Barton Springs
Edwards Aquifer
CONSERVATION DISTRICT

Is the BSEACD's Drought Trigger Methodology Representative of the Middle Trinity Aquifer?

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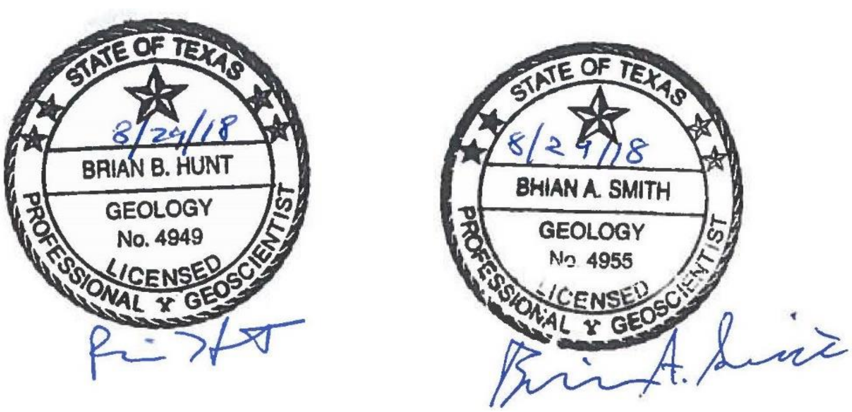


Abstract
Increased drilling and permit requests in the Middle Trinity Aquifer have highlighted the need for increased data collection and evaluation to better manage this limited resource. The purpose of this study is to evaluate the representativeness of the Barton Springs/Edwards Aquifer Conservation District's (BSEACD) drought trigger methodology (DTM) for the Middle Trinity Aquifer, which relies on indices from the Edwards Aquifer. We reviewed available hydrologic data (streamflow, rainfall), regional drought indices (PHDI, US Drought Monitor), and Middle Trinity water-level elevations of the BSEACD and Hays Trinity Groundwater Conservation District (HTGCD) monitor wells for the period of 2008-2017. These data were compared and correlated to the current DTM used for all aquifers in the BSEACD. We conclude that the BSEACD drought indices reflect regional hydrologic responses to climatic events, and consequently have a good correlation to water levels within the Edwards and Middle Trinity Aquifers. It is our recommendation that the current DTM continue to function as the primary mechanism for making BSEACD drought declarations for all aquifers in the BSEACD.

Introduction
A statutory mandate charges the Barton Springs/Edwards Aquifer Conservation District (BSEACD) with the responsibility of conserving, protecting, and enhancing all groundwater resources within the BSEACD. A drought-trigger methodology (DTM) is an important tool to achieve this goal and ensure drought-management measures are implemented in an effective fashion. The current DTM is described in Smith et al. (2013) and is the basis for the current drought-management policy. Although developed specifically for the Edwards Aquifer, the DTM reflects regional hydrologic responses to drought and consequently was reported to have a good correlation to the Middle Trinity Aquifer in the area (Smith et al., 2013). However, the Middle Trinity Aquifer is increasingly being targeted for groundwater production, and is no longer viewed as an "alternative water supply," but rather one of the primary aquifers. Thus, it is reasonable to investigate if the current DTM is also representative of hydrologic conditions within the Middle Trinity Aquifer. The purpose of this study is to compile hydrologic data and to evaluate the representativeness of the current DTM to hydrologic conditions observed in the Middle Trinity Aquifer in the study area (**Figure 1**).

Drought Trigger Methodology

Smith et al., (2013) developed a DTM that utilizes flow from Barton Springs and water levels in the Lovelady monitor well to indicate overall storage and drought status of the Barton Springs aquifer segment of the Edwards Aquifer. The DTM satisfies the guiding principles of: 1) drought declarations can be made with sufficient time to achieve benefits of curtailment and education measures, 2) representative of aquifer-wide conditions, and 3) simple to implement. The BSEACD has six drought stages from non-drought to Stage V Exceptional. At present, historic Edwards and Trinity production permits can be curtailed up to 50% and 30%, respectively.

The Hays Trinity Groundwater Conservation District (HTGCD), to the west of the BSEACD, has four drought stages spanning no drought to Stage IV Emergency. The HTGCD drought management approach consists of a northern and southern region with indices that are based upon river flow rates in the Pedernales and Blanco Rivers. The Palmer Drought Index is referenced as a third drought trigger (HTGCD, 2018a).

Approach and Data Sources

Table 1 provides an inventory of Middle Trinity monitor wells with water-level data from the period of 2008 through 2017. The data were obtained from the HTGCD (HTGCD, 2018b) and the BSEACD (unpublished data). Although **Table 1** provides a relatively comprehensive list of Middle Trinity monitor wells in the vicinity with historic data, some were not suitable for inclusion in the evaluation due to their relatively short period of record, sparse data, or questions about the well completion (such as hybrid completions).

Hydrologic data included in the evaluation were: 1) Blanco River at Ranch Road 12 (USGS, 2018); 2) precipitation from Austin's Camp Mabry (NOAA, 2018a); 3) the Palmer Hydrologic Drought Indices for South-Central Texas (NOAA, 2018b); and 4) the US Drought Monitor for Hays County as a percentage of area and drought stage (USDM, 2018).

All data sets were compiled in Microsoft (MS) Excel and then imported into a MS Access database. The data were compiled into multivariate hydrographs for qualitative evaluation. Queries were developed to match data with the same dates from datasets. Those corresponding data sets were then evaluated as scatter plots in MS Excel and fitted with linear-regression trend lines to give a quantitative measure of correlation. The R-squared value recorded is a statistical measure of how close the data are to the fitted regression line. In general, the higher (closer to 1) the R-squared value, the better the linear-regression model explains the data. For this study we assume that R-squared values greater than 0.5 are a good fit of the data to the model.

