Analysis Report Documenting Water Level Analysis, Rev. 1

Analysis Report for AP-150: Analysis Plan for the Analysis of Observed Water Level Fluctuations

Task Number 4.4.2.3.1

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Contents

1. Introduction....3
2. Approach....3
3. Data....6
4. Method and Results....10
5. Contour Map Overview....12
6. Summary and Conclusions....15
7. References....15
8. Appendix A....16
9. Appendix B....18

Tables

Table 1. Fresh Water Heads and Calculations for Selected Wells. 11

Figures

Figure 1. WIPP monitoring well network. 5
Figure 2. The AEC-7R freshwater heads data and calculations. 6
Figure 3. The P-15 freshwater heads data and calculations. 7
Figure 4. The P-17 freshwater heads data and calculations. 7
Figure 5. The WIPP-12 freshwater heads data and calculations. 8
Figure 6. The WIPP-25 freshwater heads data and calculations. 8
Figure 7. The WIPP-26 freshwater heads data and calculations. 9
Figure 8. The WIPP-30 freshwater heads data and calculations. 9
Figure 9. Combined histograms and CFDs for wells ERDA-9, WQSP-5, and IMC-461. Dashed lines represent the location of central tendency for each. 10
Figure 10. Rev 0 contour map of the centrality-based representation of freshwater heads for the Culebra monitoring network. 13
Figure 11. Rev 1 contour map of the centrality-based representation of freshwater heads for the Culebra monitoring network. 14

Information Only

1. Introduction

This Analysis Report (AR) discusses the evaluation of freshwater well heads data measured in the Waste Isolation Pilot Plant (WIPP) well monitoring network and their use as optimization targets for the calibration of transmissivity fields (T-fields) under the direction of AP-150: Analysis Plan for the Analysis of Observed Water Level Fluctuations (Bowman 2021). Fresh-water head values are used as optimization targets during the calibration of T-fields by the PEST optimization program. Traditionally, the fresh-water head measurements used for calibration are taken from a snapshot of the head measurements taken in May 2007 throughout the WIPP monitoring well network. A more complete description of the T-field generation and calibration process is discussed in Appendix T-fields (DOE 2018).

The limiting factors of this approach are that:

- A singular head measurement may not be representative of a long-term steady-state head.
- Head measurements made in wells that only existed outside of May 2007 are not in use.

A representative sample may be found using the statistics associated with non-anthropogenic head measurements from monitoring network wells. In this analysis report, data-driven statistics will be presented as recommended optimization targets for T-field calibration for the WIPP monitoring network (Figure 1). Wells included in this report are in addition to the analysis performed in HYDRO 21-01, which consists of all wells used for T-field generation and calibration in previous years.

Rev 0 of this report evaluated and compared this centrality approach against only the wells used in past T-field calibrations. It was found that the centrality approach created comparable contoured heads to the May 2007 "steady-state" approach. The benefits of the centrality approach are:

- May 2007 data no longer has to be defended as a steady-state representation of water levels,
- New data gathered will continually affect the head optimization targets at each well
- Wells in which data was gathered outside of the previous May 2007 window can now be included as an optimization targets.

Rev 1 of this AR focuses on the calculation and inclusion of wells now available due to benefit in third bullet point.

2. Approach

The overall objective of generating representative heads for the WIPP monitoring well network is to create optimization targets for T-field calibration. The premise is that the heads used in the calculation represent the natural or steady-state head profile of the Culebra Dolomite. As discussed in HYDRO-21-01, the prior approach used to generate optimization head values was to use head measurements over a concise span of time, specifically depth-to-water measurements in May 2007.

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As a new approach, the cumulative heads data will be used as opposed to data representing a concise moment of time verus water level. A statistical representation of each well will be calculated from water level measurements taken over the monitoring life of each well. Prior to calculation the data were filtered for anthropogenic influences. The filtering was completed by investigating each data set and the accompanying metadata sources (scientific notebooks, notation files) and excluding any data that did not represent natural fluctuations in water level. It is important to note that no mathematical filters were used on the data, filtering was completed purely by inspection and qualification (Bowman 2019). It is also important to note that in all cases, depth-to-water measurements were converted to freshwater heads using measured water quality values and the past knowledge obtained at each well independently. Details of this calculation and methodology can be found in Johnson (2009).

Histograms and continuous frequency distribution were generated from the filtered data for monitoring wells found outside of those used in Appendix T-fields. The distribution functions are qualified by type to choose an appropriate centralization representation to use for each well's representative head value. Additional data parameters and statistical evaluations were also calculated and reported in Table 1 to inform weights used in the Parameter Estimation (PEST) optimization software.

The benefit of this approach is that optimization targets are informed by a full use of the measured data set, and their statistics, per well. Therefore, wells that existed prior to or exist after the May 2007 time window can be included in the optimization.

One detractor of this approach in contrast to the previous method is the use of head measurements from a specific time may represent the specific hydrologic climate at that specific time. Integrating data over a time span of multiple years may mix the responses to different events years apart, thereby diluting individual events into a more homogeneous value. Recognizing this potential pitfall, the final head values for each method were compared for feasibility in HYDRO-21-01. A second detractor of this method is data density. Consider a well with a singular data point or limited data set that may not be as representative of the natural head profile of the well. A potential solution through application of data density to optimization weights will is discussed in HYDRO-21-01.

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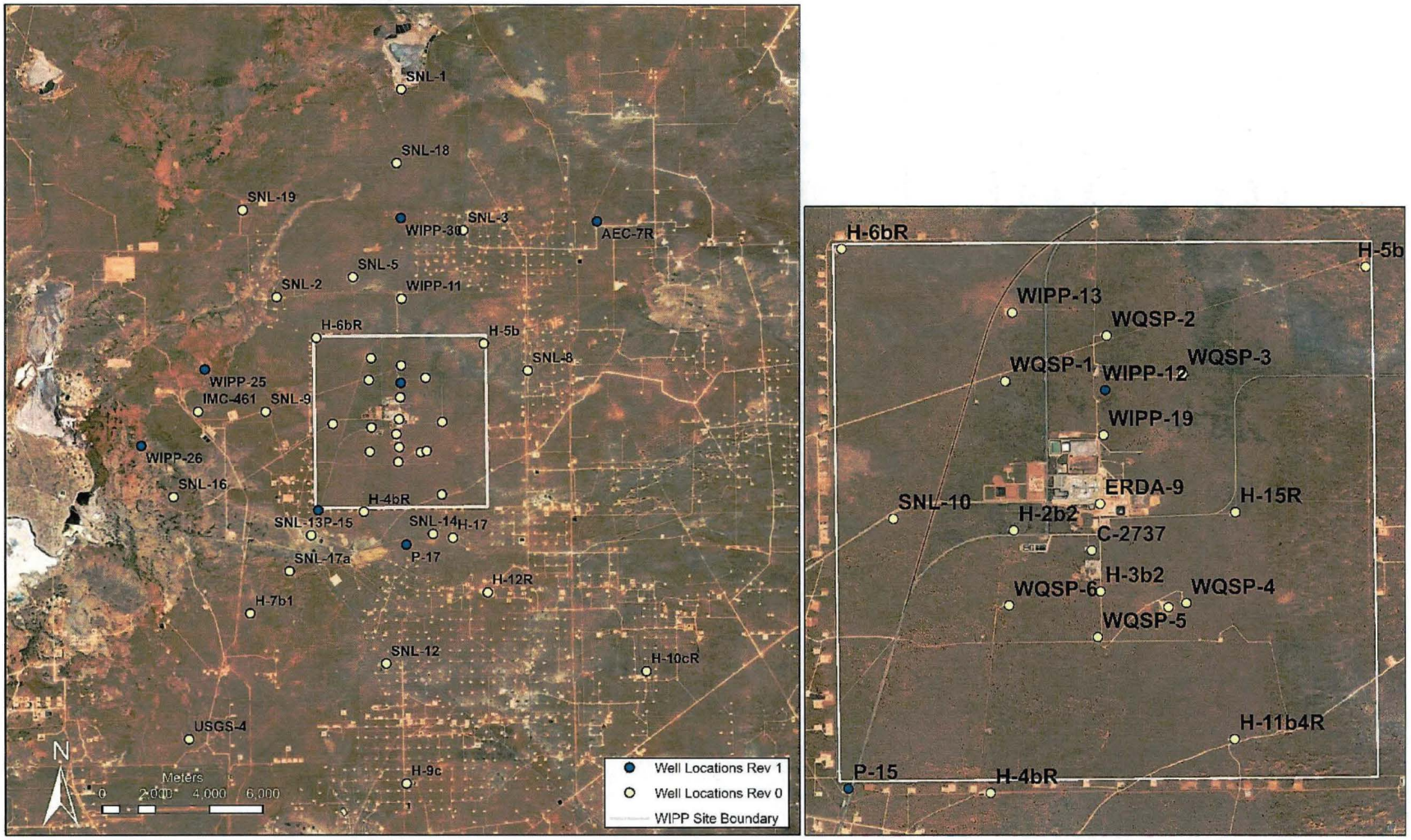

