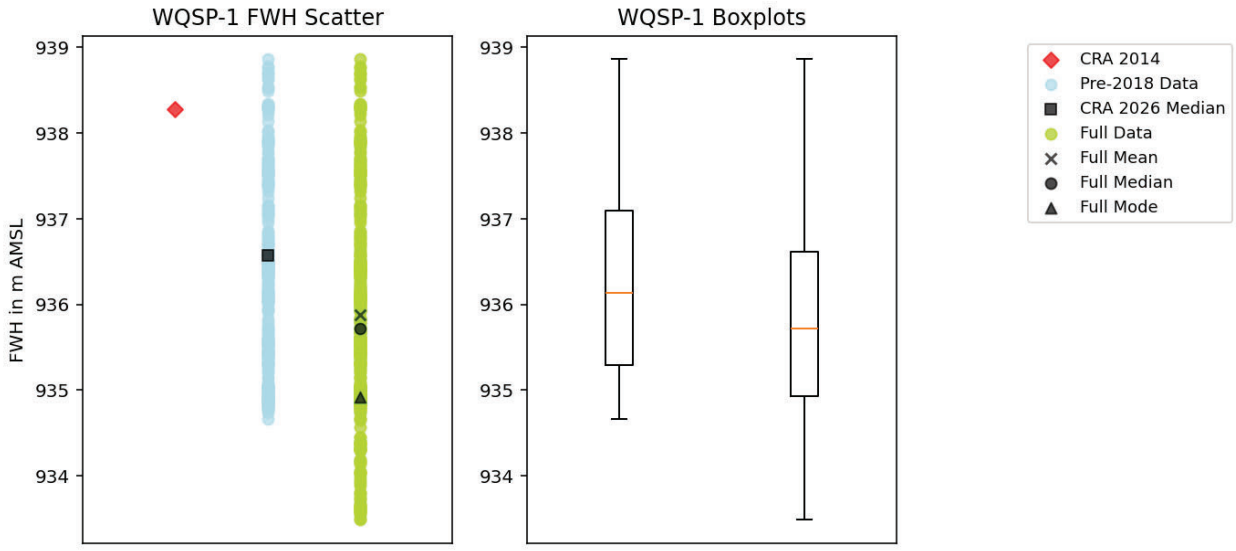

Figure B35. WQSP-1 freshwater head scatter and box plots.

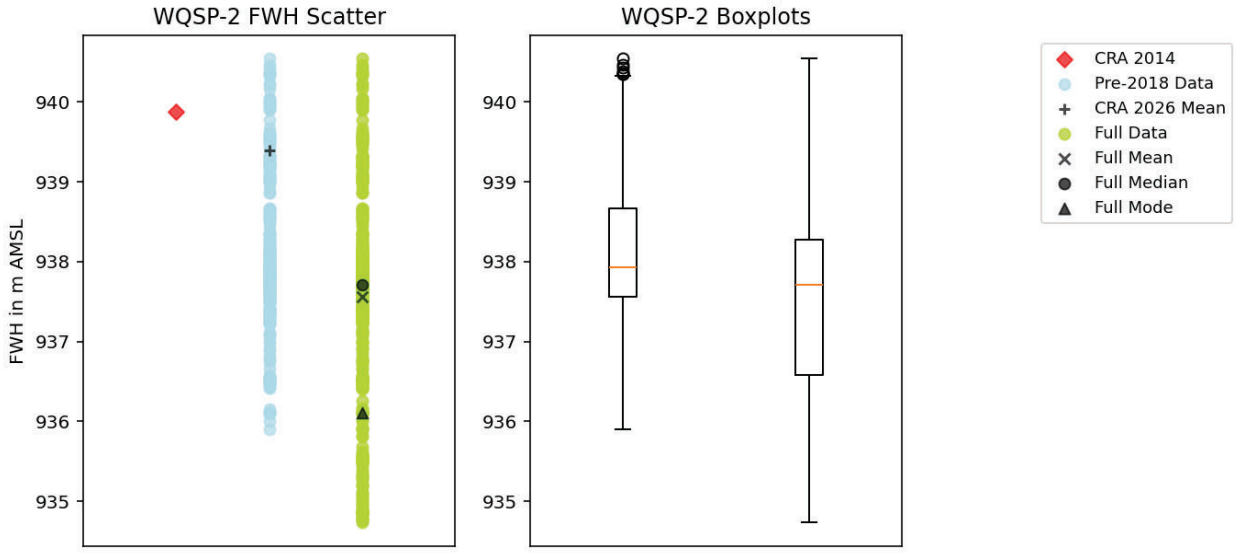

Figure B36. WQSP-2 freshwater head scatter and box plots.