Results

Figure 2 is a hydrograph showing a variety of data sets from 2008 through 2017. There is a good qualitative correlation from the hydrological indicators and drought indices (lower part of the graph) to select water-level hydrographs of the Middle Trinity and Edwards Aquifers.

Figure 3 is a hydrograph showing select Middle Trinity monitor wells and the Edwards Aquifer drought index well relative to the droughts as indicated by the US Drought Monitor. Hydrographs from the Middle Trinity and the Edwards Aquifers appear to qualitatively correlate very well with each other and drought.

Figures 4-7 are select scatter plots of data with a best-fit linear-regression line. **Table 2** provides a summary of R-squared from a variety of hydrologic data from the period of 2008-2017.

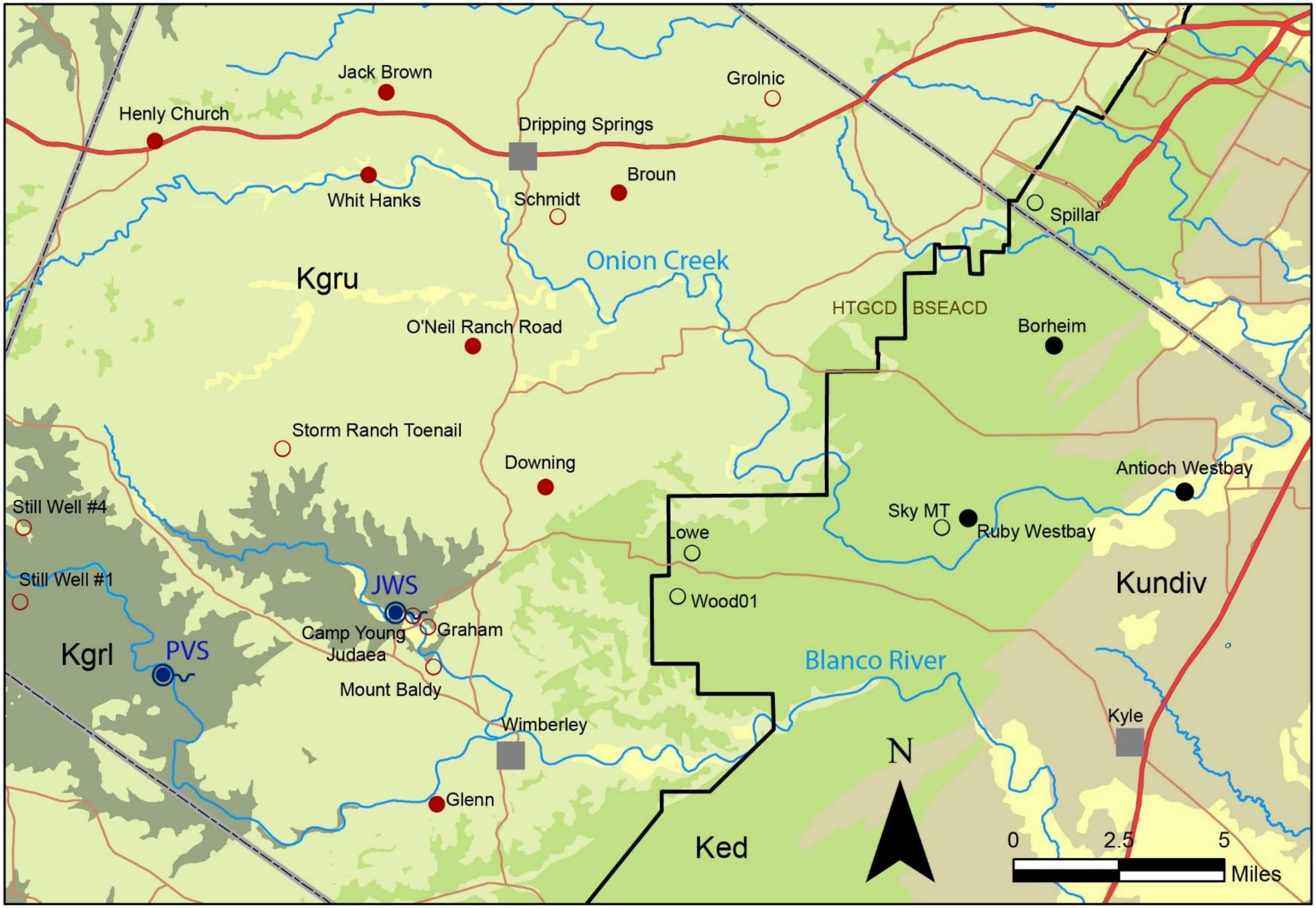
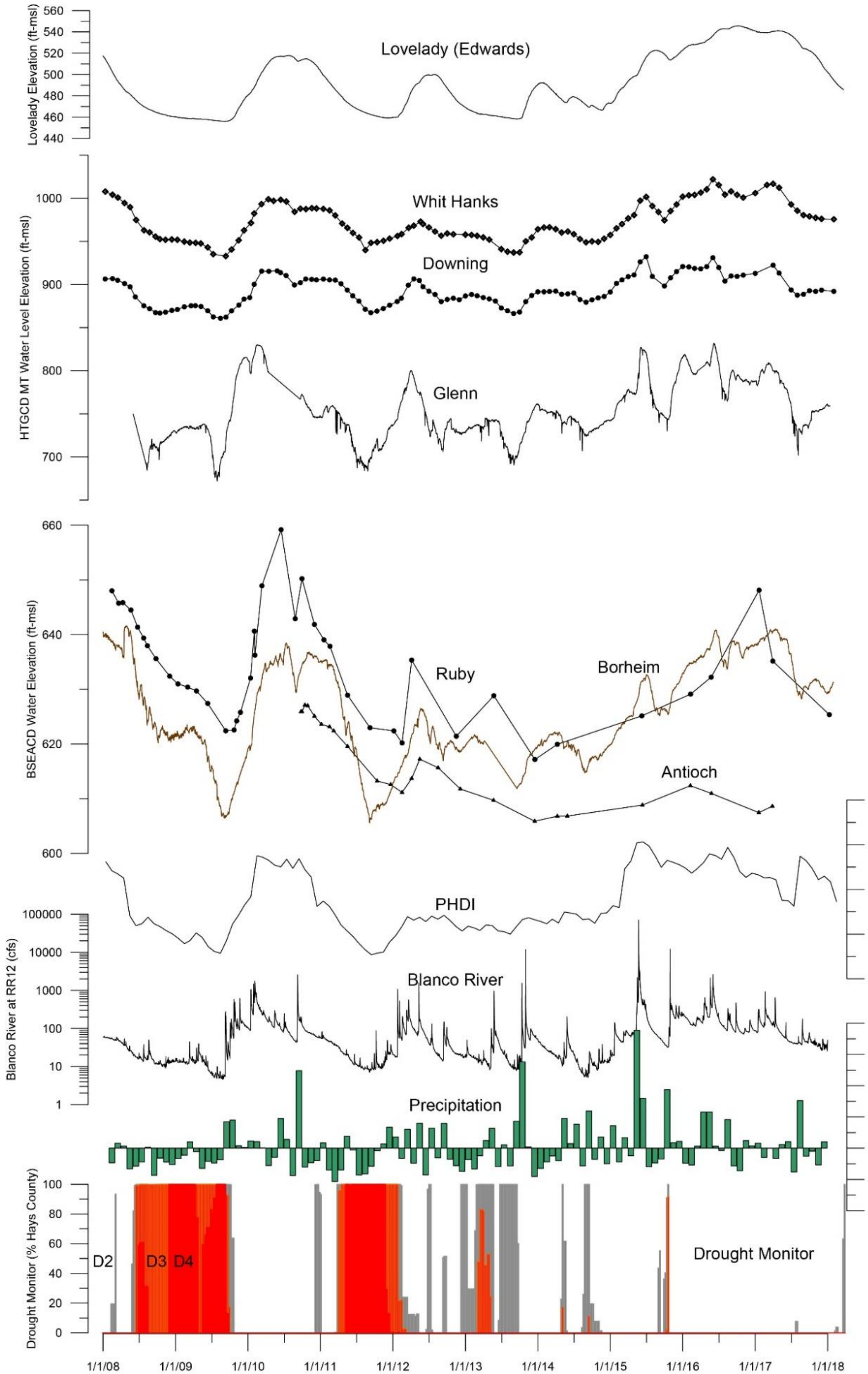