Figure 1. WIPP monitoring well network with all monitoring wells on the left and wells within the Land Withdrawal Boundary (LWB) on the right.

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3. Data

Measured depth-to-water data for select WIPP monitoring wells were screened for anthropogenic influences using methods from Bowman (2019) and used to calculate freshwater heads over the life of each well. Figures 2-8 illustrate the data being included and excluded for seven additional wells.

The following hydrographs report equivalent freshwater head values for each well. Data that represent static water level conditions are presented in blue; anthropogenically affected data in red. Water level statistics for each graphic were calculated using the static water level data (blue). Those data points that were affected by anthropogenic influences (red) and are not used in calculations. The minimum, maximum, calculated mean, and standard deviation of the blue data sets are presented in Section 4, Table 1.

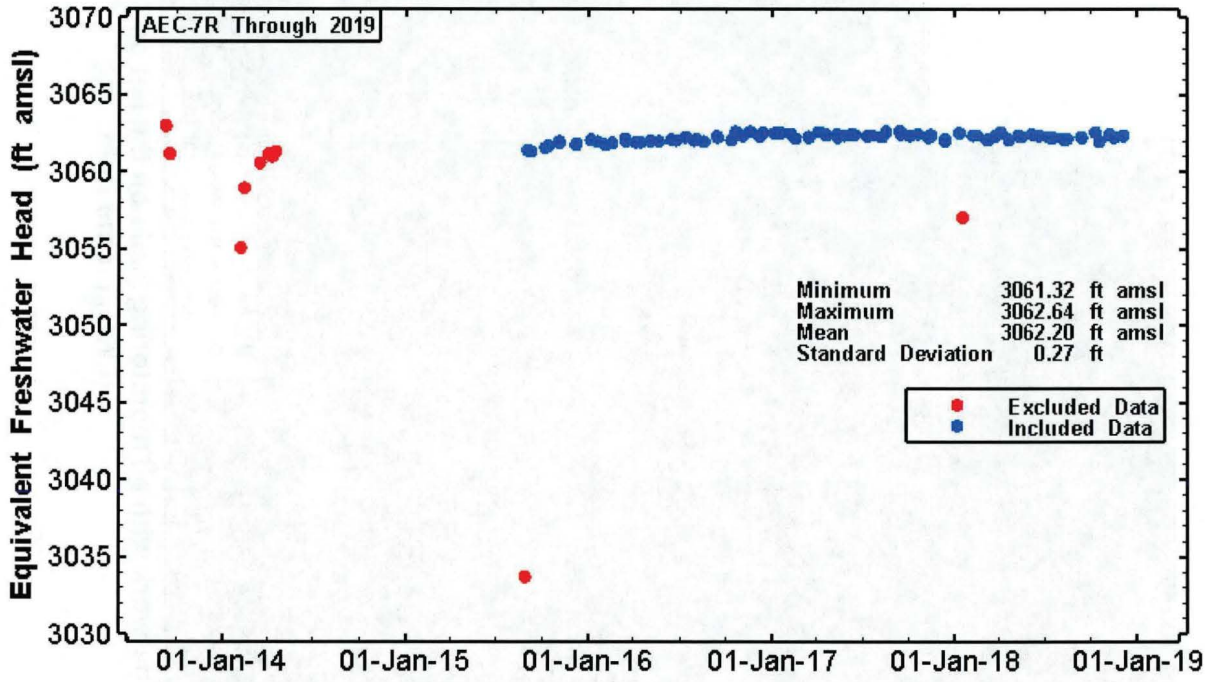

Figure 2. The AEC-7R freshwater heads data and calculations.

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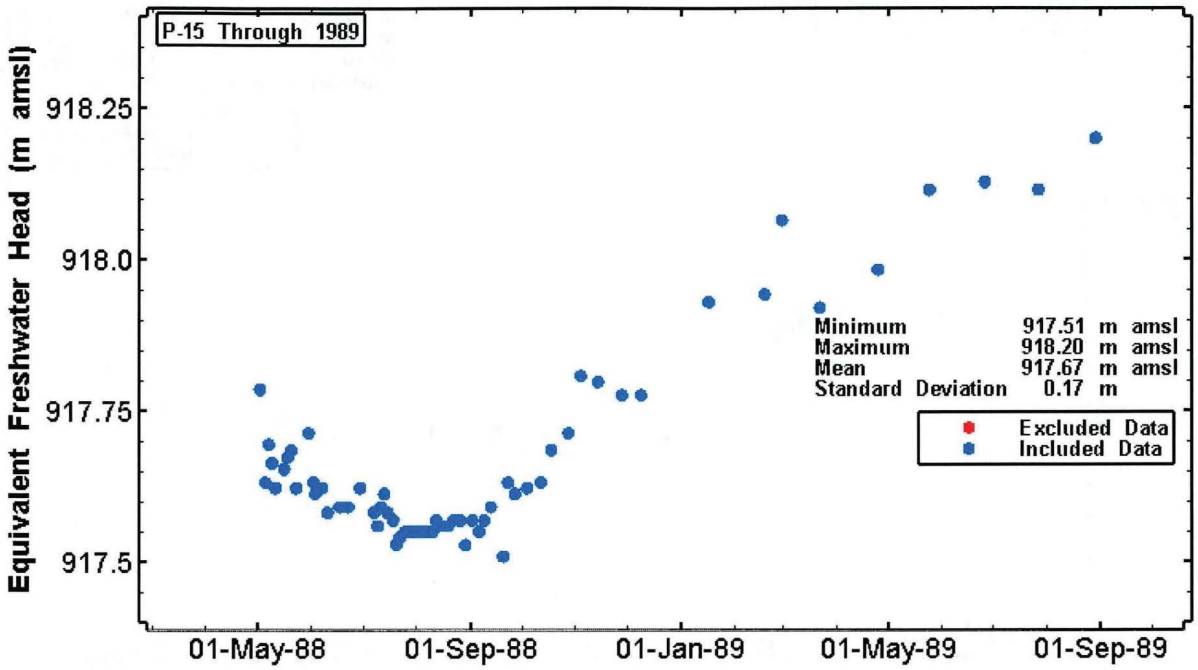

Figure 3. The P-15 freshwater heads data and calculations.