Information Only

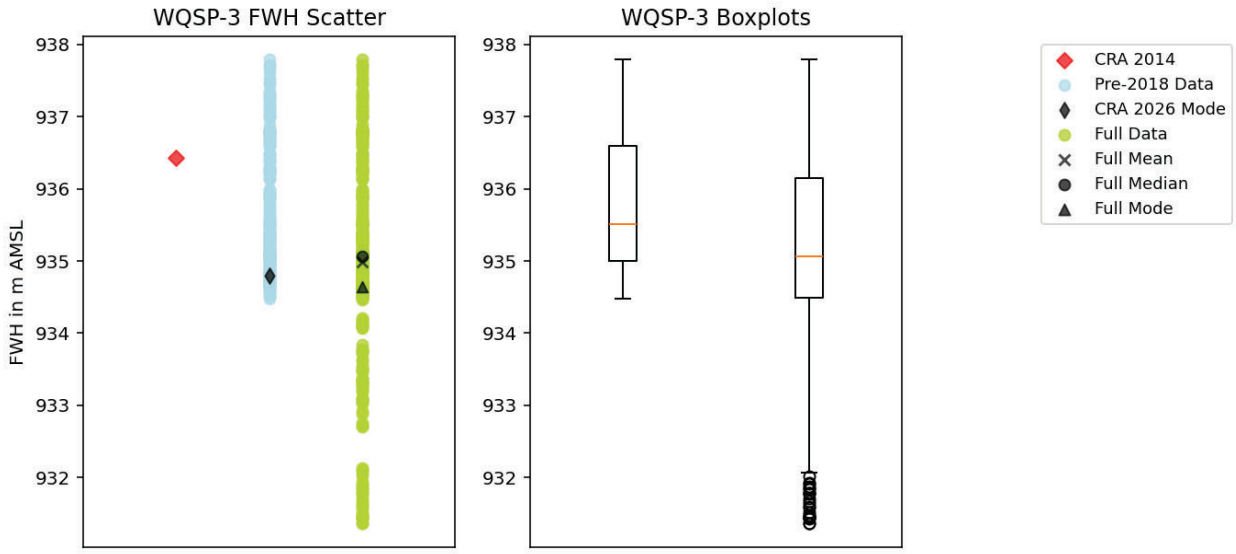

Figure B37. WQSP-3 freshwater head scatter and box plots.