Figure 1. *Location and geologic map of the study area showing selected Middle Trinity monitor wells evaluated in this study. Red circles indicate HTGCD monitor wells, while black circles represent BSEACD wells. Filled in circles represent wells evaluated in this study (Table 1). The Edwards Lovelady well is located just off the northeast corner of the map. Ked=Edwards, Kgru= Upper Glen Rose, Kgrl= Lower Glen Rose.*

Table 1. *Monitor wells in the study area*

Name	SWN	Ddlat	Ddlong	LSD (ft-msl)	GCD	Depth (ft)	Period_of_Record	Strata	County	Data	Comment
Broun	5756519	30.178330	-98.053330	1118	HTGCD	280	7/1/2005	Mid Trin	Hays	monthly	
Camp Young Judaea	5764714	30.029480	-98.118800	955	HTGCD	250	7/1/2005	Mid Trin	Hays	monthly	
Downing	5764502	30.077500	-98.078330	1218	HTGCD	600	1/1/2003	Mid Trin	Hays	daily	TWDB telemetry well
Graham	5764716	30.033330	-98.123890	964	HTGCD	153	10/1/2005	Kcc	Hays	daily	transducer; daily data
Grolnic	5756305	30.210830	-98.000550	1178	HTGCD	450	12/1/2001	Kgrl	Hays	monthly	
Henly Church	5755401	30.196110	-98.212500	1326	HTGCD	460	1/1/1999	Kcc	Hays	monthly	
Skipton Well	5755405	30.19645	-98.22431	1362	HTGCD	506	1/31/2018	Kcc	Hays	daily	TWDB telemetry well
Jack Brown	5755301	30.212780	-98.133060	1309	HTGCD	510	3/1/2003	Kcc	Hays	monthly	
Mount Baldy	5764705	30.015830	-98.116940	939	HTGCD	400	3/1/1999	Mid Trin	Hays	daily	TWDB telemetry well
Still Well #1 - WH	5762901	30.038060	-98.258610	1079	HTGCD	135	1/1/2006	Kgrl	Hays	monthly	
Still Well #4 - 1st WM	5762602	30.063610	-98.257500	1203	HTGCD	240	1/1/2006	Mid Trin	Hays	monthly	
Whit Hanks	5755607	30.184440	-98.139170	1128	HTGCD	372	10/1/2002	Mid Trin	Hays	daily	TWDB telemetry well
Glenn	6808107	29.968783	-98.115626	1080	HTGCD	680	8/5/2008	Mid Trin	Hays	daily	HTGCD transducer
O'Neil Ranch Road	5756710	30.125833	-98.103333	1193	HTGCD	420	12/15/2007	Mid Trin	Hays	monthly	
Dripping Springs WSC	5756702	30.154166	-98.08611	1030	HTGCD		1/28/2015	Kcc	Hays	daily	TWDB telemetry well
Ruby Westbay	5857513	30.066667	-97.933334	815	BSEACD	1120	2/15/2008	Kcc	Hays	quarterly	Multiport well
Antioch Westbay	5858431	30.075833	-97.859167	702	BSEACD	1375	9/25/2010	Kcc	Hays	quarterly	Multiport well; short POR
Lowe	5764607	30.054833	-98.028209	1069	BSEACD	860	6/10/2015	Kcc	Hays	daily	BSEACD transducer; short POR
Wood01	5764907	30.039986	-98.033022	1067	BSEACD	790	1/28/2015	Kcc, Kgrl	Hays	daily	BSEACD transducer; short POR
Sky Ranch MT	5857507	30.063580	-97.942519	837	BSEACD	1000	11/9/2012	Kcc	Hays	daily	BSEACD transducer; short POR
Borheim Trinity	5849925	30.125940	-97.903820	786	BSEACD	1000	1/30/2002	Kcc, Kgrl, Kgru?	Hays	daily	BSEACD transducer
Spillar	5849615	30.175032	-97.910404	985	BSEACD	1210	4/23/2013	Kcc, Kgrl, Kgru/Ked?	Travis	daily	BSEACD transducer; Ked communication likely