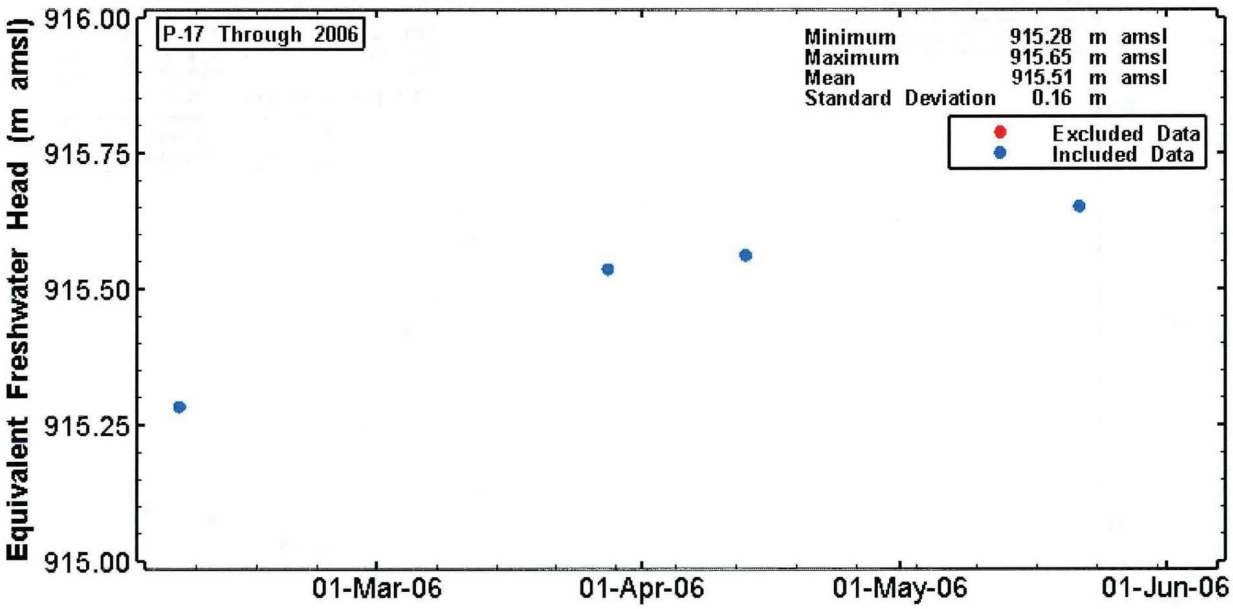

Figure 4. The P-17 freshwater heads data and calculations.

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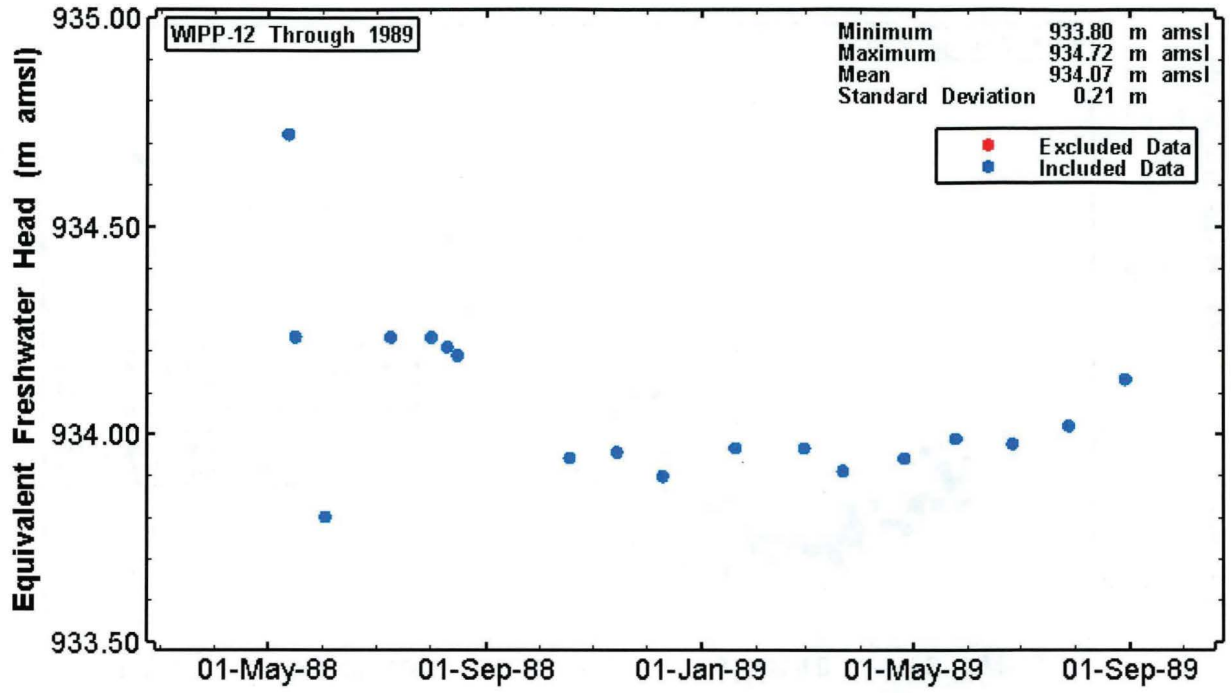

Figure 5. The WIPP-12 freshwater heads data and calculations.

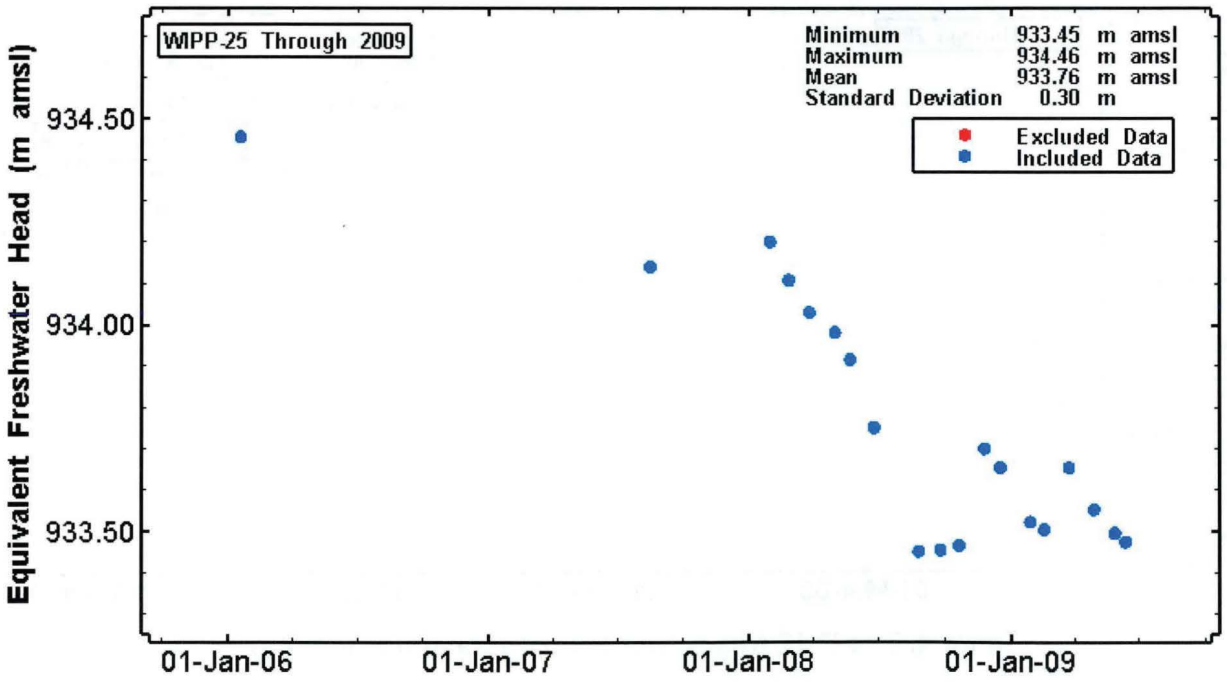

Figure 6. The WIPP-25 freshwater heads data and calculations.