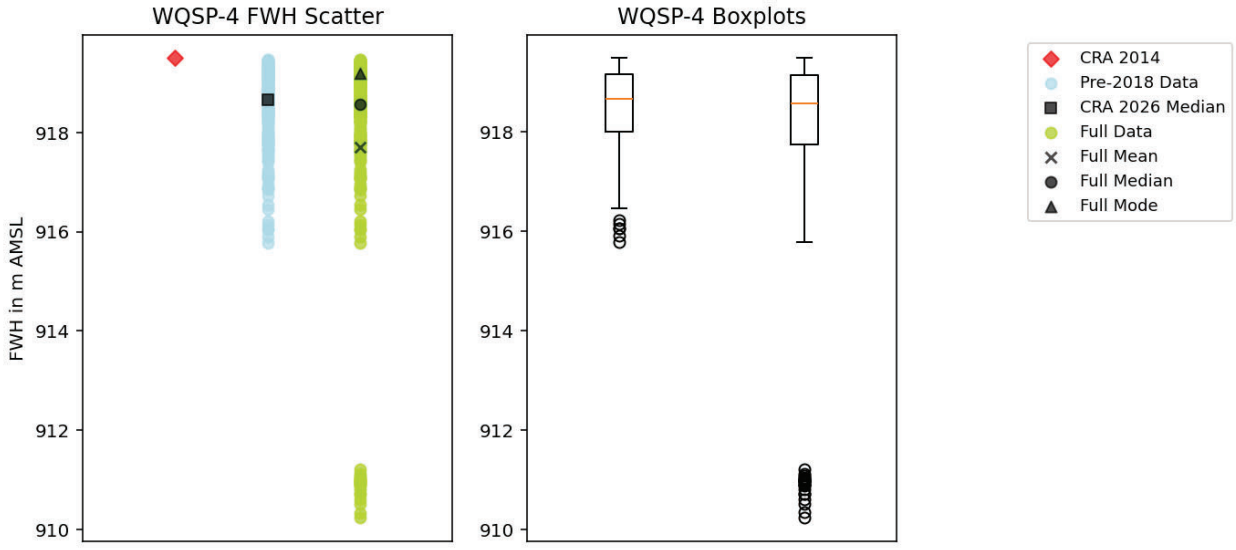

Figure B38. WQSP-4 freshwater head scatter and box plots.

Information Only

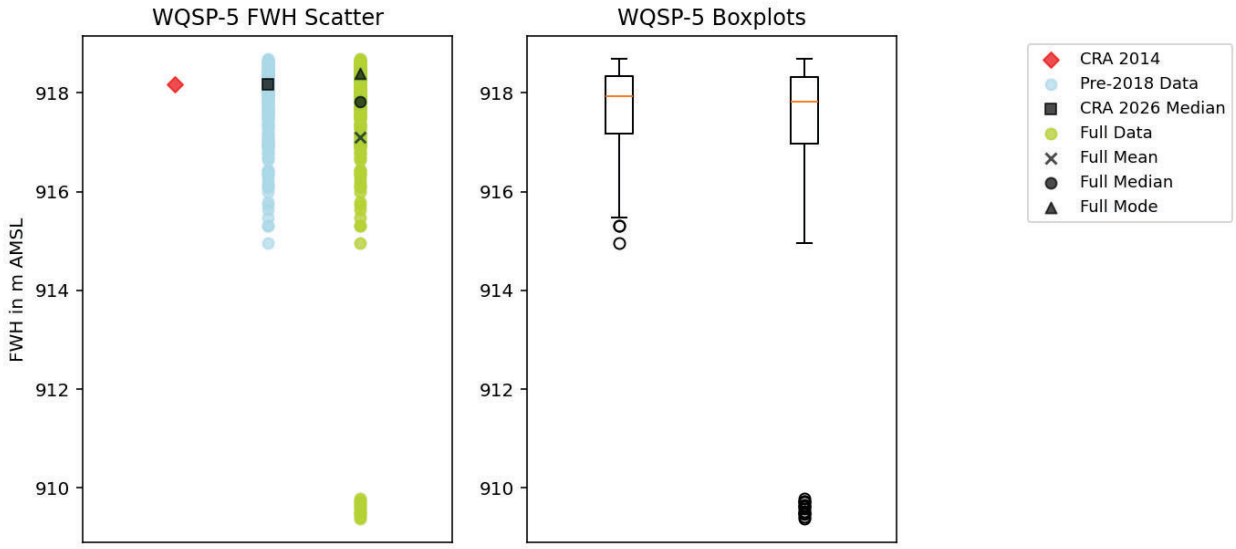

Figure B39. WQSP-5 freshwater head scatter and box plots.