Figure 2. *Hydrograph from 2008 through 2017. Drought stages indicated as D2-D4.*



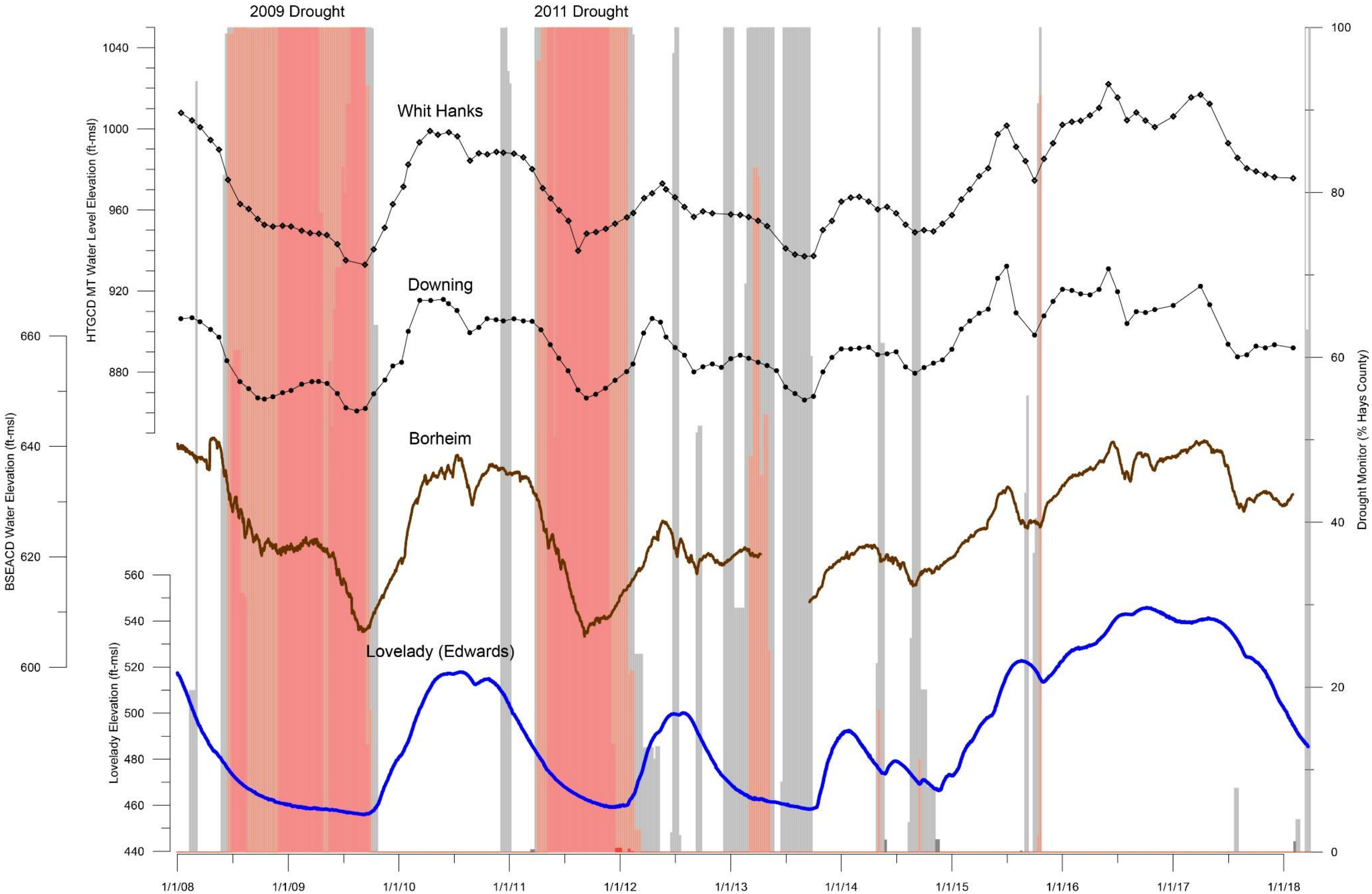


Figure 3. *Hydrograph showing select Middle Trinity monitor wells and the Edwards Aquifer drought index well relative to the droughts as indicated by the colored US Drought Monitor stages. Drought stages are indicated as D2 (grey), D3 (orange), and D4 (red).*