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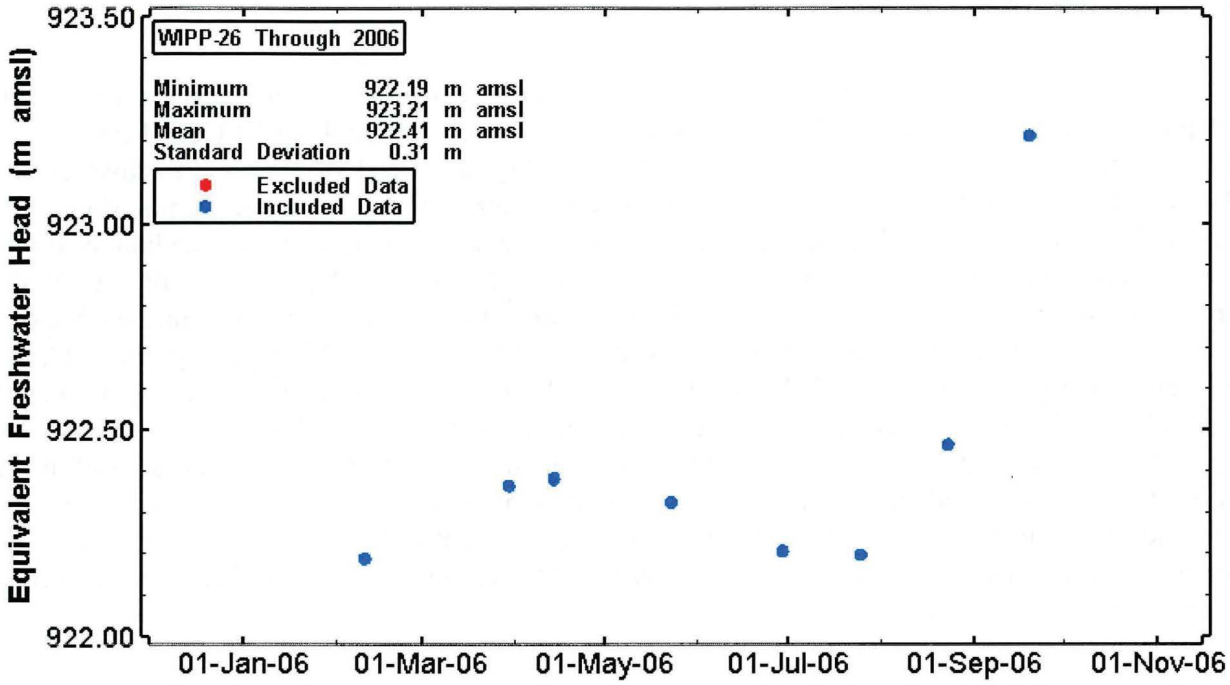

Figure 7. The WIPP-26 freshwater heads data and calculations.

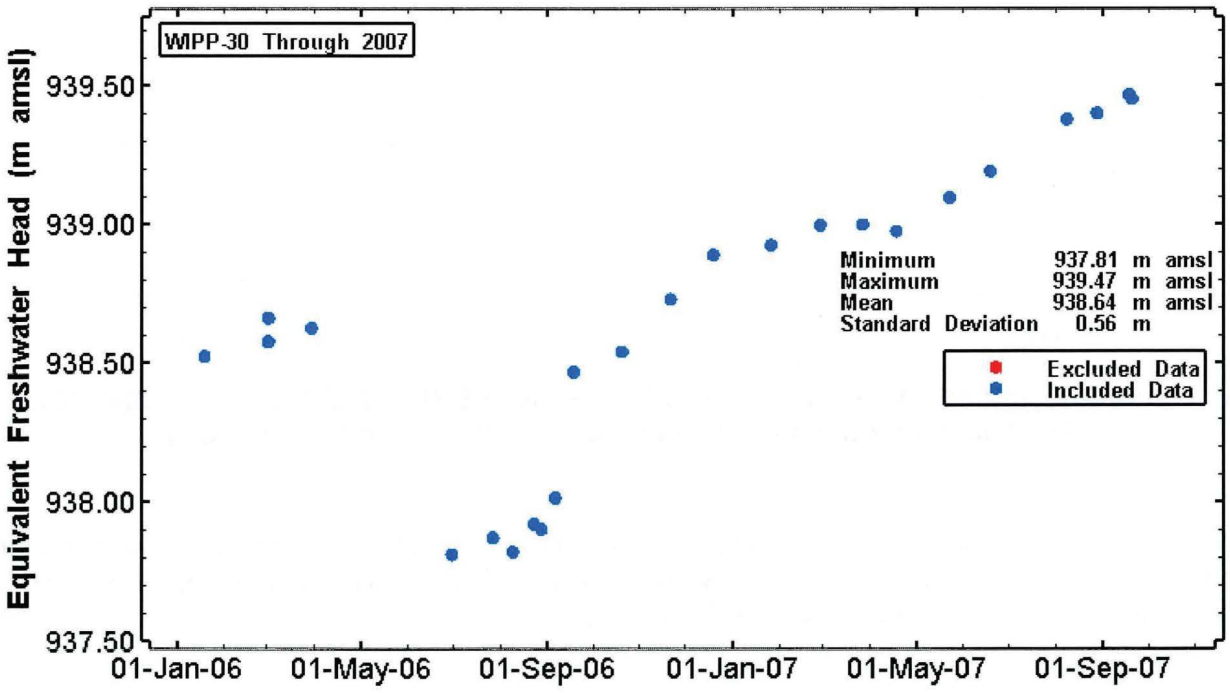

Figure 8. The WIPP-30 freshwater heads data and calculations.

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4. Method and Results

The resulting freshwater heads data were summarized by histograms featuring a continuous frequency distribution (CFD) using the ggplot2 package of R version 4.0.3 (R Core Team, 2021). These histograms and CFDs provide a visual characterization of the distribution of freshwater head data for each well, where three distribution classes were assigned to each well: normal, skewed, or bimodal. The distribution class dictates the measure of central tendency (mean, median, or mode) used to represent the available data. Wells with freshwater head data that are normally distributed are represented by the mean, skewed distributions are represented by the median, and bimodal distributions are represented by the mode (Borradaile, 2003). The combined histogram and CFDs of wells ERDA-9, WQSP-5, and IMC-461 from HYDRO 21-01, are displayed in Figure 9 as an example of the visual determination between centrality types. Freshwater head values are displayed on the X-axis, and on the Y-axis is density, whose units make the total area of all the bars add to 1. Combined histograms and CFDs for all applicable wells included in this analysis are provided in Appendix A. In all cases, the measures of central tendency are displayed on the histogram with mean, median, and mode measurements being represented by blue, red, and green dashed lines, respectively.