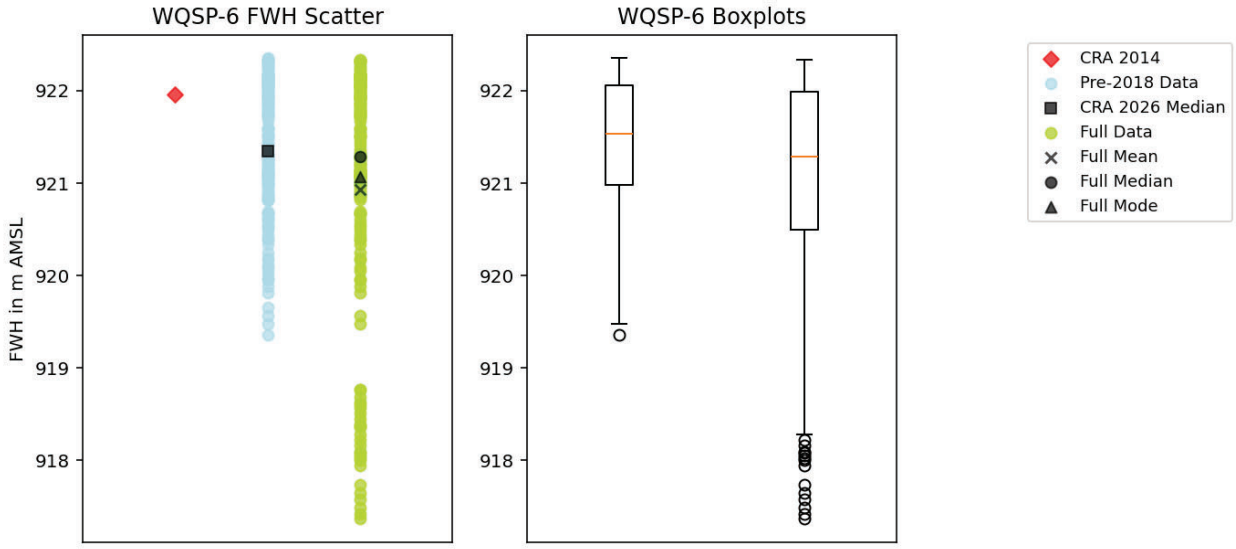

Figure B40. WQSP-6 freshwater head scatter and box plots.

Information Only

9. Appendix C – Regression Code

The following code was used to calculate regression models and residual values discussed in the Results section of this report.

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
from sklearn.linear_model import LinearRegression

# 1. Read in the file and assign it x,y,z designations
# Define CSV file folder
csv_file_path =
    'C:/Users/dobowma/Desktop/Priority_Reports_AH/Conceptual_Model_Deliverable/Regression/2026_Tar2.csv'

# Read CSV file data and count
df =
    pd.read_csv('C:/Users/dobowma/Desktop/Priority_Reports_AH/Conceptual_Model_Deliverable/Regression/2026
    _Tar2.csv')

# Designate Columns
x = df['Lat']
y = df['Long']
z = df['DTW']
nam = df['Well']

# Combine x and y into a single feature matrix for scikit-learn
X = np.column_stack((x, y))

# 2. Perform 2D Linear Regression
model = LinearRegression()
model.fit(X, z)

# Get the predicted z values
z_predicted = model.predict(X)

# 3. Calculate Residuals
residuals = z - z_predicted

# 4. Visualize the results
fig = plt.figure(figsize=(12, 6))

# Plot 1: 3D scatter plot of observed data and regression plane
ax1 = fig.add_subplot(121, projection='3d')
ax1.scatter(x, y, z, label='Observed Data', color='blue', alpha=0.7)

# Create a meshgrid for plotting the regression plane
x_surf, y_surf = np.meshgrid(np.linspace(min(x), max(x), 20), np.linspace(min(y), max(y), 20))
xy_surf = np.column_stack((x_surf.ravel(), y_surf.ravel()))
z_surf = model.predict(xy_surf).reshape(x_surf.shape)
ax1.plot_surface(x_surf, y_surf, z_surf, alpha=0.5, color='orange', label='Regression Plane')

ax1.set_xlabel('Lat')
ax1.set_ylabel('Long')
ax1.set_zlabel('FWH (m)')
ax1.set_title('2D Regression: 2026 FWH Perturb Target and Regression Plane')
# For legend in 3D plot, often needs custom handling or just rely on plot elements

# Plot 2: Residuals vs. Predicted Values (or against one of the independent variables)
ax2 = fig.add_subplot(122)
ax2.scatter(z_predicted, residuals, color='green', alpha=0.7)
ax2.axhline(y=0, color='red', linestyle='--', linewidth=1) # Reference line at 0 residuals
ax2.set_xlabel('Predicted Head Values')
ax2.set_ylabel('Residuals')
ax2.set_title('Residuals Plot')
```


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```
plt.tight_layout()
plt.show()

#writing to csv

data=pd.DataFrame({'Well': nam,'z_observed': z,'z_predicted': z_predicted,'residual': residuals})
data.to_csv('C:/Users/dobowma/Desktop/Priority_Reports_AH/Conceptual_Model_Deliverable/Regression/2026_res
    idual_per.csv',index=False)

# Print coefficients and intercept
print(f"Regression Coefficients (m1, m2): {model.coef_}")
print(f"Regression Intercept (b): {model.intercept_}")
print(f"Mean Absolute Residual: {np.mean(np.abs(residuals))}")
print(f"Root Mean Squared Error (RMSE): {np.sqrt(np.mean(residuals**2))}")
```


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