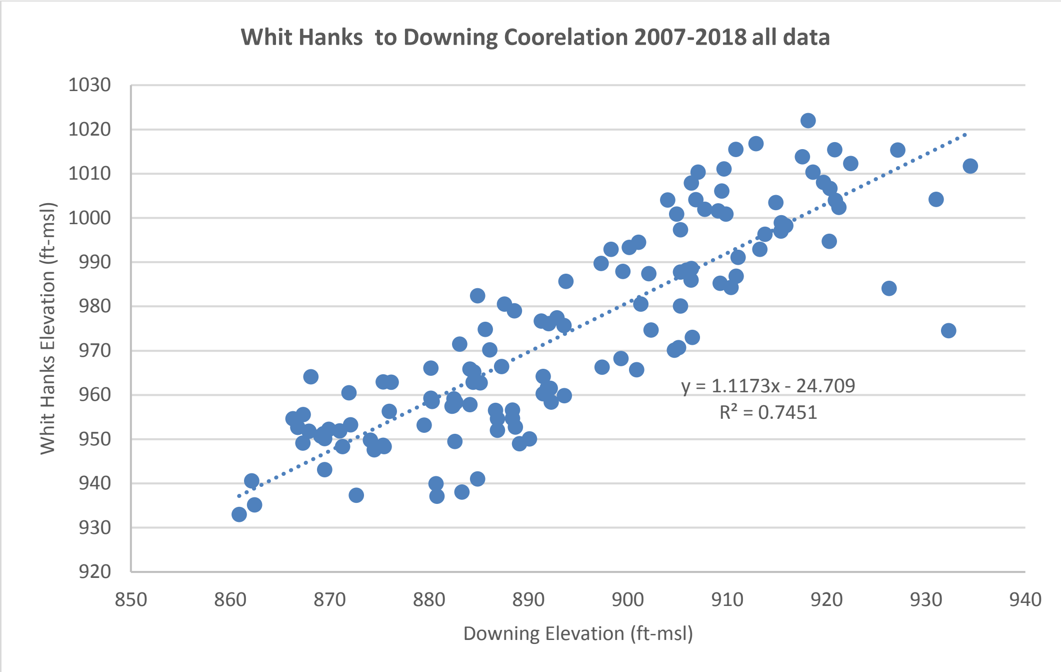


Figure 4. *Correlation of water level elevations in the HTGCD Middle Trinity Whit Hanks and Downing monitor wells. Data are monthly measurements from 2008 through 2017. There is an overall good correlation between the data of R2= 0.75.*

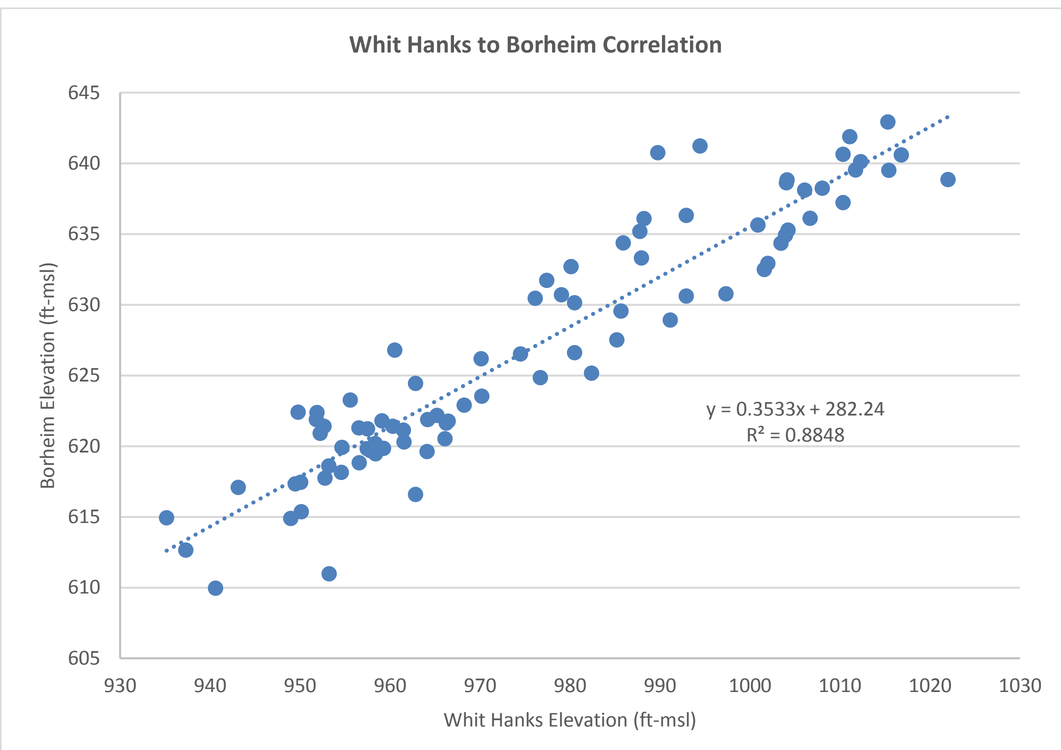


Figure 5. *Correlation of water-level elevations in the Middle Trinity BSEACD Borheim well to the Middle Trinity HTGCD Whit Hanks well. Data are monthly measurements from 2008 through 2017. There is an overall good correlation between the data of R2=0.88. The Downing well also had a good correlation of R2=0.66.*