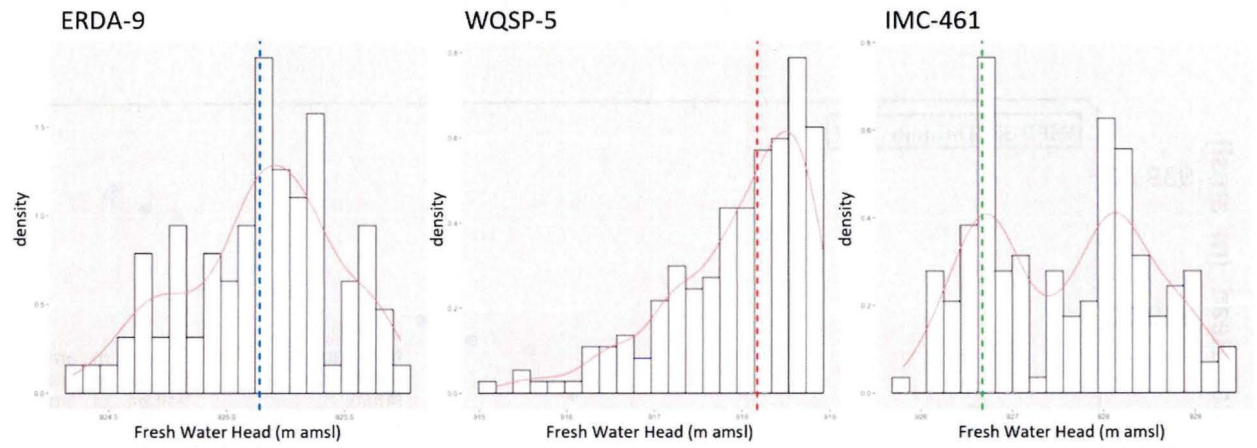

Figure 9. Combined histograms and CFDs for wells ERDA-9, WQSP-5, and IMC-461. Dashed lines represent the location of central tendency for each.

Measures of central tendency were calculated in R as well as standard deviation, minimum, and maximum freshwater head in meters above mean sea level (m amsl) and are reported in Table 1. The script for these calculations is given in Appendix B.

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Table 1. Fresh Water Heads and Calculations for Selected Wells, with Rev 1 wells in bold.

Well	Minimum (m amsl)	Maximum (m amsl)	Mean (m amsl)	Median (m amsl)	Mode (m amsl)	Standard Deviation (m)	Data Point Count	Previous FWH (m amsl)	Change (m)
Normal Distributions									
ERDA-9	924.35	925.74	**925.14**	925.16	925.33	0.32	87	924.88	0.26
H-3b2	918.42	919.49	**919.00**	919.04	919.06	0.20	85	918.68	0.32
SNL-2	933.96	938.67	**936.31**	936.23	935.71	0.93	349	937.65	-1.34
SNL-9	929.60	932.05	**930.76**	930.71	930.63	0.64	273	932.05	-1.29
USGS-4	910.98	911.31	**911.13**	911.10	911.08	0.10	13	911.11	0.02
WQSP-2	937.17	941.85	**939.39**	939.21	937.81	1.02	294	939.87	-0.48
Skewed Distributions									
C-2737	919.99	921.94	921.24	**921.32**	921.63	0.40	80	921.23	0.09
H-4bR	915.83	917.21	916.75	**916.78**	917.01	0.29	92	916.34	0.44
H-5b	938.79	940.30	939.70	**939.76**	939.90	0.40	146	939.12	0.64
H-9c	911.23	913.39	912.88	**912.97**	912.98	0.40	63	912.80	0.17
H-10cR	920.28	923.37	921.30	**921.07**	921.04	0.52	76	922.02	-0.95
H-15R	919.10	920.04	919.78	**919.86**	919.86	0.21	58	920.32	-0.46
H-17	915.79	916.89	916.61	**916.66**	916.64	0.21	83	916.24	0.42
H-19b0	917.84	919.13	918.70	**918.73**	918.70	0.28	101	918.84	-0.11
SNL-12	915.29	916.24	915.87	**915.87**	915.76	0.20	193	915.24	0.63
SNL-13	919.58	920.62	920.26	**920.37**	920.50	0.26	109	918.19	2.18
SNL-14	915.24	916.31	915.93	**915.94**	916.12	0.22	152	916.33	-0.39
SNL-16	916.99	918.68	917.70	**917.63**	917.63	0.36	258	918.68	-1.05
SNL-19	938.10	941.79	939.50	**939.25**	938.47	0.83	274	937.58	1.67
WIPP-13	933.95	938.39	936.14	**936.35**	937.23	1.23	678	939.78	-3.43
WQSP-1	935.09	939.31	936.69	**936.57**	935.35	1.13	301	938.28	-1.71
WQSP-4	915.78	919.49	918.49	**918.67**	919.21	0.83	186	919.50	-0.83
WQSP-5	915.18	918.92	917.94	**918.17**	918.63	0.79	187	918.18	-0.01
WQSP-6	917.99	922.33	921.17	**921.34**	922.05	0.99	185	921.96	-0.62
AEC-7R	**931.79**	**933.49**	**933.34**	**933.37**	**933.37**	**0.19**	**79**	**NA**	**NA**
P-15	**917.51**	**918.20**	**917.67**	**917.61**	**917.55**	**0.17**	**64**	**NA**	**NA**
P-17	**915.28**	**915.65**	**915.51**	**915.55**	**NA**	**0.16**	**4**	**NA**	**NA**
WIPP-12	**933.80**	**934.72**	**934.08**	**933.99**	**934.23**	**0.21**	**18**	**NA**	**NA**
WIPP-25	**933.45**	**934.46**	**933.76**	**933.65**	**933.65**	**0.30**	**20**	**NA**	**NA**
WIPP-26	**922.19**	**923.21**	**922.41**	**922.36**	**922.36**	**0.32**	**9**	**NA**	**NA**
WIPP-30	**937.81**	**939.47**	**938.64**	**938.66**	**937.82**	**0.57**	**25**	**NA**	**NA**
Bimodal Distributions									
H-2b2	927.90	928.73	928.44	928.56	**928.61**	0.25	59	929.62	-1.01
H-6bR	935.14	937.28	936.11	935.99	**935.63**	0.57	131	936.44	-0.81
H-7b1	913.75	914.85	914.24	914.08	**914.04**	0.34	95	914.58	-0.54
H-11b4R	916.04	919.25	918.04	918.37	**918.42**	0.74	92	917.09	1.33
H-12R	917.43	918.29	917.90	917.91	**917.91**	0.16	101	916.53	1.38
IMC-461	925.80	929.37	927.57	927.64	**927.52**	0.90	153	928.95	-1.43
SNL-1	937.63	942.27	939.56	939.58	**938.46**	1.15	333	941.86	-3.40
SNL-3	936.58	940.28	938.27	938.25	**937.45**	0.91	324	939.81	-2.36
SNL-5	935.85	939.29	937.39	937.24	**936.57**	0.91	321	938.59	-2.02
SNL-8	930.84	932.69	931.75	931.66	**931.70**	0.57	238	929.94	1.76
SNL-10	928.79	931.86	930.40	930.72	**930.74**	0.98	263	931.54	-0.80
SNL-17a	915.68	916.89	916.40	916.38	**916.26**	0.31	174	916.78	-0.52
SNL-18	935.83	938.94	937.37	937.21	**936.60**	0.82	282	939.87	-3.27
WIPP-11	937.76	940.85	939.14	939.08	**938.29**	0.81	308	940.65	-2.36
WIPP-19	931.20	935.43	933.41	933.44	**934.64**	1.28	376	933.66	0.98
WQSP-3	934.62	937.94	935.85	935.55	**934.80**	0.92	218	936.43	-1.63

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5. Contour Map Overview

A contour map was developed using Esri's ArcMap software, version 10.8, through the addition of freshwater heads from this report's analysis to the freshwater heads analyzed in Rev 0 of this report (Bowman et al., 2021). In the Rev 0 version of this report, a visual comparison of contour maps generated from the May 2007 "steady-state" data set and the centrality approach was investigated to gauge the feasibility of the new approach. Similarly in Rev 1, a visual comparison is made between the Rev 0 contour map (Figure 10) and the one generated using additional Rev 1 data/wells (Figure 11). All contour maps were developed using an interpolation tool from the Spatial Analyst toolbox in ArcMap for the data sets discussed in this report in addition to the dataset analyzed in Rev 0. Contours were classified on an equal interval scale and utilize the representative centrality (mean, median, and mode).

The Rev 1 as compared to the Rev 0 contour map continues to represent the northern high-head area as a dome of water while the valley of water to the south-east of the LWB shifts to the south and connects with lower head areas on the outer edge of the monitoring network. Conceptually, the values given by the centrality approach for the additional wells are reasonable and do not present any unexplainable spatial or freshwater head value discontinuities. The resulting contours are smooth; no undulating values exist well-to-well to create difficult optimization targets.

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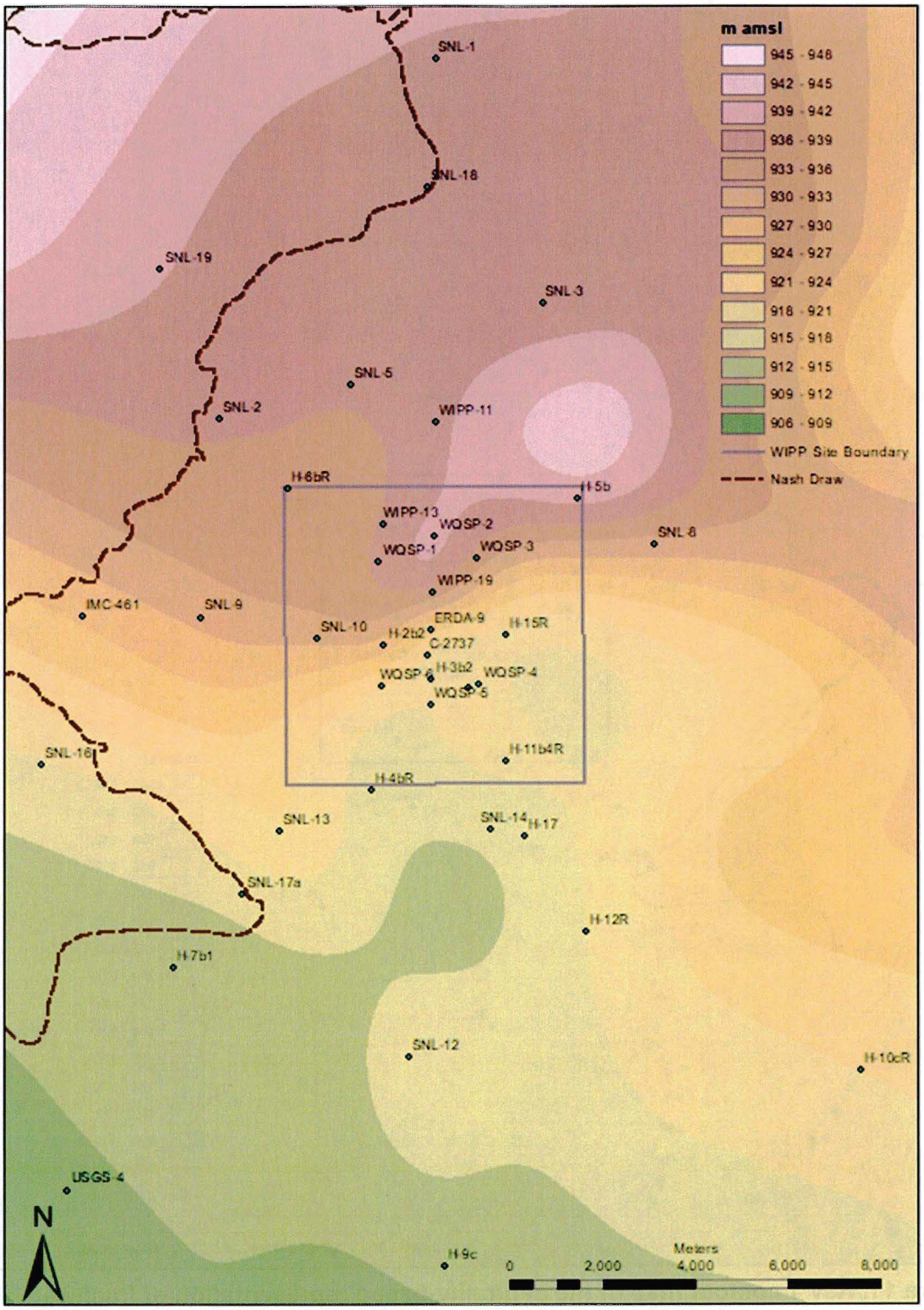

Figure 10. Rev 0 contour map of the centrality-based representation of freshwater heads for the Culebra monitoring network.

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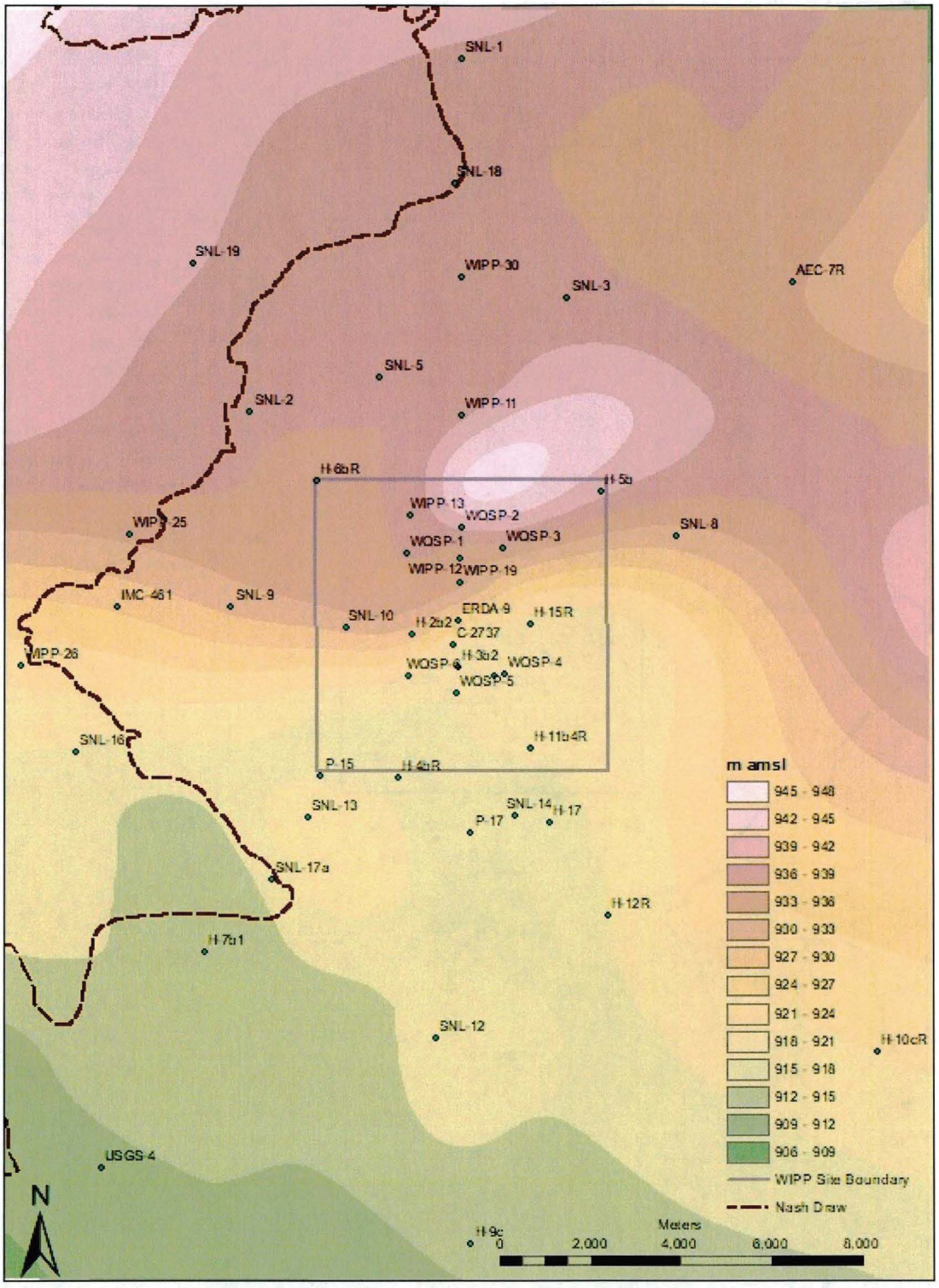

Figure 11. Rev 1 contour map of the centrality-based representation of freshwater heads for the Culebra monitoring network.