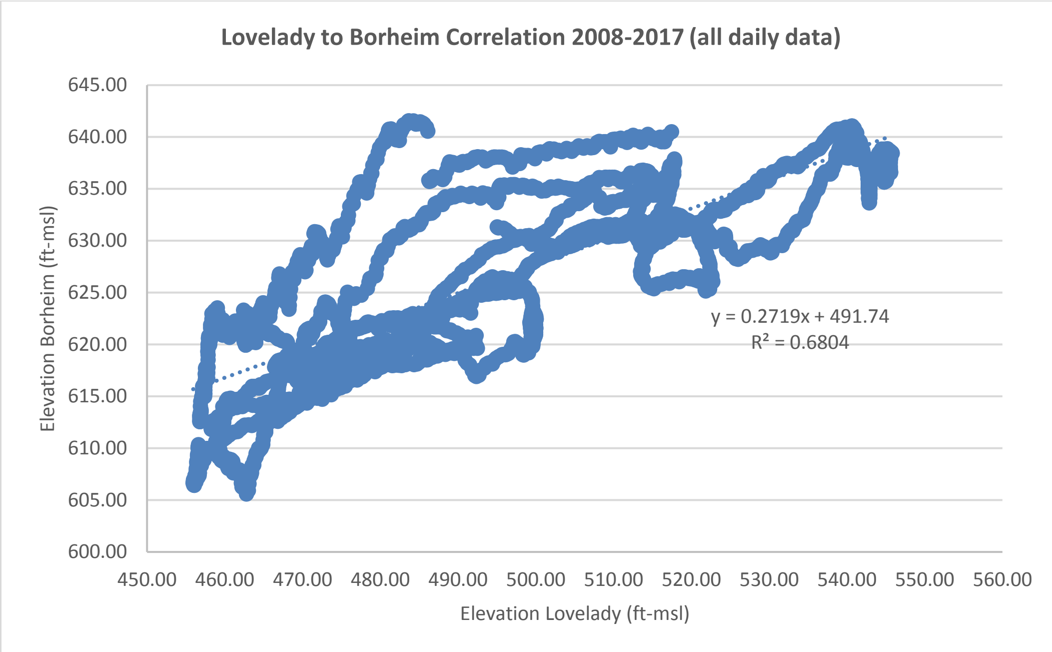


Figure 6. *Correlation of water-level elevations in the Edwards Aquifer Lovelady drought trigger monitor well and the Middle Trinity Borheim well. Data represents daily frequency from pressure transducers. There is an overall good correlation of R2= 0.68. The correlation improves to R2=0.73 during Stage IV drought conditions (below 457.1 ft-msl in the Lovelady).*

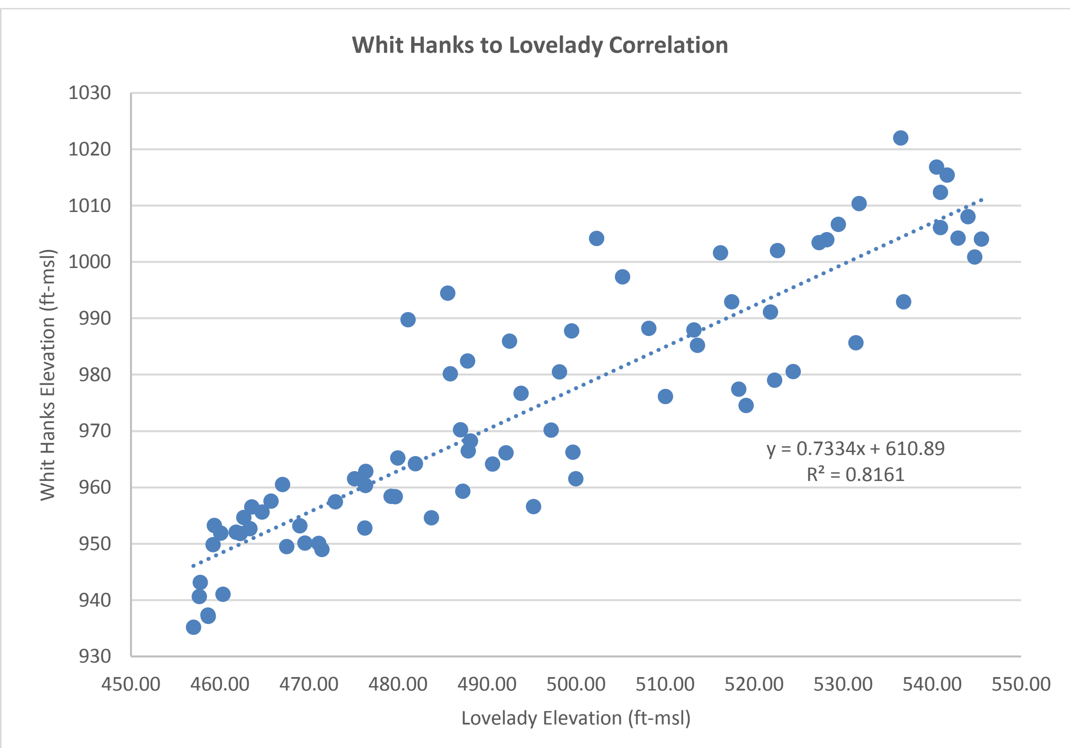


Figure 7. *Correlation of water-level elevations in the BSEACD Edwards Aquifer Lovelady drought trigger monitor well and the HTGCD Middle Trinity Whit Hanks well. There is an overall good correlation between the data R2= 0.82.*