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6. Summary and Conclusions

This AR investigates the use of a statistical representation of the cumulative measured head data versus a single data point per well as optimization targets for the calibration of T-fields. Depth-to-water measurements were converted to freshwater heads and qualified against anthropogenic effects. Data distributions were used to qualify the appropriate centrality method used per well data set. This differing approach produced a reasonable representation of heads as compared to its May 2007 counterpart. Weighting factors as applied to the optimization of T-fields to the freshwater head values provided were discussed and the application of inverse standard deviation is recommended as an appropriate weighting factor.

7. References

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R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

US Department of Energy (DOE), 2018. Title 40 CFR Part 191 Subparts B and C Compliance Recertification Application 2014 for the Waste Isolation Pilot Plant: Appendix TFIELD-2014 Transmissivity Fields. Carlsbad Field Office, Carlsbad New Mexico. DOE/WIPP-14-3503

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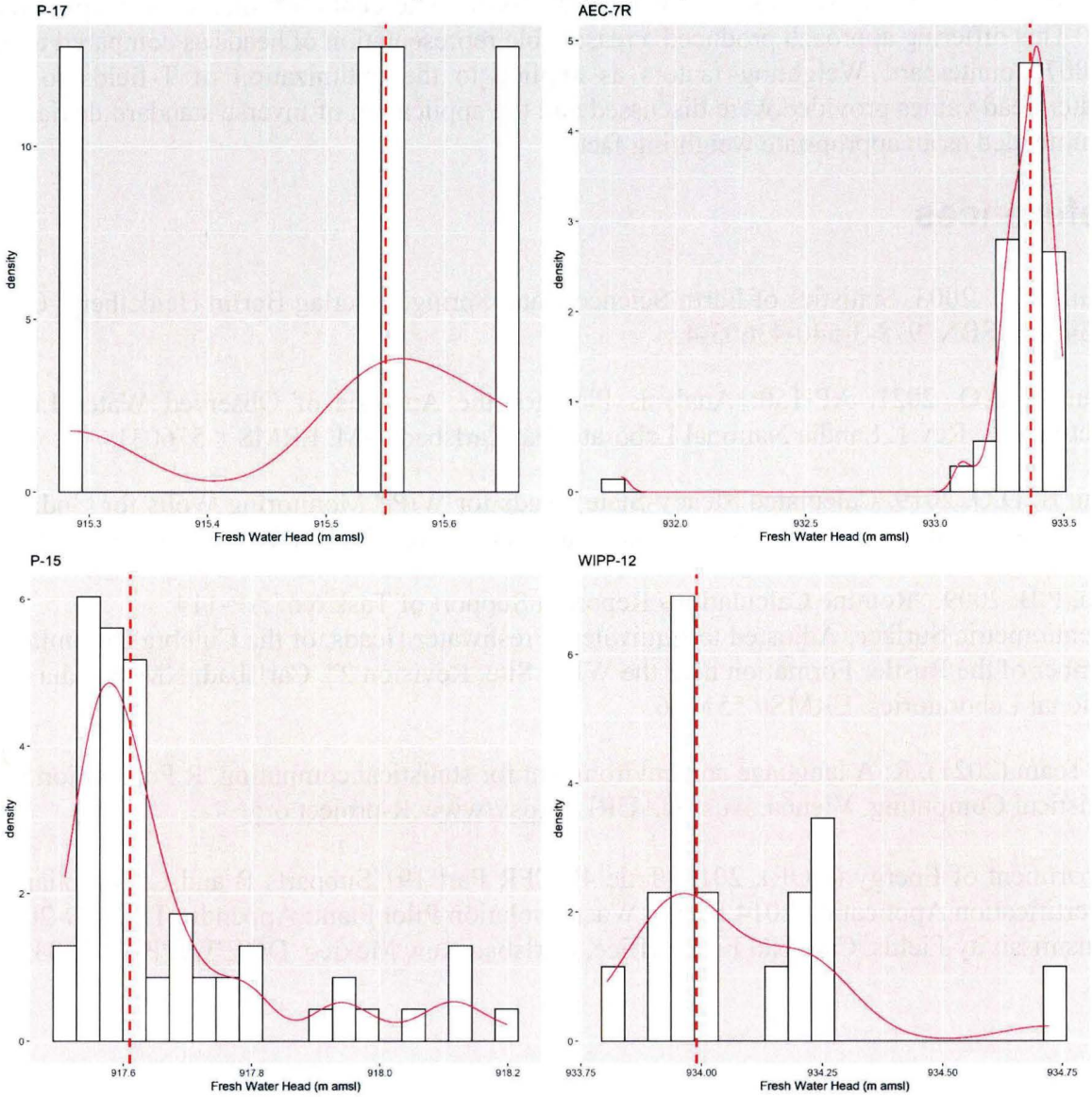
8. Appendix A

Appendix A is populated with the combined histograms and CFDs for each well discussed in this analysis. As described in Section 3 of this report, dashed vertical lines plotted on each histogram represent the measure of central tendency used for each well. The wells analyzed in this report were all found to be represented by the median (red line).



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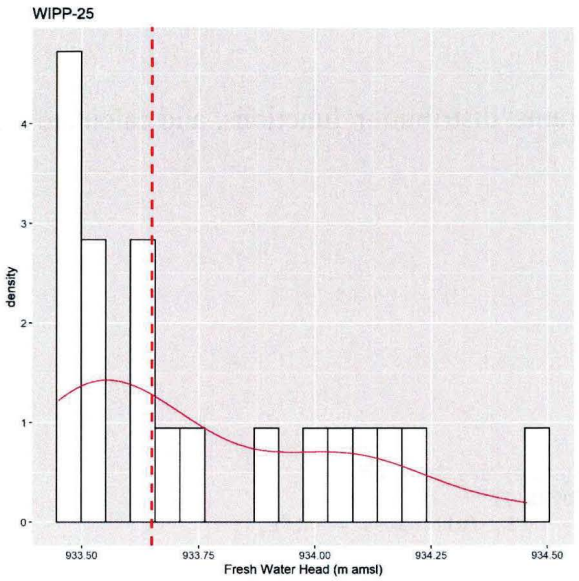