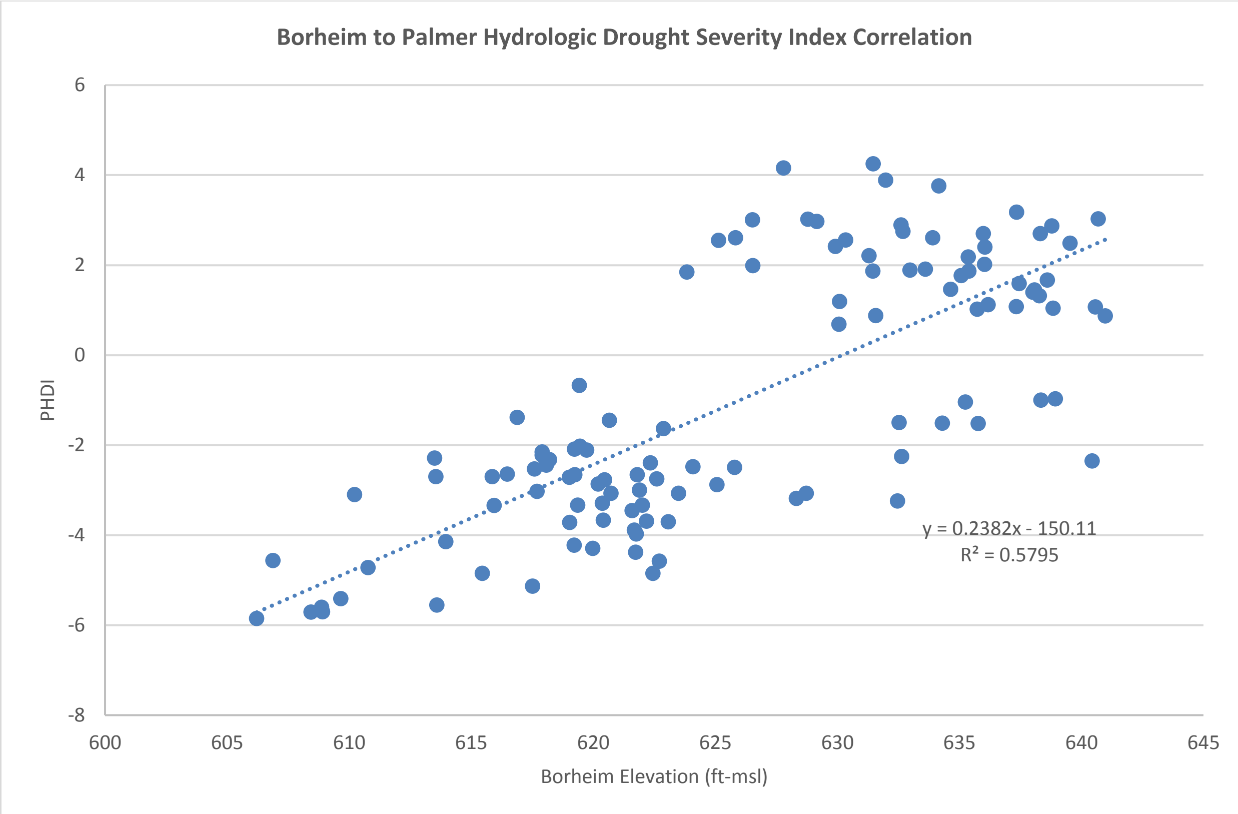


Figure 8. *Correlation of water level elevations in the Middle Trinity Borheim well to the Palmer Drought Severity Indices (PHDI). There is an overall good correlation between the data of R2=0.58. Positive PHDI indicates wet (non-drought) conditions. The Lovelady monitor well has a correlation to the PHDI of R2=0.69.*

Table 2. *Summary of R^2 data correlations from the period of 2008-2017. Number of data indicated in parenthesis. A value of > 0.5 is considered a good correlation for this study and highlighted in blue.*

	PHDI	Lovelady	Borheim	Whit Hanks	Downing	Glenn	Lowe**	Woods01**	Sky MT	Spillar	Ruby Westbay
PHDI	1										
Lovelady	0.69 (116)	1									
Borheim	0.58 (115)	0.68 (3685); 0.73 (86)*	1								
Whit Hanks	NA	0.82 (82)	0.88 (89)	1							
Downing	NA	0.62 (82)	0.66 (128)	0.75 (128)	1						
Glenn	0.54 (108)	0.43 (3119)	0.42 (3252)	0.61 (102)	0.68 (103)	1					
Lowe	NA	NA	0.37 (870)	NA	NA	NA	1				
Woods01	NA	NA	0.33 (821)	NA	NA	NA	0.26 (685)	1			
Sky MT	0.60 (23)	0.94 (616)	0.91 (548)	0.86 (19)	0.47 (21)	0.44 (710)	NA	NA	1		
Spillar	0.56 (50)	0.72 (1465)	0.81 (1388)	0.85 (48)	0.86 (46)	0.83 (1495)	NA	NA		1	
Ruby Westbay	NA	0.24 (41)	0.55 (42)	NA	NA	0.08 (34)	NA	NA	NA	0.33 (8)	1
Antioch Westbay	NA	NA	0.16 (24)	NA	NA	NA	NA	NA	NA	0.71 (487)	0.34 (18)

**Below 457.1 ft-msl, Stage IV at Lovelady; **short period of record, influenced by EP aquifer testing; NA= Not analyzed; generally too few data*

Discussion

The area west of the Edwards outcrop serves as a recharge zone for the Upper and Middle Trinity Aquifers and as the contributing zone for the Edwards Aquifer. Therefore, rainfall and runoff will have an impact on the Edwards and Trinity Aquifers, as will the lack of rainfall (Hunt et al., 2017).

Despite the heterogeneity in the hydrogeology shown in **Figure 1**, many of the HTGCD Middle Trinity monitor wells have data with a relatively high degree of correlation to one another across much of the HTGCD, such as the Whit Hanks, Downing, and Glenn wells, among others (**Figure 4; Table 2**).

There is a demonstrated hydrologic correlation of the Middle Trinity Aquifer in the Hill Country to the Middle Trinity units within the Balcones Fault Zone. Groundwater generally flows west to east within the Middle Trinity in the study area, and structures such as relay ramps between faults may provide lateral continuity of flow (and pressure pulses) into the Balcones Fault Zone and the BSEACD (Hunt et al., 2015). A variety of head, geochemical, and structural data support the lateral hydrologic continuity of the Middle Trinity Aquifer. This is further supported by the similar hydrologic response to wet and dry periods for HTGCD wells in the Hill Country and the BSEACD wells in the Balcones Fault Zone (**Figures 3 and 5; Table 2**). Although the data support a lateral continuity of flow, the correlation of these confined wells is a pressure response due to regional hydrologic conditions.