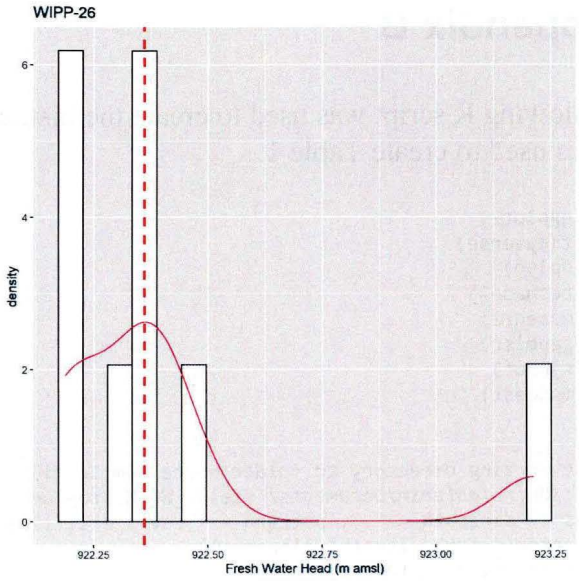

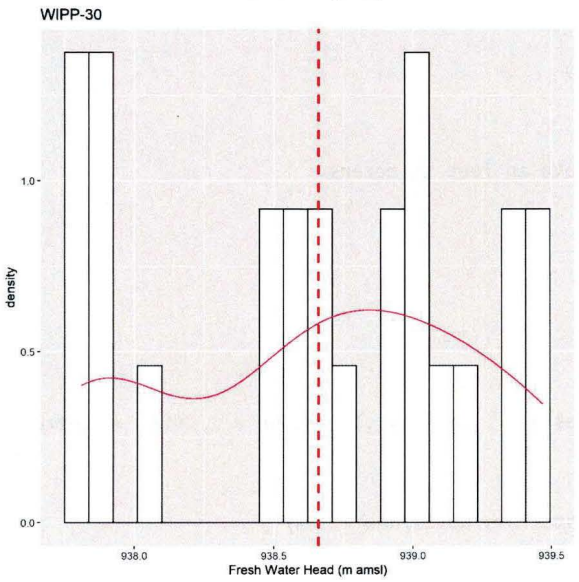

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9. Appendix B

The following R script was used to create the histograms, distribution functions, and calculate the statistics used to create Table 1.

```
library(ggplot2)
library(tidyverse)
library(dplyr)
library(reshape2)
library(moments)
library(ggpmisc)
library(sjPlot)
library(modeest)


# Set the working directory to folder where sample files (.txt) are located.
setwd("C:/Users/mdfarin/Documents/Tfields_WD/Histograms/Nov21/")
filenames <- dir(path = ".", pattern = ".csv", all.files = TRUE, full.names = FALSE, )
lst <- vector("list", length(filenames))
#loop for creating histograms
for (i in 1 : length(filenames)) {

  Hdat <- read.csv(filenames[i], stringsAsFactors = FALSE)
  Hdat[, 1]  <- as.numeric(Hdat[, 1])
  sitename <- sub(".csv$", "", filenames)
  Hdat$ID <- sitename[i]
  Hdat$FWH_amsl <- Hdat$FWH_amsl * 0.3048 #convert head data in feet to meters
  Hdat$Mean <- mean(Hdat$FWH_amsl)
  Hdat$Median <- median(Hdat$FWH_amsl)
  Hdat$H_Round <- round(Hdat$FWH_amsl, digits = 3)
  Modes <- mfv(Hdat$H_Round) #mfv = most frequent value
  Hdat$Mode <- paste(Modes, collapse = " and ")
  Hdat$Min <- min(Hdat$FWH_amsl)
  Hdat$Max <- max(Hdat$FWH_amsl)
  Hdat$Std <- sd(Hdat$FWH_amsl)

  p <- ggplot(Hdat, aes(x = FWH_amsl)) + geom_histogram(aes(y = ..density..), colour = 1, fill = "white",
    bins = 20) +
    geom_density(colour = 2) +
    ggtitle(sitename[i])
  ggsave(paste0("C:/Users/mdfarin/Documents/Tfields_WD/Histograms/Nov21/New_Files/",
                sitename[i],
                ".png"), plot = p)
  write.csv(Hdat,
            paste0("C:/Users/mdfarin/Documents/Tfields_WD/Histograms/Nov21/New_Files/",
                   sitename[i],
                   ".csv"),
            row.names = FALSE)
}


#create file with all data
setwd("C:/Users/mdfarin/Documents/Tfields_WD/Histograms/Nov21/New_Files/")
LOF <- list.files(pattern = ".csv")
outFile <- file("all.csv", "w")
for (i in LOF) {
  x <- readLines(i)
  #colnames(outFile, sitename)
  writeLines(x, outFile)

}
close(outFile)

#read in cumulative well list of all data and process
Hdat_Total_raw <- read.csv("all.csv")
```


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```
Hdat_Total <- subset(Hdat_Total_raw, FWH_amsl !="FWH_amsl") #remove header rows
Hdat_Total <- Hdat_Total[!duplicated(Hdat_Total$ID), ] #remove duplicates of ID
Hdat_Total <- Hdat_Total[, -5]
Hdat_Total <- Hdat_Total[c(2, 1, 3, 4, 5, 6, 7, 8)] #reorder columns
write.csv(Hdat_Total,"Head_dat.csv")
```

The following code loads the statistical table created from the first loop and applies it to new histograms in order to create the mean-median-mode dashed lines for each histogram.

```
#This loop was first run without the Stat_List read in, nor the Centrality lines.
#They were added after initial histograms and well files were created.
setwd("C:/Users/mdfarin/Documents/Tfields_WD/")
Centrality <- read.csv("Stat_list_1121.csv")
# Set the working directory to folder where sample files (.txt) are located.
setwd("C:/Users/mdfarin/Documents/Tfields_WD/Histograms/Nov21/")
filenames <- dir(path = ".", pattern = ".csv", all.files = TRUE, full.names = FALSE, )
lst <- vector("list", length(filenames))
#loop for creating histograms
for (i in 1 : length(filenames)) {

  Hdat <- read.csv(filenames[i], stringsAsFactors = FALSE)
  sitename <- sub(".csv$", "", filenames)
  Hdat$ID <- sitename[i]
  Hdat$FWH_amsl <- Hdat$FWH_amsl * 0.3048 #convert head data in feet to meters
  Hdat$Mean <- mean(Hdat$FWH_amsl)
  Hdat$Median <- median(Hdat$FWH_amsl)
  Hdat$H_Round <- round(Hdat$FWH_amsl, digits = 3)
  Modes <- mfv(Hdat$H_Round)
  Hdat$Mode <- paste(Modes, collapse = " and ")
  Hdat$Min <- min(Hdat$FWH_amsl)
  Hdat$Max <- max(Hdat$FWH_amsl)
  Hdat$Std <- sd(Hdat$FWH_amsl)
  mean_line <- Centrality$Mean
  median_line <- Centrality$Median
  mode_line <- Centrality$Mode
  p <- ggplot(Hdat, aes(x = FWH_amsl)) + geom_histogram(aes(y = ..density..), colour = 1, fill = "white",
    bins = 20) +
    geom_density(colour = 2) +
    labs(x = "Fresh Water Head (m amsl)") +
    geom_vline(xintercept = mean_line[i], linetype = 'dashed', col='blue', lwd=1) +
    geom_vline(xintercept = median_line[i], linetype = 'dashed', col='red', lwd=1) +
    geom_vline(xintercept = mode_line[i], linetype = 'dashed', col='green', lwd=1) +
    ggtitle(sitename[i])
  ggsave(paste0("C:/Users/mdfarin/Documents/Tfields_WD/Histograms/Nov21/New_Files/",
                sitename[i],
                ".png"), plot = p)
  write.csv(Hdat,
            paste0("C:/Users/mdfarin/Documents/Tfields_WD/Histograms/Nov21/New_Files/",
                   sitename[i],
                   ".csv"),
            row.names = FALSE)
}
```


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