Response of the aquifer systems to regional hydrologic changes is well illustrated by the close correlation and similar magnitude of variation of the Middle Trinity wells to the BSEACD (Lovelady) Edwards Aquifer index well (**Figures 3, 6 and 7; Table 2**). The Edwards Aquifer and the Middle Trinity Aquifer are not in hydrologic communication with each other (e.g. no inter-aquifer communication) in the study area. In fact, studies have shown that these two aquifer systems are (vertically) hydrologically isolated from each other (Smith and Hunt, 2010; Wong et al., 2014; **Figure 9**). Instead, the strong correlation to one another is the result that both aquifer systems are responding to the same regional hydrologic or climatic conditions such as recharge and drought. This is further illustrated by the correlation of the monitor-well data to regional indices such as the Palmer Hydrologic Drought Index (PHDI, **Figure 8; Table 2**).

The correlation among the various well data, springs, and drought indices is always not optimal in space and time. Some of the issues in data correlation may be related to sparse data sets and the confounding effects of well completions. In addition, some data discrepancies in correlation of the data may also be related to more localized rainfall and recharge events. Thus, the correlation may be low for the early stages of drought, which are more sensitive to local conditions. The poor correlation (R^2= 0.34) of the Antioch Multiport well and the Ruby Ranch Multiport well needs to be evaluated further and could be the result of sparse data or perhaps indicate some isolation due to faulting between the two wells.

In summary, when the region experiences severe drought (D4 in **Figures 2 and 3**), the various data sets from wells appear to be in good correlation no matter their location or aquifer.

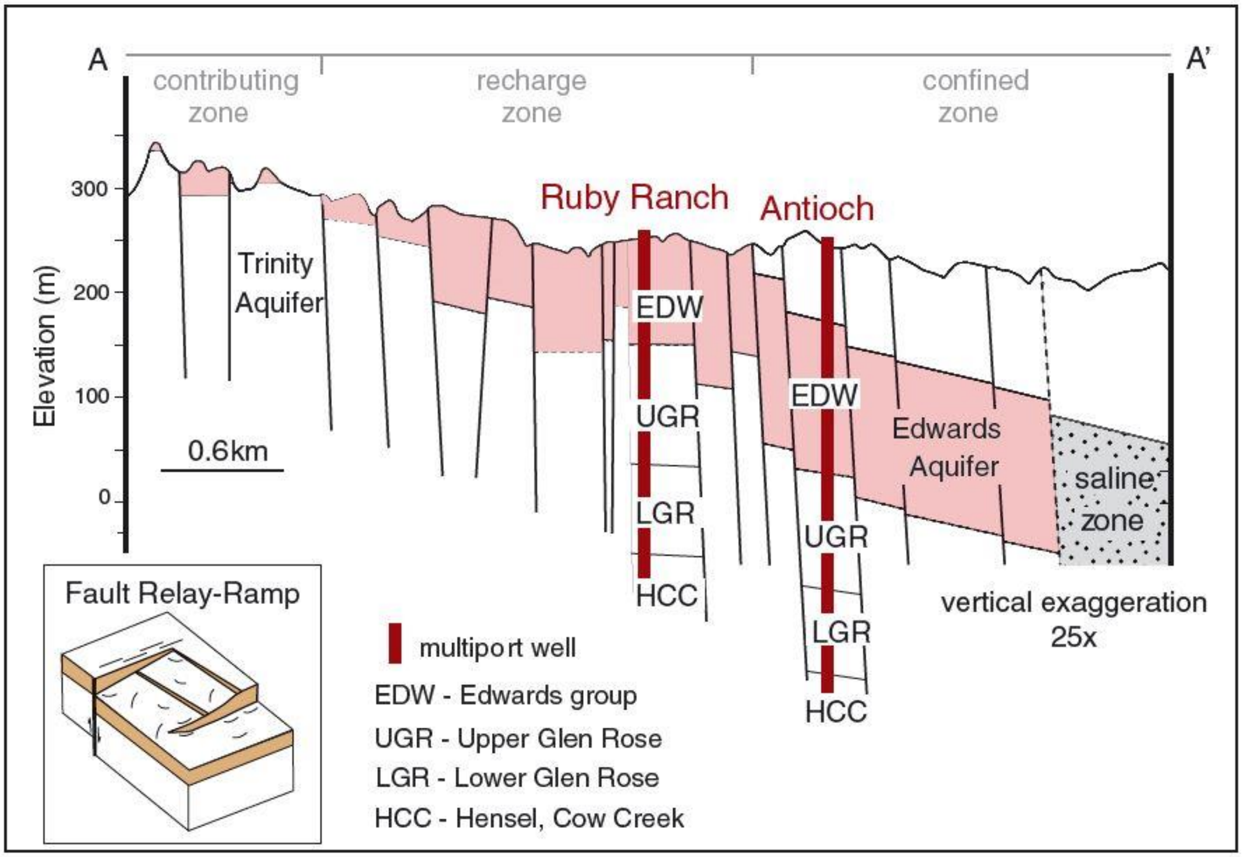


Figure 9. *Generalized cross section from west to east showing the location of the Ruby Ranch and Antioch multiport wells (from Wong et al., 2014).*

Conclusion

The District's DTM (Smith et al., 2013) reflects regional hydrologic responses to climate and consequently has a good correlation to the Edwards and Middle Trinity Aquifers in the study area. The BSEACD's methodology is therefore representative of the Middle Trinity Aquifer and serves as an overall good indicator of drought for all aquifers in the BSEACD.

Future Work

It is important to continue collecting data and developing new monitor wells throughout the District as the hydrologic conditions can change over time, and pumping from the various aquifers is rapidly increasing. With more data, we may better understand the effects of depletion, interference, and capture within the Trinity Aquifers that may influence future policies, drought determinations and pumpage curtailments.

The Lower Trinity Aquifer was not part of this evaluation. Very little data exists for the Lower Trinity within the BSEACD at this time. It is recommended to identify a potential monitoring well and begin to collect data.

Acknowledgements

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